Research Article

Evaluation and Calibration of Christiansen Method for Estimating Daily Evaporation from Class-A Pan under the Conditions of Van, Turkey

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Abstract

Evaporation (E_{pan}) measured from Class-A pan evaporimeter is widely used in many studies within the scope of hydrology. Due to various reasons, it may be necessary to complete the unmeasured evaporation data using empirical estimation methods. The reliability of these methods varies depending on climatic and environmental conditions. Therefore, they need to be tested under the local conditions and calibrated if necessary. This study aims to test the usability of Christiansen evaporation estimation method under the conditions of Van, and to calibrate it in compatible with local conditions. Firstly, the original equation of this method was tested using nine years of daily climate data measured between 2012 and 2020. Then, the original equation was calibrated using the same data and its modified equation was created. The validity of evaporation values estimated using both the original and modified equations was tested with climate data from the period of 2021–2022. The performance of Christiansen method, calibrated using the linear regression approach, in estimating daily evaporation was evaluated using the determination coefficient (R^2), mean absolute percentage error (MAPE), and Nash–Sutcliffe Efficiency (NSE) statistical metrics. While the original Christiansen equation estimated evaporation values with 74.90% accuracy (R^2= 0.79, MAPE= 25.10%, NSE= 0.48), the accuracy improved to 86.58% (R^2= 0.79, MAPE= 13.42%, NSE= 0.77) using the modified equation. The differences between the means of the data groups consisting of the measured evaporation values and those estimated using the modified Christiansen equation were not statistically significant (p > 0.05). It has been concluded that, the daily evaporation values estimated by the modified Christiansen equation can be used instead of the measured values.

Keywords: *Calibration, Class-A pan, Estimation method, Evaporation, Reliability analysis*

1. Introduction

Evaporation is the process of water transforming from the liquid phase to water vapor. It is the primary means by which water is transferred to the atmosphere as water vapor [1, 2]. Evaporation is the most important data of many studies carried out within the scope of hydrology such as determination of irrigation water requirements of crops, water budgeting, drought monitoring and water resources management. Therefore, accurately measured or estimated evaporation data are needed to effectively manage available water resources and prioritize their future use [3, 4, 5, 6].

Evaporation (E_{pan}) occurring from open water surfaces is measured using Class-A pan evaporimeter, which consists of a cylindrical evaporation pan made of stainless steel sheet (diameter = 120.7 cm, height = 25 cm) placed on a wooden platform 15 cm high. This evaporimeter is sited on a short green (grass) cover and surrounded by fallow soil (50 m or more) [7]. The Class-A pan evaporimeter method is widely used worldwide due to the simplicity of the technique, low cost and ease of application [8]. In addition to the hydrological studies mentioned above, many studies have shown that this method can be successfully used to estimate evaporation occurring from the water surface of lakes, ponds reservoirs, and dams [9, 10, 11, 12, 13].

Evaporation measurements cannot be made due to overflow of the water in the Class-A pan evaporimeter during heavy rainfall, freezing in cold weather and breakdown of automatic measuring devices. In addition, E_{pan} can be measured incorrectly due to animal activity in and around the evaporation pan and debris in the water. For these reasons, it may be necessary to complete the unmeasured or inaccurately measured E_{pan} data [8, 14, 15]. Numerous empirical methods, such as Penman [16], Kohler & Nordensen [17], Christiansen [18], Priestley & Taylor [19], and Linacre [20], have been developed to estimate E_{pan} from the Class-A pan evaporimeter. Evaporation is a complex and non-linear phenomenon because it depends on several interacting climatological factors, such as air temperature, relative humidity, wind velocity, solar radiation, sunshine percentage, latitude, and altitude. Christiansen, the most comprehensive empirical evaporation estimation method using almost all of these parameters, was developed based on the multiple correlation approach [18, 21, 22].

