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Research Paper

Comparative evaluation of different solar radiation models with Angstrom-Prescott model for Hazaribagh, Jharkhand

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ABSTRACT

This study evaluates the performance of six solar radiation models for Hazaribagh in Jharkhand by comparing their estimates with those derived from the Angstrom-Prescott (A-P) model, which served as the benchmark reference. The results revealed significant variability in model performance on both a monthly and seasonal basis. The Togrul-Onat and Ertekin-Xaldiz models tended to overestimate solar radiation, particularly during the summer months, while underestimating it in the remaining months. In contrast, the Ogelman model consistently underestimated solar radiation throughout the entire year. The Almorox-Hontoria model showed only minor overestimations in certain months, while the Chen model primarily overestimated during the spring and early summer. On a monthly scale, all selected models showed a positive correlation with the standard Angstrom-Prescott (A-P) model, with R^2 values ranging from 0.52 to 0.99. Notably, the Almorox-Hontoria model exhibited the strongest positive correlation ($R^2 = 0.993$) with the A-P model, identifying it as the most reliable for estimating solar radiation. On a seasonal scale, the models generally performed well, with R^2 values ranging from 0.85 to 0.99. However, the Togrul-Onat and Ertekin-Xaldiz models exhibited weaker correlations with the A-P model, particularly during the Zaid season, indicating their limitations in accurately estimating average daily solar radiation during this period. These results highlight the necessity of careful model selection and calibration to account for seasonal variability. Overall, the Almorox-Hontoria model demonstrated the highest accuracy and consistency across both monthly and seasonal scales, emphasizing the importance of adjusting models to specific temporal and geographic conditions.

Key Words: Correlation, Model performance, Solar radiation, Seasonal variation.

Solar energy is the primary driver of Earth's climatic and environmental systems, including temperature regulation, ecosystem dynamics, and hydrological cycles (Gani *et al.,* 2015; Sivakumar 2023). The intensity of radiation at Earth's upper atmosphere is estimated to be about 1,367Wm^{-2}, with roughly 40% of this reaching the surface. The Earth's atmosphere reflects and scatters a portion of this visible radiation, while absorbing ultraviolet, gamma, and X-ray radiation, converting it to heat. The Earth's albedo reflects approximately 30% of incoming visible light back into space. Understanding global solar radiation is crucial for applications such as crop development modeling, evapotranspiration estimation, architectural design, and solar energy systems, an accurate site-specific solar radiation data is essential for designing effective solar energy systems. Given that solar radiation at Earth's surface is influenced by local meteorological conditions, empirical models are employed to estimate solar irradiance (Almorox, 2011). These models incorporate various factors, including astronomical (e.g., solar constant, Earth-sun distance), geographical (e.g., latitude, altitude), and physical parameters (e.g., albedo, atmospheric scattering) to predict solar radiation accurately (Almorox, 2011). Despite its importance, acquiring precise and long-term records of solar radiation is challenging due to the high costs and maintenance of measuring equipment. Solar energy, with its abundant and sustainable nature, presents a viable solution for meeting global energy demands and mitigating climate change impacts. Solar radiation has a direct impact on evapotranspiration and, consequently, on crop water needs. Choosing the right model to estimate solar radiation, which is essential for calculating reference evapotranspiration (ET_O), is vital

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for effective irrigation planning. Accurate estimation ensures better alignment of irrigation schedules with actual crop requirements, promoting efficient water management (Sharma *et al.,* 2023). The primary goal of this evaluation is to compare these models against the Angstrom-Prescott model to determine their accuracy and reliability in estimating solar radiation. This comparative analysis aims to identify the most effective model for predicting average monthly and seasonal solar radiation in the study area, thereby improving our understanding of solar radiation patterns in the region. This study was planned to determine the monthly and seasonal average values of solar radiation as well as to compare solar radiation (Rs) values obtained from various models with those from a standard reference model in selected study area.

MATERIALS AND METHODS

The study was conducted in the Hazaribagh district of Jharkhand, India, situated at latitude of 23.98°N, a longitude of 85.5°E, and an elevation of 604 meters above sea level. The region experiences three distinct seasons: summer (March–June), monsoon (July–October), and winter (November–February), with a sub-humid and subtropical climate. The study employed the Angstrom-Prescott (A-P) method alongside five alternative models to evaluate solar radiation. For this purpose, comprehensive meteorological data were collected daily over a 23-year period (2000-2023) at the meteorological observatory of the Central Rain Fed Upland Rice Research Station of Hazaribagh in Jharkhand state. The dataset included measurements of maximum and minimum air temperatures, maximum and minimum relative humidity, wind speed, and actual sunshine duration. These variables were recorded to ensure a robust assessment of solar radiation, leveraging both established and alternative methodologies to provide a thorough analysis of solar radiation patterns in the region.

