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Estimation of Daily Average Solar Radiation Using The Angström & Prescott Model Under The Conditions of Van, Turkey

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ABSTRACT

Solar radiation (R_s), which has been widely used as a renewable clean energy source in recent years, is one of the main factors that ensure the sustainability of many biological and chemical processes such as photosynthesis, evaporation, and evapotranspiration. In this context, accurately measured or estimated R_s data are needed to maximise the benefit from the sun. This study aims to develop a calibration equation for the Angström & Prescott solar radiation estimation model that is compatible with the semi–arid to arid climatic and environmental conditions of Van Province. The calibration coefficients (a_s= 0.19, b_s= 0.50) of this model were determined via the Microsoft Excel solver add-on, using the monthly averages of the daily sunshine duration and R_s data measured between 2012 and 2020. The calibration equation created with these coefficients was tested with daily current climatic data measured between 2012 and 2020, and daily average R_s values ranging between 5.13–25.93 MJ m^{-2} day^{-1} were estimated. The daily average measured R_s values in the same years were between 3.45–26.49 MJ m^{-2} day^{-1}. The daily average R_s values with an accuracy of 87.00% (MAPE= 13.00%) were estimated with the Angström & Prescott model calibration equation. It was concluded that the daily average solar radiation values estimated by this model could be used instead of the measured values (P> 0.05, n= 365).

KEYWORDS: Evapotranspiration, Calibration, Solar Radiation, Estimation model.

ARTICLE DETAILS

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1. INTRODUCTİON

Solar radiation, which is defined as 55% of the extraterrestrial radiation emitted from the sun and reaching the outer surface of the atmosphere, and which constitutes the most basic data of many engineering and architectural applications, is now widely used in the production of electrical energy and in the production of hot water with heating, ventilation and lighting systems based on this energy [1]. It is a scientific fact that the demand for energy will gradually increase in parallel with the increasing world population and accordingly, the available energy resources will be rapidly depleted. However, increasing the use of renewable energy sources is one of the primary measures that can be taken against climate change, which has developed due to the use of fossil fuels in energy production and has become a major threat to the whole world. The fact that solar radiation-based energy has zero carbon emission and most importantly, it is free of charge increases its preferability among renewable energy sources [2]. It has been emphasised by many researchers that the energy obtained from the total solar radiation falling on the earth in a year is much more than the energy obtained from all fossil fuels on earth [3, 4]. In order to obtain maximum efficiency from such a large energy source, accurately measured or estimated solar radiation data are needed.

The main factor determining the irrigation water requirement of crops is evapotranspiration (ET), which is called crop water consumption. ET, an important component of the hydrological cycle, utilises approximately 60% of solar radiation [5, 6]. However, it is known that solar radiation is closely related to some parameters such as photosynthesis, water requirement, nutrient uptake, soil heat flux change, evaporation and transpiration, which are effective on crop growth [7]. Solar radiation, which has a significant effect on crop growth and water consumption, can be used as a trigger that initiates irrigation alone in the preparation of irrigation schedules and in automatic irrigation systems [8, 9, 10, 11]. Solar radiation is one of the most important factors that should be taken into consideration in the design and projecting phase of agricultural production structures such as shelters and greenhouses. In order for crops grown in greenhouse conditions to grow and develop, environmental factors such as radiation energy, air, soil temperature, carbon dioxide concentration and humidity must be provided adequately in addition to nutrients and water [12]. The amount of solar radiation entering the greenhouse as radiation energy varies depending on the location, dimensions, orientation, roof slope and especially the cover material. The most important factor affecting the selection of greenhouse cover material is the radiation intensity affecting the outer surfaces of the greenhouse [13]. In cattle shelters where radiation is directly effective, animals can be exposed to heat stress. In order to prevent this heat stress, which causes decreases in milk and fertility yields and great economic losses in intensive enterprises, some structural measures should be taken at the design and project design stage [14, 15].