Many studies have been conducted to evaluate, compare, and further validate some empirical evaporation estimation methods, including Christiansen, under the different climatic and environmental conditions. Irmak & Haman [22] reported that, among the Penman, Priestley & Taylor, Kohler & Nordensen, Linacre, and Christiansen methods tested for daily E_{pan} estimations under the humid Florida state conditions in United States, the best and worst performing methods were Kohler & Nordensen and Linacre, respectively. They also stated that the Christiansen method ranked fourth, following Penman and Priestley & Taylor. Similarly, in a study conducted under the semi-arid Iğdır Plain conditions in Turkey, where the same methods, except for Priestley & Taylor, were

tested for daily E_{pan} estimations, the best performing method was Kohler & Nordensen. This was followed by the Christiansen, Linacre, and Penman methods, respectively [8]. In a study conducted under the Telangana state conditions in India, among eight empirical potential evapotranspiration (PET) estimation methods based on temperature, radiation and combination, including the Christiansen method, the top three best-performing methods were declared as Turc, Hargreaves and Priestley & Taylor, respectively. The evaporation-based Christiansen method was ranked fourth, following these methods [23]. In contrast to this study, Durgam & Sastri [24] expressed that the Christiansen method was the best-performing method among seven empirical potential evapotranspiration (PET) estimation methods based on temperature and radiation, including the Christiansen method, evaluated under the Chhattisgarh state conditions in India. Usta et al. [25] stated that the four E_{pan} estimation methods they compared under the semiarid-humid Kahramanmaraş conditions in Turkey, were ranked from best to worst according to their performance in daily estimates as Kohler & Nordensen, Priestley & Taylor, Linacre, and Penman. Similarly, in another study comparing the same methods, except for Penman under the semiarid-humid Van conditions in Turkey, the ranking was from best to worst as Linacre, Kohler & Nordensen, and Priestley & Taylor [26]. Although both Kahramanmaraş and Van have a semiarid-humid climate, the Linacre method, which had the best estimation performance in Kahramanmaraş, exhibited the worst performance in Van. It is thought that the different performances of the Linacre method in both cities are due to differences in altitude, latitude, and extraterrestrial radiation.

It has been revealed that the empirical E_{pan} estimation methods evaluated within the scope of previous studies are generally compatible with the conditions of the regions where they were developed, and also that their estimation performance varies depending on the climatic and environmental conditions. Therefore, it has been stated that these methods should be tested and, if necessary, calibrated under the local conditions in which they will be used. In addition to this, in some studies where various empirical methods used in E_{pan} and PET estimations were calibrated under the different climatic and environmental conditions, it was observed that the accuracy, which was very low levels before calibration, increased after calibration [2, 27, 28, 29, 30].

This study aims to evaluate the usability and reliability of Christiansen method under the climatic and environmental conditions of Van, Turkey, and to calibrate it to be compatible with local conditions using the linear regression statistical approach. It is believed that the modified Christiansen equation, which is aimed to be created as a result of the calibration process, can help minimize the errors in E_{pan} estimates made within the context of irrigation schedules, water budgets, and drought action plans prepared under the climatic and environmental conditions of Van.

2. Materials and Methods

Van is the sixth largest city of Turkey in terms of surface area (19062 km²). It is located within the borders of the Eastern Anatolia Region, which has cold and snowy winters and cool, mild summers. However, due to its microclimate structure originating from Van Lake, a milder climate is felt throughout the city, unlike the Eastern Anatolia Region. The location of Van on the Turkey map, located between 37° 43' – 39° 26' north latitude and 42° 40' – 44° 30' east longitude, is shown in Fig. 1. The altitude of Van is 1726 m. Its annual average temperature and humidity are 9.50 °C and 58.67%, respectively. It is one of the most sun-drenched cities in Turkey with an annual average daily sunshine duration of 7.90 hours. The annual total precipitation is 392.70 mm [31].
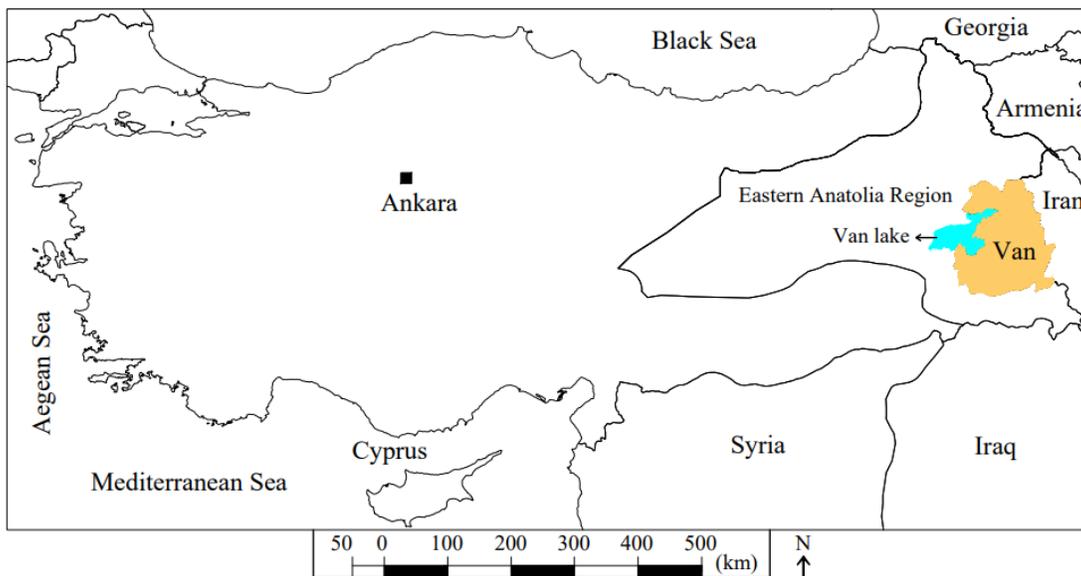