Models for estimating solar radiation

To estimate average monthly and seasonal solar radiation in the study area, evaluated a selection of models. The Angstrom-Prescott (A-P) model was chosen as the benchmark standard due to its well-established application in solar radiation estimation Angstrom (1924). The effectiveness of the A-P model was assessed by comparing it with five alternative models:

Angstrom-Prescott (A-P): Angstrom (1924) first put forth the A-P model which was revised by Prescott (1940). The linear link between monthly mean daily Rs and sunlight hours served as the foundation for the development of the A-P formula.

$$\mathrm{Rs} = [0.25 + 0.50(\tfrac{n}{N})]R_a \qquad (1)$$

Where, n is the number of actual sunshine hours (hr) and N is the number of potential sunshine hours (hr), Rs is solar radiation (MJ m^{-2} day^{-1}), Ra is extraterrestrial solar radiation (MJ m^{-2} day^{-1}), and a (0.25) and b (0.50) are the empirical A-P coefficients.

Chen model **:** Chen *et al.,* (2004) proposed the following model-

$$\mathrm{Rs} = [0.28\ \ln(T_{max} - T_{min}) + 0.15]R_a \qquad (2)$$

Where, Tmax is the highest temperature, Tmin is the lowest temperature (in degrees Celsius), and Rs is solar radiation (MJ m^{-2} day^{-1}), Ra is alien solar radiation (MJ m^{-2} day^{-1}).

Ertekin-Yaldiz model**:** Ertekin and Yaldiz (1999) reported that R_S can be calculated by the following equation:

$$\mathrm{Rs} = -4.46 + 0.477\ \mathrm{Ra} - 0.226\ \mathrm{T} \qquad (3)$$

Where, T is the mean air temperature (°C), Ra is alien solar radiation (MJ m^{-2} day^{-1}), and Rs is solar radiation (MJ m^{-2} day^{-1}).

Togrul-Onat model**:** Togrul-Onat (1999) estimated R_S for Elazig, Turkey by a multiple linear regression as follows

$$\mathrm{Rs} = -1.3876 + 0.518\ \mathrm{Ra} + 2.3064\ (\tfrac{n}{N}) \qquad (4)$$

Where, n is the number of actual sunshine hours (hs), Rs is solar radiation (MJ m^{-2} day^{-1}), Ra is extraterrestrial solar radiation (MJ m^{-2} day^{-1}), and N is the number of potential sunshine hours (hs).

Almorox- Hontoria model**:** Almorox and Hontoria (2004) have suggested an exponential type model.

$$\mathrm{Rs} = [-\ 0.0271 + 0.3096\ \exp\ (\tfrac{n}{N})]R_a \qquad (5)$$

Where, n is the number of actual sunshine hours (hs) and N is the number of potential sunshine hours, Rs is solar radiation (MJ m^{-2} day^{-1}), Ra is extraterrestrial solar radiation (MJ m^{-2} day^{-1}).

Ogelman model**:** Ogelman *et al.,* (1984) suggested a second order polynomial equation for estimating

$$\mathrm{Rs} = [0.195 + 0.676\ (\tfrac{n}{N}) - 0.142\ (\tfrac{n}{N})2]R_a \qquad (6)$$

Where, n and N are the actual and projected sunshine hours, and Rs is solar radiation (MJ m^{-2} day^{-1}), Ra is alien solar radiation (MJ m^{-2} day^{-1}).

Statistical analysis

To assess the accuracy of solar radiation estimates and compare the performance of different models for validate, two key statistical metrics Root Mean Square Error (RMSE) and the coefficient of correlation (R^2) were used.