The most reliable and accurate solar radiation measurements are made by meteorological ground observation stations located mainly in city centres. In rural areas where agricultural activities are carried out, measurements cannot be made regularly due to the lack of adequate and equipped stations. The high cost and difficult calibration of the devices used in measurement processes constitute other problems. For these reasons, estimation of solar radiation using easily measurable or available parameters is more preferred [16]. In this direction, many estimation models have been developed based on daily sunshine duration [17, 18, 19, 20, 21, 22] and air temperature [23, 24, 25, 26, 27, 28]. Some previous studies have shown that sunshine duration-based models have much higher forecasting performance than temperature-based models [28, 29]. Angström & Prescott (Eq. 1), one of the sunshine duration-based models, is widely used in solar radiation (R_s) estimates in many regions with different climatic and geographical characteristics due to its simplicity and high estimation performance [30, 31]. The foundations of this model based on extraterrestrial radiation (R_a), daily actual sunshine duration (n) and possible maximum daily actual sunshine duration (N) parameters were laid by Angström in 1924 and further developed by Prescott in 1940 and presented under the name Angström & Prescott model [17, 18].

$$R_s = \left[a_s + b_s \times \left(\frac{n}{N}\right)\right] \times R_a \quad (1)$$

The input variables (n, R_a, N) of the Angström & Prescott model vary depending on geographical location and time. Therefore, it is necessary to calibrate this model in accordance with the local conditions in which it will be used to estimate Rs and to determine the most appropriate values of the calibration coefficients (a_s, b_s) [32, 33]. In the Angström & Prescott model, the only input variable determined by measurement is n and R_a and N variables can be estimated based on latitudinal geographical location and time (365 days) [34]. Local R_s data are needed in the calibration process of the Angström & Prescott model. In cases where these data cannot be measured or obtained, Angström [17] suggested 0.20 and 0.50 and Prescott [18] suggested 0.22 and 0.54 as calibration coefficients (a_s, b_s) that can be used without calibration. The same coefficients were recommended as 0.25 and 0.50 for all climatic conditions in the Irrigation - Drainage publication No. 56 prepared by the Food and Agriculture Organization of the United Nations (FAO) [34]. However, some researchers have stated that these coefficients represent only the local conditions for which they were developed and cannot be used for all regions [19, 35]. Similarly, some studies conducted in regions with different climatic and geographical locations have shown that the usability and reliability of these coefficients in local conditions are not sufficient [36, 37]. The use of these proposed a_s and b_s coefficients in R_s estimations without testing their suitability for local conditions may lead to erroneous and irreparable results. This can lead to high deviations in the calculations, especially for ET, which utilises 60% of the R_s [38, 39]. For these reasons, it is recommended to use the coefficients obtained as a result of the calibration process with locally measured or obtained R_s data as Angström & Prescott model calibration coefficients [40, 41].

This study aims to develop a calibration equation for the Angström & Prescott solar radiation estimation model that is compatible with the semi–arid to arid climatic and environmental conditions of Van Province. Additionally, the reliability of this equation is tested using the current daily data measured under local conditions.

2. MATERİALS AND METHODS

Van province is located in the Eastern Anatolia Region of Turkey, between 37° 43'–39° 26' north latitude and 42° 40'–44° 30' east longitude (Fig. 1). The altitude of the province is 1726 m, the average annual air temperature is 9.50 °C and the relative humidity is 58.67%. Van is one of the sunniest provinces in Turkey with an average annual sunshine duration of 7.90 hours day^{-1} and a solar radiation intensity of 15.32 MJ m^{-2} day^{-1}, and is located in the semi–arid to arid climate zone with a total annual precipitation of 392.70 mm. However, semi–arid to humid climate characteristics are felt more in the coastal areas of Lake Van [42].