Figure 1: Geographical location of Van on the Turkey map

The original equation of Christiansen method has been evaluated and calibrated using nine years of daily climate data measured by the Van Edremit meteorological ground observation station during the period between 2012 and 2020. The accuracy and reliability levels of the original and modified equations of the Christiansen method were tested using current climate data from the 2021–2022 period measured by the same station. The monthly average values of daily total evaporation realised from the Class-A pan evaporimeter (E_{pan}), daily actual duration of sunshine (n), daily average air temperature (T), daily average relative humidity (RH), and daily average wind velocity at 2 m above the ground surface (U_2) data using for the evaluation, calibration and testing processes are given in Table 1 and Table 2, respectively [31]. The study was conducted for the April–October period, considering the growing seasons of agricultural crops which are predominantly cultivated in Van [32].

Table 1: Monthly average values of some daily climate data (2012–2020)

Months	E_{pan} (mm day^{-1})	T (°C)	n (hour day^{-1})	RH (%)	U_2 (m s^{-1})
April	3.84	8.51	7.12	64.95	2.42
May	5.67	13.61	8.70	62.30	2.82
June	8.11	18.55	10.50	53.21	2.78
July	10.02	22.20	12.00	45.84	2.67
August	9.67	22.30	12.03	44.80	2.56
September	7.36	17.83	10.22	46.70	2.51
October	4.18	11.63	8.05	60.44	2.76
Average	7.00	16.38	9.80	54.03	2.65

Table 2: Monthly average values of some daily climate data (2021–2022)

Months	E_{pan} (mm day^{-1})	T (°C)	n (hour day^{-1})	RH (%)	U_2 (m s^{-1})
April	4.50	9.40	7.50	60.16	3.21
May	6.90	14.38	9.00	54.38	2.78
June	9.53	18.66	10.55	43.33	3.11
July	10.40	22.13	11.98	48.51	2.98
August	9.65	20.95	11.47	46.71	3.06
September	7.70	18.02	10.30	45.35	2.57
October	4.65	11.95	8.17	52.17	2.76
Average	7.63	16.50	9.85	50.10	2.92

The Christiansen equation is given Eq. (1). The components of this equation were determined using the Eq. (2–6). In these equations; E_{pan} is the evaporation realised from the Class-A pan evaporimeter (mm day^{-1}), R_a is the extraterrestrial radiation (mm day^{-1}) and C_T, C_W, C_H, C_S, C_E, and C_M represent the coefficients for air temperature, wind velocity, relative humidity, sunshine percentage, altitude, and Christiansen's monthly coefficients, respectively [18, 22]. C_M was taken as "1" suggested by Burman [21]. T is the daily average air temperature (°C), W is the daily average wind velocity at the 15.20 cm above the rim of the Class-A pan evaporimeter (km day^{-1}), H is the daily average relative humidity (%), S is the sunshine percentage (%), and E is the altitude (m).