RESULT AND DISCURSION

Table 1 presents the monthly average daily solar radiation (MJ m^{-2} day^{-1}) for five models in selected study area. This data was used to assess the variation in average daily solar radiation (in MJ m^{-2} day^{-1}) with estimates provided by standard equation (A-P model) and other selected models, including Togrul-Onat, Ogelman, Almorox-Hontoria, Ertekin-Xaldiz, and Chen. The data spans from January to December, highlighting differences between A-P model and estimated values by other models across different months. For instance, in January, the observed value is 14.1 MJ m^{-2} day^{-1}, whereas estimates from the models range from 9.5 to 14.3 MJ m^{-2} day^{-1}. Seasonal averages are also compared for *Kharif, Rabi*, and *Zaid* seasons, showing variability in different model. The solar radiation values (obtained as per standard model) for these seasons are 15.7 MJ m^{-2} day^{-1}, 15.8 MJ m^{-2} day^{-1}, and 21.5 MJ m^{-2} day^{-1}, respectively, with model estimates ranging widely. The estimated daily solar

Table 1: The comparison between observed values and estimated values monthly average daily solar radiation (MJ m^{-2} day^{-1}) for Hazaribagh, Jharkhand.

Month/ Season	As per standard model: A-P	Models				
		Togrul-Onat	Ogelman	Almorox- Hontoria	Ertekin-Xaldiz	Chen
Jan	14.1	11.9	13.2	14.3	9.5	13.6
Feb	17.4	14.5	16.2	17.6	12.7	16.9
Mar	20.5	17.3	19.1	20.7	16.3	20.6
Apr	22.9	22.7	21.0	22.8	21.0	23.8
May	23.1	18.1	20.9	22.8	24.2	24.2
Jun	18.7	16.0	15.7	18.2	20.1	19.7
July	16.0	20.1	14.5	15.7	20.6	15.3
Aug	15.6	17.8	12.7	15.2	17.8	14.1
Sept	15.6	16.5	13.4	15.2	16.7	13.4
Oct	15.6	14.0	14.2	15.5	13.2	14.0
Nov	14.3	12.0	13.3	14.5	10.3	13.3
Dec	13.2	11.0	12.3	13.4	8.7	12.8
Kharif	15.7	18.1	13.5	15.3	18.3	14.2
Rabi	15.8	13.4	14.7	16.0	11.7	15.2
Zaid	21.5	18.9	19.2	21.2	21.7	22.5

radiation produced by several equations was compared to the radiation that was computed by standard Angstrom-Prescott model (Table 1) indicated that, on monthly basis, the estimated values of average daily solar radiation by Togrul-Onat (1999) model for July, August and September months were overstated from the Angstrom-Prescott (A-P) model by 25.6, 20.5, and 5.7% respectively, and underestimated for the remaining months. While, the estimated values of average daily solar radiation by Ogelman model, were found underestimated for all the months. The estimated values of average daily solar radiation by Almorox- Hontoria model results over estimated values for January (1.4%), February (1.1%), March (0.9%), November (1.3%) and December (1.5%) as compared to estimated values of average daily solar radiation by standard model (A-P). The estimated values of average daily solar radiation by Ertekin-Xaldiz model for May, June, July, August and September months were overstated from the Angstrom-Prescott (A-P) model by 4.7, 7.4, 28.7, 23, and 7% respectively, and underestimated for the remaining months. The estimated values of average daily solar radiation by Chen model results over estimated values for March (0.4%), April (3%), May (4%), and June (5%) as compared to estimated values of average daily solar radiation by standard model (A-P). The comparison of estimated daily solar radiation values from various models with those from the Angstrom-Prescott (A-P) standard model highlights differences in accuracy among the models. The Togrul-Onat and Ertekin-Xaldiz models generally overestimate solar radiation during the summer months (June to September), with discrepancies ranging from 5.7% to 28.7%, but tend to underestimate in other periods.

The Ogelman model consistently underestimates solar radiation throughout the year. The Almorox-Hontoria model shows slight overestimations in January, February, March, November, and December which can be neglect. The Chen model tends to overestimate solar radiation mainly in March, April, May, and June. Overall, the variability in model performance by month underscores the importance of selecting the most appropriate model for specific time periods. On a seasonal basis, the estimated daily solar radiation values show significant discrepancies compared to the Angstrom-Prescott (A-P) model. During the *Kharif* season, the Togrul-Onat and Ertekin-Xaldiz models overestimate solar radiation by 15.2% and 16.5%, respectively. For the *Rabi* season, the Almorox-Hontoria models slightly overestimate by 1.2% which can consider as negligible. In the *Zaid* season, Ertekin-Xaldiz and Chen model shows a slight overestimation of 0,9 and 4.6%, respectively. These variations suggest that seasonal factors significantly impact the accuracy of solar radiation estimates from different models. The Ertekin-Xaldiz model's considerable overestimation during the *Kharif* season indicates it may not fully account for seasonal solar radiation changes. Similarly, its notable discrepancies in the Rabi season point to potential issues with its seasonal calibration. In contrast, the Chen model, although it shows minor overestimations in the *Zaid* season and some discrepancies in the *Rabi* season, generally provides more consistent estimates compared to other models. These observations highlight the need to carefully select and potentially adjust models to align more accurately with seasonal conditions in the study area.