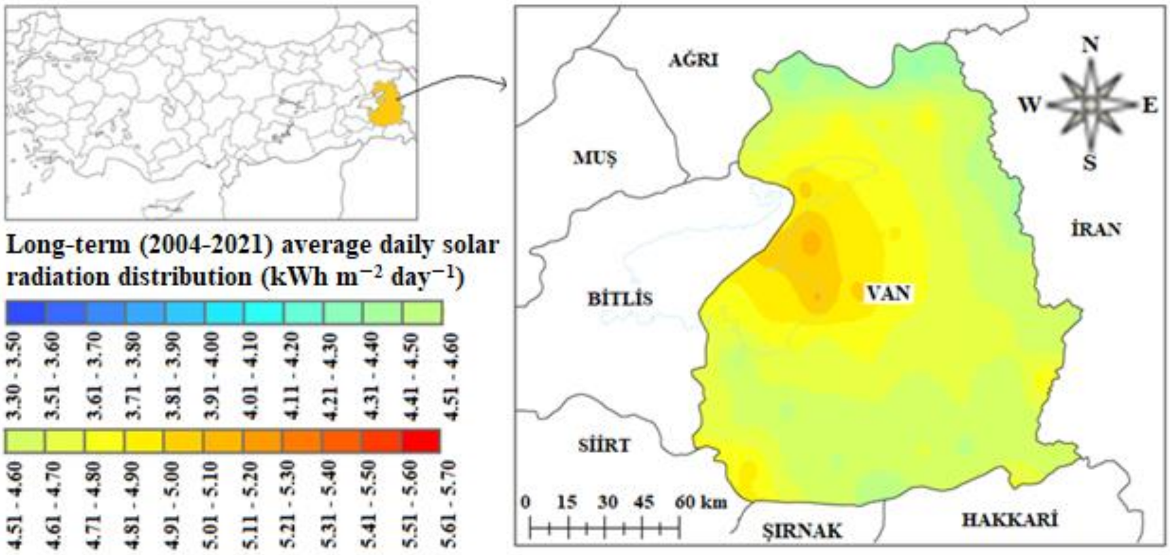

Figure 1. Geographical location and solar radiation distribution of Van on the Turkey map

Within the scope of the study, firstly, using the monthly average values of the daily average n and R_s data measured between 2012 and 2020 (Table 1), the most appropriate values of the calibration coefficients a_s and b_s of the Angström & Prescott model (Eq. 1) compatible with the climatic and environmental conditions of Van province were determined using the Microsoft Excel program solver add-on. The other components of this model were estimated using Eq. (2-8) respectively. The Julian date in daily estimations was determined by Eq. (9) [34, 42, 43].

Table 1. Monthly averages of the daily sunshine duration and solar radiation (2012–2020)

Months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
n (hours)	4.6	5.4	5.9	7.3	9.3	11.7	12.1	11.3	9.8	7.0	5.5	4.3
R_s (MJ m^{-2} day^{-1})	7.5	8.3	11.1	14.7	18.2	21.6	24.1	24.2	21.1	16.8	12.3	9.0

$$j = [(30.40 \times M) - 15 \quad (2)$$

$$d_r = 1 + 0.033 \times \cos\left(\frac{2 \times \pi \times j}{365}\right) \quad (3)$$

$$\delta = 0.409 \times \sin\left[\left(\frac{2 \times \pi \times j}{365}\right) - 1.39\right] \quad (4)$$

$$\emptyset = E \times \left(\frac{\pi}{180}\right) \quad (5)$$

$$w_s = \arccos(-\tan\emptyset \times \tan\delta) \quad (6)$$

$$R_a = 24 \times \left(\frac{60}{\pi}\right) \times G_{sc} \times d_r \times [(w_s \times \sin\emptyset \times \sin\delta) + (\cos\emptyset \times \cos\delta \times \sin w_s)] \quad (7)$$

$$N = \left(\frac{24}{\pi}\right) \times w_s \quad (8)$$

$$j = [(30.56 \times M) - 30 + D] - 2 \quad (9)$$

In the above equations; J, Julian date; M, month number (1–12) converted to Julian date; d_r, Earth-Sun inverse relative distance; δ, solar declination (radians); E, latitude (degrees); Ø, latitude (radians); w_s, sunset hour angle (radians); G_{sc}, solar constant (0.0820 MJ m^{-2} minute^{-1}); R_a, extraterrestrial radiation (MJ m^{-2} day^{-1}); n, daily sunshine duration (hours); N, maximum possible daily sunshine duration (hours), and D, day number (1–31) converted to Julian date. In order to test the Angström & Prescott, which was adapted to the conditions of Van province, and to reveal the level of reliability in daily average solar radiation estimations, daily data for 2021 and 2022 measured by the meteorological ground observation station were used (Fig. 2).