$$E_{pan} = 0.473 \times R_a \times C_T \times C_W \times C_H \times C_S \times C_E \times C_M \qquad (1)$$

$$C_T = 0.393 + 0.5592 \times \left(\frac{T}{20}\right) + 0.04756 \times \left(\frac{T}{20}\right)^2 \qquad (2)$$

$$C_W = 0.708 + 0.3276 \times \left(\frac{W}{96.60}\right) - 0.036 \times \left(\frac{W}{96.60}\right)^2 \qquad (3)$$

$$C_H = 1.250 - 0.212 \times \left(\frac{H}{57.40}\right) - 0.038 \times \left(\frac{H}{57.40}\right)^2 \qquad (4)$$

$$C_S = 0.542 + 0.640 \times \left(\frac{S}{80}\right) - 0.4992 \times \left(\frac{S}{80}\right)^2 + 0.3174 \times \left(\frac{S}{80}\right)^3 \qquad (5)$$

$$C_E = 0.970 + 0.030 \times \left(\frac{E}{305}\right) \qquad (6)$$

The daily average R_a values have been estimated using Eq. (7–12) based on geographical location and altitude [7]. In these equations; j is the Julian date, M is the number of the month (1–12), D is the number of the day (1–31), d_r is the inverse relative distance Earth-Sun, δ is the solar declination (Radians), L is the latitude (Degrees), Ø is the latitude (Radians), W_s is the sunset hour angle (Radians), R_a is the daily average extraterrestrial radiation (MJ m^{-2} day^{-1}), and G_{sc} is the solar constant (0.0820 MJ m^{-2} minute^{-1}). As a result of the calculations, R_a expressed in MJ m^{-2} day^{-1} has been converted to the equivalent evaporation (E_{pan}) value in mm day^{-1} by correcting with the conversion factor of 0.473 in original Christiansen equation [18, 22].

$$j = [(30.56 \times M) - 30 + D] - 2 \tag{7}$$

$$d_r = 1 + 0.033 \times \cos(2 \times \pi \times j \times 365^{-1}) \tag{8}$$

$$\delta = 0.409 \times \sin[(2 \times \pi \times j \times 365^{-1}) - 1.39] \tag{9}$$

$$\emptyset = L \times \pi \times 180^{-1} \tag{10}$$

$$w_s = \arccos(-\tan\emptyset \times \tan\delta) \tag{11}$$

$$R_a = 24 \times \frac{60}{\pi} \times G_{sc} \times d_r \times [(w_s \times \sin\emptyset \times \sin\delta) + (\cos\emptyset \times \cos\delta \times \sin w_s)] \tag{12}$$

The daily average wind velocity (W) at the 15.20 cm above the rim of the Class-A pan evaporimeter was determined using Eq. (13). In these equation; U_2 is the daily average wind velocity at 2 m above the ground surface (m s^{-1}), and h is the height at which W is measured. "h" was determined as 55.20 cm by summing the height of the wooden platform (15 cm), the height of the evaporation pan (25 cm) and the height at which W was measured (15.20 cm), respectively (Fig. 2). As a result of the calculations, W expressed in m s^{-1} has been corrected by a coefficient of 86.40 and converted in km day^{-1} (1 m s^{-1} = 86.40 km day^{-1}) [7, 33, 34].

$$U_2 = W \times \frac{4.87}{\ln(67.8 \times h - 5.42)} \tag{13}$$
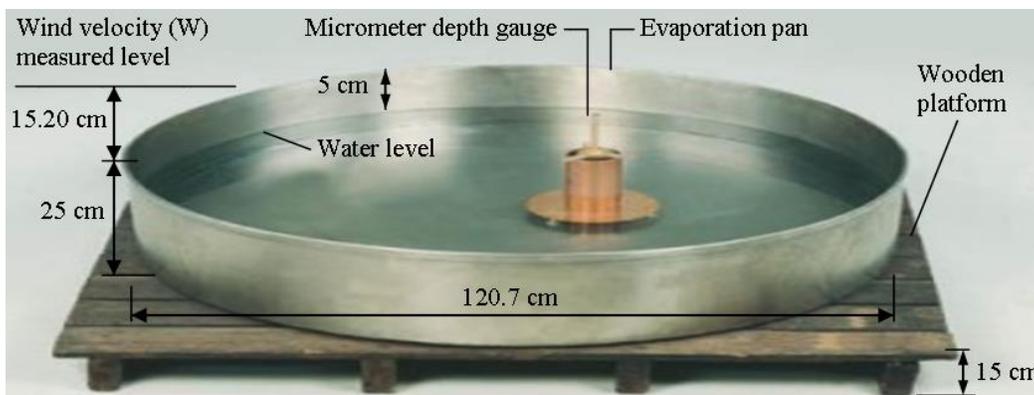