Regression analysis

The results of the regression analysis between the standard model (A-P) and other selected models are presented in Table 2. The Almorox-Hontoria model stands out as the most accurate for estimating solar radiation, showing near-perfect R^2 values (up to 0.99) across both annual and seasonal (*Kharif, Rabi, Zaid*) scales. The Chen and Ogelman models also perform well, particularly on annual basis and during the *Rabi* season, with high R^2 values ranges from 0.95 to 0.99, though they show slightly less R^2 during the *Kharif* season. In contrast, the Togrul-Onat and Ertekin-Xaldiz models demonstrate relatively lower accuracy, particularly for Zaid where their R^2 values drop below 0.50, indicating weaker predictive power (Table 2).

The low performance of the Togrul-Onat and Ertekin-Xaldiz models seasons may be due to several factors. Models not specifically calibrated for fluctuating weather conditions may

Table 2: Linear regression equation with coefficient of determination (R^2) and root mean square error (RMSE) between standard Angstrom-Prescott (A-P) model and the five selected models

Models	Linear equation	R^2	RMSE
Annual			
Togrul-Onat	Y = 0.756x + 2.943	0.520	5.064
Ogelman	Y = 0.913x - 0.221	0.953	3.763
Almorox- Hontoria	Y = 0.997x + 0.262	0.993	0.548
Ertekin-Xaldiz	Y = 1.167x – 4.207	0.597	6.972
Chen	Y =1.234x - 4.487	0.970	1.924
Kharif			
Togrul-Onat	Y = 7.375x - 97.9	0.872	2.3
Ogelman	Y = 3.625x - 43.5	0.851	2.7
Almorox- Hontoria	Y = 1.25x - 4.3	0.999	0.53
Ertekin-Xaldiz	Y = 8.375x - 113.4	0.925	3.08
Chen	Y = 3.875x - 46.7	0.867	2.77
Rabi			
Togrul-Onat	Y = 0.843x + 0.083	0.973	1.84
Ogelman	Y = 0.931x - 0.045	0.996	1.43
Almorox- Hontoria	Y = 1.002x + 0.117	0.998	0.25
Ertekin-Xaldiz	Y = 0.998x - 4.049	0.908	2.91
Chen	Y = 1.097x - 2.199	0.970	1.39
Zaid			
Togrul-Onat	Y = 0.984x - 2.295	0.509	2.67
Ogelman	Y = 1.218x - 7.071	0.996	2.26
Almorox- Hontoria	Y = 1.068x - 1.767	0.996	0.42
Ertekin-Xaldiz	Y = 0.606x + 8.689	0.488	2.78
Chen	Y = 1.001x + 0.965	0.998	1.31

struggle to predict accurately during the year. Furthermore, these models might rely on assumptions or datasets better suited for more stable, dry seasons like *Rabi,* where weather conditions are less variable. Regional differences in climate and environmental factors may also contribute to the reduced predictive accuracy of these models during the *Kharif* and *Zaid* seasons. This can be attributed to several factors, such as seasonal shifts in weather patterns, geographic conditions, and limitations within the model algorithms. For example, variations in cloud cover, atmospheric humidity, and other meteorological factors can greatly impact the accuracy of solar radiation estimates, resulting in inverse relationships between the observed and predicted values (Smith *et al.,* 2020; Jones and Brown, 2021). These models may not adequately adapt to seasonal variations in solar radiation, such as changes in cloud cover and the angle of sunlight, leading to discrepancies in their estimates. Misalignment between a model's assumptions and the specific seasonal patterns of the study area can also contribute to lower correlations (Hao and Liu, 2021).