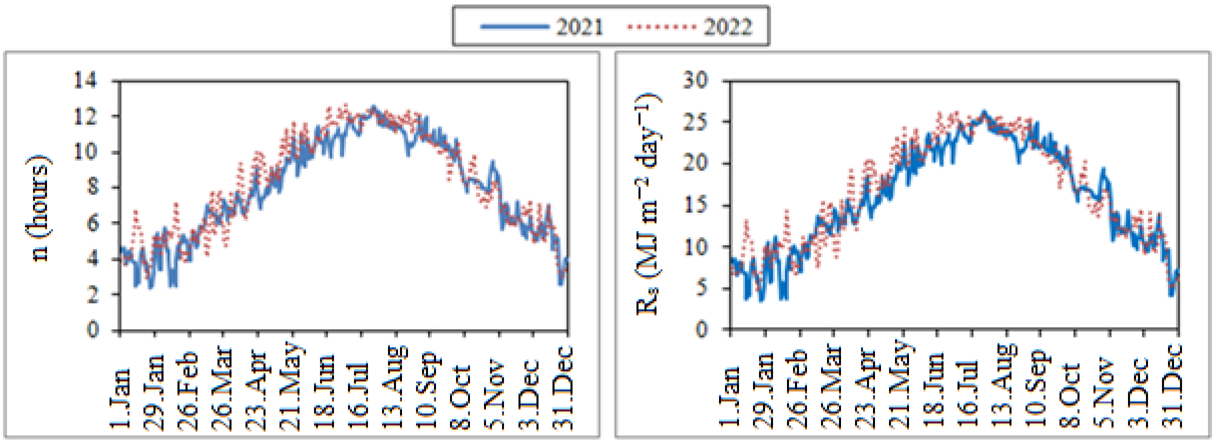

Figure 2. Daily sunshine duration and solar radiation values (2021–2022)

The daily average R_s values estimated using the Angström & Prescott model calibration equation were compared with the actual measured R_s values (Fig. 2). Mean absolute error (Eq. 10), mean absolute percentage error (Eq. 11) and root mean square error (Eq. 12) were used as comparison criteria. The accuracy of the estimated R_s values was considered "excellent" if MAPE < 10%, "good" if MAPE= 10–20%, "reasonable" if MAPE= 20–50% and "inaccurate" if MAPE > 50% [44]. Regression analysis was performed to reveal the level of statistical relationship between measured and estimated daily average R_s values (Eq. 13). Additionally, unpaired T-tests were performed using Microsoft Excel Program to determine whether the differences between the means of the data groups formed by the measured and estimated daily R_s values were statistically significant. In these tests conducted at a 95% confidence interval, differences between the means were considered not statistically significant when $P \geq 0.05$, and significant when $P < 0.05$. Where, P represents the possible error amount [45]

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}(|X_i - Y_i|) \quad (10)$$

$$\mathrm{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|X_i - Y_i|}{X_i}100\right) \quad (11)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2} \quad (12)$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i - \hat{X})(Y_i - \hat{Y})\right]^2}{\sum_{i=1}^{n}(X_i - \hat{X})^2 \sum_{i=1}^{n}(Y_i - \hat{Y})^2} \quad (13)$$

In the above equations; MAE, mean absolute error (MJ m^{-2} day^{-1}); MAPE, mean absolute percentage error (%); RMSE, root mean square error (MJ m^{-2} day^{-1}); X_i and Y_i, actual and estimated daily average R_s values (MJ m^{-2} day^{-1}), respectively; $\hat{X}$ and $\hat{Y}$, averages of the actual and estimated daily average R_s values (MJ m^{-2} day^{-1}), respectively; R^2, determination coefficient; and n, number of observations.

3. RESULTS AND DISCUSSION

Firstly, the monthly average R_a and N values were determined based on the monthly average n and R_s data measured between 2012 and 2020, and given in Table 2. Then, Angström & Prescott calibration coefficients were determined by using the Microsoft Excel program solver add-on. After the necessary parameters were entered into the Microsoft Excel and formula definitions were made, the calibration coefficients a_s and b_s were assigned the value "1". The sum of the squares of the differences between the estimated R_s values, obtained using these coefficients, and the measured R_s values was assigned to the target cell in the solver. Then, the solver was run, yielding the coefficients a_s (0.19) and b_s (0.50), which minimized the total sum of squares.

Table 2. Monthly averages of the Angstrom & Prescott calibration equation components (2012–2020)

Months	J	d_r	Ø (radians)	δ (radians)	W_s (radians)	R_a (MJ m^{-2} day^{-1})	N (hours)
January	15.4	1.03	0.67	-0.37	1.26	16.02	9.62
February	45.8	1.02	0.67	-0.24	1.38	21.22	10.57
March	76.2	1.00	0.67	-0.04	1.55	28.50	11.81
April	106.6	0.99	0.67	0.18	1.71	35.40	13.09
May	137.0	0.98	0.67	0.34	1.85	40.06	14.16
June	167.4	0.97	0.67	0.41	1.92	41.83	14.68

July	197,8	0.97	0.67	0.37	1.88	40.70	14.40
August	228.2	0.98	0.67	0.24	1.76	36.76	13.45
September	258.6	0.99	0.67	0.04	1.60	30.42	12.21
October	289.0	1.01	0.67	-0.18	1.43	23.11	10.93
November	319.4	1.02	0.67	-0.34	1.29	17.16	9.86
December	349.8	1.03	0.67	-0.41	1.22	14.53	9.33

The daily average R_s values estimated for the years 2021 and 2022 with the calibration equation created using the a_s (0.19) and b_s (0.50) coefficients, and the daily R_s values measured by the Meteorological ground observation station in the same years are given in Fig. 3. The measured daily average R_s values for 2021 and 2022 ranged between 3.45–26.22 MJ m^{-2} day^{-1} and 4.60–26.49 MJ m^{-2} day^{-1}, respectively. The annual average values were 15.93 MJ m^{-2} day^{-1} for 2021 and 16.60 MJ m^{-2} day^{-1} for 2022. The daily average R_s values estimated using the Angström & Prescott calibration equation, similar to the measured values, ranged from 4.81–25.17 MJ m^{-2} day^{-1} in the first year and 5.13–25.93 MJ m^{-2} day^{-1} in the second year. The annual average values were determined to be 15.19 MJ m^{-2} day^{-1} for 2021 and 15.57 MJ m^{-2} day^{-1} for 2022.