CONCLUSIONS

The results show significant variability in model performance both monthly and seasonally. The Togrul-Onat and Ertekin-Xaldiz models generally overestimated solar radiation during the summer months, while underestimating it during the rest of the year. Conversely, the Ogelman model consistently underestimates solar radiation across all months. The Almorox-Hontoria model displays minor overestimations in certain months, and the Chen model mostly overestimates during the spring and early summer. The regression analysis with the A-P model, revealed R^2 values ranging from 0.52 to 0.99. The Almorox-Hontoria model had the highest correlation ($R^2 = 0.993$), making it the most reliable model. On a seasonal basis, all models demonstrated acceptable performance, with R^2 values ranging from 0.85 to 0.99. However, the Togrul-Onat and Ertekin-Xaldiz models showed weak relations with the A-P model, especially during the *Zaid* season, suggesting that these models are unsuitable for estimating average daily solar radiation during this period. These findings highlight the need to carefully select and calibrate models to account for seasonal variations. Overall, the Almorox-Hontoria model emerged as the most accurate and consistent throughout the year, underscoring the importance of adapting models to specific temporal and geographic conditions.

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REFERENCES

Almorox, J. and Hontoria, C. (2004). Global solar radiation estimation using sunshine duration in Spain. *Energ. Conver. Manage.,* 45(9-10): 1529-1535. https://doi.org/10.1016/j.enconman.2003.08.022

Almorox, J. (2011). Estimating global solar radiation from common meteorological data in Aranjuez, Spain. *J Atmos. Solar-Terrest. Phy.,* 73(13): 1989-1998. https://doi.org/10.1016/j.jastp.2011.06.011.

Angstrom, A. (1924). Solar and terrestrial radiation. *Quart. J. Royal Meteorol. Soc.,* 50(210): 121-126. https://doi.org/10.1002/qj.49705021008

Chen, R., Ersi, K., Yang, J., Lu, S. and Zhao, W. (2004). Validation of five global radiation models with measured daily data in China. *Energy Convers. Manage.,* 45(11-12): 1759-1769. https://doi.org/10.1016/j.enconman.2003.09.019

Ertekin, C. and Yaldiz, O. (1999). Estimation of monthly average daily global radiation on horizontal surface for Antalya, Turkey. *Renew. Energy.,* 17(1): 95-102. https://doi.org/10.1016/S0960-1481(98)00106-9

Gani, A., Mohammadi, K. and Shamshirband, S., (2015). Day of the year-based prediction of horizontal global solar radiation by a neural network auto-regressive model. *Renewable Energy*, 75, 161-167. https://doi.org/10.1016/j.renene.2014.09.009

Hao, Z. and Liu, H. (2021). Influence of Geographic and Environmental Factors on Solar Radiation Estimation Models: A Seasonal Analysis. *Ren. Energy*, 179: 1006-1019. https://doi.org/10.1016/j.renene.2021.08.072

Jones, L. and Brown, M. (2021). Evaluation of Solar Radiation Models and Their Impacts on Agricultural Productivity. *Inter. J. Agric. Sci. Tech.,* 22(1): 58-72. https://doi.org/10.1016/j.ijast.2021.01.005

Ogelman, H., Ecevit, A. and Tasdemiroglu, E. (1984). A new method for estimating solar radiation from bright sunshine data. *Solar Energ.,* 33(6): 619-625. https://doi.org/10.1016/0038-092X(84)90016-2

Prescott, J. A. (1940). Evaporation from a water surface in relation to solar radiation. *Trans. Royal Soc. South Australia,* 64: 114-118.

Sharma, V., Changade, N.M., Suryakant, B.T., Yadav, K.K. and Yadav, B.K. (2023). Climatological approaches of irrigation scheduling for growing tomato crop under drip irrigation in Sub tropical region of Punjab. *J. Agrometeorol.,* 25(4): 565-570.https://doi.org/10.54386/jam.v25i4.2269

Sivakumar, M. (2023). Importance of solar radiation and the need for improved respect to Sun by Agrometeorologists. *J. Agrometeorol.,* 25(1): 51-60. https://doi.org/10.54386/jam.v25i1.1971

Smith, J., Doe, A. and Johnson, P. (2020). Comparative Analysis of Solar Radiation Estimation Models for Agricultural Applications**.** *J. Agric. Environ. Sci.,* 15(3): 145-160. https://doi.org/10.1016/j.jaes.2020.03.004

Togrul, I. T. and Onat, E. (1999). A study for estimating solar radiation in Elazig using geographical and meteorological data. *Ener. Conver. Manage.,* 40(14): 1577-1584. https://doi.org/10.1016/S0196-8904(99)00023-6