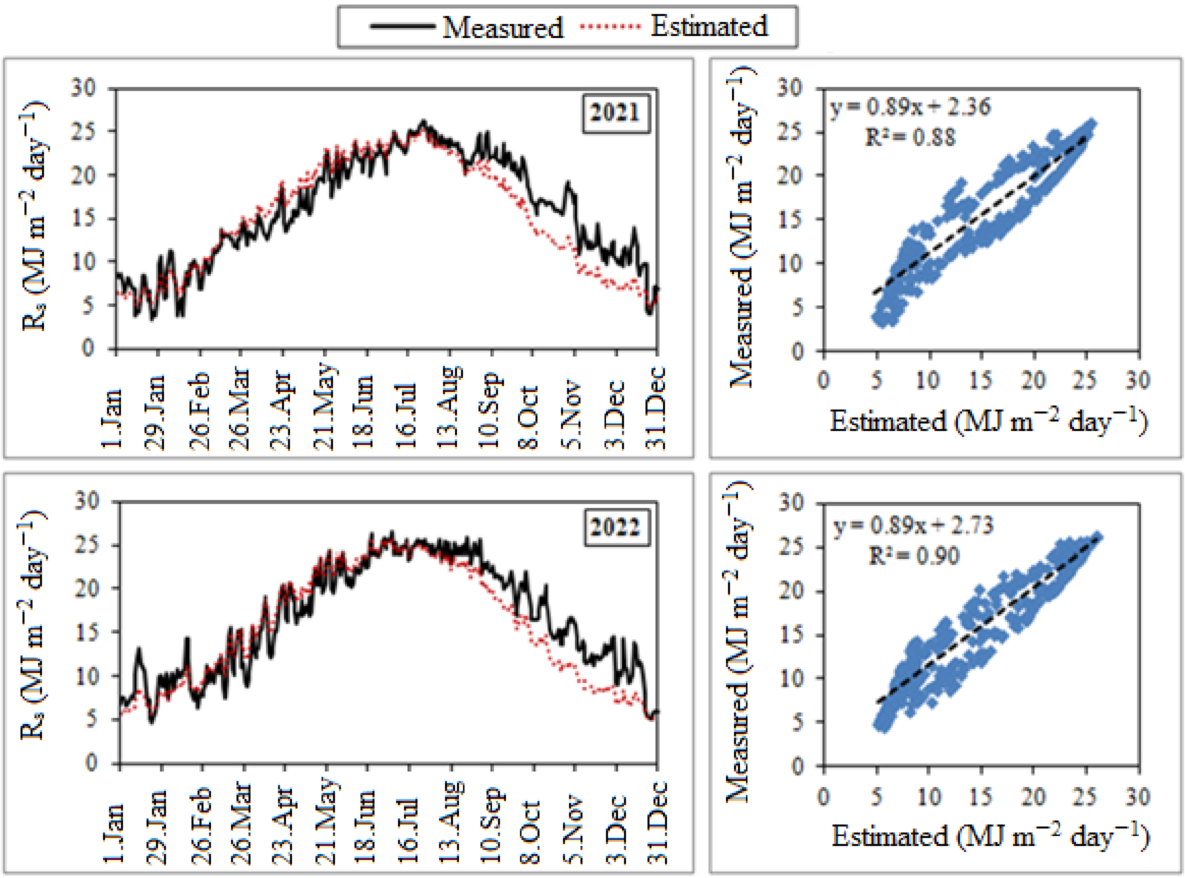

Figure 3. Daily average measured and estimated solar radiation values (2021–2022)

The ratio of daily average solar radiation values estimated using the calibration equation to explain the variation in measured solar radiation values was 88.00% (R^2= 0.88) in the first year and 90.00% (R^2= 0.90) in the second year (Fig. 3). The monthly averages of the measured and estimated daily solar radiation values and the errors (MAE, MAPE, RMSE) calculated as an indicator of the deviation between these values are given in Table 3 and Table 4. The annual average MAE, MAPE and RMSE were determined as 1.94 MJ m^{-2} day^{-1}, 14.31% and 2.37 MJ m^{-2} day^{-1} respectively in the first year. The same errors were obtained as 1.87 MJ m^{-2} day^{-1}, 13.29% and 2.33 MJ m^{-2} day^{-1} for the second year, respectively.

Table 3. The performance of the Angstrom & Prescott in estimating daily solar radiation (2021)

Months	R_s (MJ m^{-2} day^{-1})		MAE	MAPE	RMSE	Accuracy
	Measured	Estimated	(MJ m^{-2} day^{-1})	(%)	(MJ m^{-2} day^{-1})	
January	6.86	6.27	1.21	18.70	1.35	Good
February	7.82	8.22	0.97	15.82	1.26	Good

March	12.01	12.83	0.83	7.10	0.95	Excellent
April	14.50	16.50	1.99	14.05	2.07	Good
May	18.46	20.40	1.94	10.89	2.02	Good
June	21.72	22.93	1.20	5.66	1.27	Excellent
July	24.28	24.20	0.56	2.32	0.66	Excellent
August	23.16	22.20	0.96	4.15	1.02	Excellent
September	22.03	19.07	2.97	13.53	3.02	Good
October	17.34	13.43	3.92	22.61	4.01	Reasonable
November	13.08	9.13	3.95	29.83	4.09	Reasonable
December	9.40	6.72	2.80	27.38	3.15	Reasonable
Average	15.93	15.19	1.94	14.31	2.37	Good

Table 4. The performance of the Angstrom & Prescott in estimating daily solar radiation (2022)

Months	**R_s (MJ m^{-2} day^{-1})**		**MAE**	**MAPE**	**RMSE**	**Accuracy**
	Measured	**Estimated**	**(MJ m^{-2} day^{-1})**	**(%)**	**(MJ m^{-2} day^{-1})**	
January	8.25	6.80	1.63	18.01	1.99	Good
February	9.43	8.91	1.22	12.53	1.40	Good
March	11.22	12.38	1.25	12.47	1.55	Good
April	16.45	17.69	1.26	8.63	1.50	Excellent
May	20.06	21.41	1.35	7.21	1.51	Excellent
June	23.12	23.82	0.77	3.49	0.92	Excellent
July	24.94	24.63	0.41	1.61	0.48	Excellent
August	24.45	22.98	1.47	6.00	1.60	Excellent
September	21.29	18.66	2.63	12.40	2.68	Good
October	16.89	13.23	3.66	21.66	3.74	Reasonable
November	13.29	9.19	4.10	30.69	4.17	Reasonable
December	9.37	6.71	2.67	24.74	3.21	Reasonable
Average	16.60	15.57	1.87	13.29	2.33	Good

The daily average R_s values estimated using the Angström & Prescott calibration equation were observed to have "acceptable" accuracy (MAPE= 20–50%) during October, November, and December, when humidity levels reached their peak in both years. In January and February, the accuracy level was classified as "good" (MAPE= 10–20%). In other months, characterized by predominantly clear skies and low humidity levels, the accuracy was "excellent" (MAPE < 10%). Considering annual average values, the daily average R_s values estimated using the Angström & Prescott calibration equation demonstrated "good" accuracy (MAPE= 10–20%) in both years. Using this equation, daily average R_s values were estimated with an accuracy rate of 85.69% (MAPE= 14.31%) in the first year and 86.71% (MAPE= 13.29%) in the second year. In cases where local R_s data required for Angström & Prescott model calibration cannot be measured or obtained, universal coefficients a_s and b_s that can be used under all climatic conditions have been proposed: Angström [17] suggested values of 0.20 and 0.50, Prescott [18] recommended 0.22 and 0.54, while Allen et al. [34] proposed 0.25 and 0.50. The Angström & Prescott model calibration equations developed using these coefficients were tested with daily data from Van Province for 2021 and 2022. The estimated annual average R_s values and the corresponding MAE, MAPE, and RMSE errors are presented in Tables 5 and Table 6.

Table 5. The performances of the proposed coefficients (a_s, b_s) in estimating daily solar radiation (2021)

Angström & Prescott equation	**a_s**	**b_s**	**R_s (MJ m^{-2} day^{-1})**		**MAE**	**MAPE**	**RMSE**
			Measured	**Estimated**	**(MJ m^{-2} day^{-1})**	**(%)**	**(MJ m^{-2} day^{-1})**
Angström [17]	0.20	0.50	15.93	15.48	1.97	14.61	2.36
Prescott [18]	0.22	0.54	15.93	16.84	2.42	17.37	2.72
Allen et al. [34]	0.25	0.50	15.93	16.92	2.81	18.21	2.81
Proposed for Van	0.19	0.50	15.93	15.19	1.94	14.31	2.37

Table 6. The performances of the proposed coefficients (a_s, b_s) in estimating daily solar radiation (2022)

Angström & Prescott equation	a_s	b_s	R_s (MJ m^{-2} day^{-1})		MAE (MJ m^{-2} day^{-1})	MAPE (%)	RMSE (MJ m^{-2} day^{-1})
			Measured	Estimated			
Angström [17]	0.20	0.50	16.60	15.86	1.86	13.23	2.28
Prescott [18]	0.22	0.54	16.60	17.24	2.20	14.75	2.53
Allen et al. [34]	0.25	0.50	16.60	17.30	2.23	15.20	2.58
Proposed for Van	0.19	0.50	16.60	15.57	1.87	13.29	2.33

It was observed that the a_s (0.19) and b_s (0.50) coefficients obtained for the Angström & Prescott model calibrated to Van Province conditions show a very close similarity to the coefficients proposed by Angström [17]. However, differences were observed when compared to the coefficients suggested by Prescott [18] and Allen et al. [34]. As seen in Table 5 and Table 6, the annual average daily R_s values estimated using the coefficients a_s (0.19) and b_s (0.50), determined for the conditions of Van Province, were calculated as 15.19 MJ m^{-2} day^{-1} for 2021 and 15.57 MJ m^{-2} day^{-1} for 2022. The measured annual average daily R_s values for the same years were 15.93 MJ m^{-2} day^{-1} and 15.60 MJ m^{-2} day^{-1}, respectively. The nearest values to these measurements were estimated using the coefficients proposed by Angström [17]. The annual average daily R_s values obtained with these coefficients were 15.48 MJ m^{-2} day^{-1} for the first year and 15.86 MJ m^{-2} day^{-1} for the second year. Using the calibration coefficients determined for Van Province, the daily average R_s values were estimated with an accuracy of 85.69% (MAPE= 14.31%) for the first year and 86.71% (MAPE= 13.29%) for the second year. Similarly, using the coefficients a_s (0.20) and b_s (0.50) proposed by Angström [17], the accuracy rates were 85.39% (MAPE= 14.61%) and 86.77% (MAPE= 13.23%) for the two years, respectively. These results suggest that the coefficients proposed by Angström [17] can be used in Van Province without calibration. The daily average R_s values estimated using the coefficients a_s (0.22) and b_s (0.54) proposed by Prescott [18] achieved accuracy rates of 82.63% (MAPE= 17.37%) for the first year and 85.25% (MAPE= 14.75%) for the second year. Similarly, the coefficients a_s (0.25) and b_s (0.50) proposed by Allen et al. [34] resulted in accuracy rates of 81.79% (MAPE= 18.21%) for the first year and 84.80% (MAPE= 15.20%) for the second year. The accuracy levels of R_s estimates obtained using the coefficients proposed by Prescott [18] and Allen et al. [34] were lower than those of Angström [17]. Based on their estimation performance under the climatic and environmental conditions of Van Province, the proposed coefficients can be ranked from best to worst as Angström [17], Prescott [18], and Allen et al. [34]. While all coefficients provided “good” accuracy levels (MAPE= 10–20%) for estimating daily average R_s values, using these coefficients without testing their suitability for local conditions can lead to significant and irreparable errors in evapotranspiration (ET) calculations [38, 39]. Malekinezhad [46], Isikwue et al. [47], and Mahida [48] demonstrated a strong positive correlation between R_s and ET ($R^2 \geq 0.90$), and reported that inaccurately measured or estimated R_s values significantly influence ET levels. ET, the fundamental data used to determine the irrigation water requirements of crops, must be accurately calculated. Incorrect estimations can result in providing crops with either insufficient or excessive water. If crops receive less water than required, they may experience water stress. Conversely, overwatering can lead to environmental problems such as soil erosion, rising groundwater levels, salinization, and land degradation, as well as crop-specific issues like root rot and chlorosis, which negatively affect yield and quality [49]. For these reasons, it is essential to use coefficients obtained through local calibration processes as the calibration coefficients for the Angström & Prescott model. This approach ensures greater accuracy in the estimation of R_s, which is critical for reliable ET calculations and sustainable water management.

4. CONCLUSION

In this study, the calibration equation of the Angström & Prescott model, adapted to the conditions of Van Province, was developed using the monthly average values of daily sunshine duration and solar radiation measured between 2012 and 2020. The calibration coefficients (a_s= 0.19, b_s= 0.50) were determined using the Microsoft Excel program solver add-on. The model, tailored to the local conditions, was tested using daily data from 2021 and 2022. With the Angström & Prescott model calibration equation, daily average solar radiation values were estimated with an accuracy rate of approximately 87.00% (MAPE= 13.00%). The differences between the measured and estimated solar radiation values were not statistically significant (P> 0.05, n= 365). It was concluded that the daily average solar radiation values estimated by Angström & Prescott model could be used instead of the measured values under the conditions of Van Province (P> 0.05, n= 365). The reliability of empirical solar radiation estimation models varies depending on climatic and environmental conditions. Therefore, it is recommended that they be tested and, if necessary, calibrated under the local conditions where they will be used.

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