Figure 2: Class-A pan evaporimeter

The daily sunshine percentage (S) values have been estimated using Eq. (14–16). In these equations; S_c is the sky cover scaled from 0 to 10, n is the daily actual duration of sunshine (hour day^{-1}), N is the daily maximum possible duration of sunshine (hour day^{-1}), and W_s is the sunset hour angle (Radians) [7, 35].

$$S = 1 - 0.016 \times S_c - 0.0084 \times (S_c)^2 \tag{14}$$

$$S_c = \frac{0.9691 - \frac{n}{N}}{0.0842} \tag{15}$$

$$N = \left(\frac{24}{\pi}\right) \times w_s \tag{16}$$

The modified equation of the Christiansen method was created by assigning calibration coefficients "a" and "b" to the original equation Eq. (17). The optimal values of the calibration coefficients were determined using the linear regression method Eq. (18). In the calibration processes carried out using Microsoft Excel Program, the actual E_{pan} values ($E_{pan\_measured}$) measured from the Class-A pan evaporimeter are considered the dependent variables (y) and the E_{pan} values ($E_{pan\_estimated}$) estimated by original Christiansen equation are considered the independent variables (x). The constants "a" (slope) and "b" (intercept) are defined as calibration coefficients. The calibrated equation must have "a" close to unity, while "b" should be near zero for the best results. To bring the coefficient "a" closer to unity, the slope of the regression line was multiplied by the inverse of the slope. Additionally, to get "b" closer to zero, the opposite sign value of the intercept was added to the new regression equation [36].

$$E_{pan} = a \times (0.473 \times R_a \times C_T \times C_W \times C_H \times C_S \times C_E \times C_M) + b \tag{17}$$

$$y = ax + b \qquad E_{pan\_measured} = a \times E_{pan\_estimated} + b \tag{18}$$

The daily E_{pan} values estimated using the original and modified equations of the Christiansen method were compared with the actual daily E_{pan} values measured from the Class-A pan evaporimeter. The statistical approaches of the mean absolute percentage error (MAPE) (Eq. (19)), and Nash–Sutcliffe Efficiency (NSE) value (Eq. (20)) were used as comparison criterion. The accuracy of the estimated E_{pan} values was considered "excellent" if MAPE < 10%, "good" if MAPE= 10–20%, "reasonable" if MAPE= 20–50% and "inaccurate" if MAPE > 50%. In addition, according to the evaluation based on NSE, the accuracy of the estimated E_{pan} values was considered "good" if NSE > 0.75, "satisfying" if NSE= 0.36–0.75 and "less satisfactory" if NSE < 0.36 [37, 38, 39]. Linear regression analyses were performed to reveal the level of statistical relationship between measured and estimated E_{pan} values (Eq. (21)). In the following equations; MAPE is mean absolute percentage error (%), NSE is Nash–Sutcliffe Efficiency value, X_i and Y_i are actual and estimated E_{pan} values (mm day^{-1}), respectively, $\hat{X}$ and $\hat{Y}$ are averages of the actual and estimated E_{pan} values (mm day^{-1}), respectively, R^2 is determination coefficient, and n is number of observations.

$$\text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{X_i - Y_i}{X_i} \right| \times 100 \tag{19}$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}(X_i - \widehat{X})^2} \tag{20}$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i - \widehat{X}) \times (Y_i - \widehat{Y})\right]^2}{\sum_{i=1}^{n}(X_i - \widehat{X})^2 \times \sum_{i=1}^{n}(Y_i - \widehat{Y})^2} \tag{21}$$

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 E_{pan} 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.

3. Results and Discussion

As a result of the calibration processes carried out through the linear regression method using the daily climate data for the period of 2012–2020, the calibration coefficients "a" and "b" which align the original Christiansen equation with the climatic and environmental conditions of Van were determined as 0.838 and –0.345, respectively. The original Christiansen equation was corrected with these coefficients (Eq. (22)) and the modified equation was created (Eq. (23)).

$$E_{pan} = 0.838 \times (0.473 \times R_a \times C_T \times C_W \times C_H \times C_S \times C_E \times C_M) - 0.345 \tag{22}$$

$$E_{pan} = (0.396 \times R_a \times C_T \times C_W \times C_H \times C_S \times C_E \times C_M) - 0.345 \tag{23}$$

The daily measured E_{pan} values ranged from 2.29 to 12.77 mm day^{-1} during the period between 2012 and 2020. For the same period, the E_{pan} values estimated using the original and modified equations of the Christiansen method varied between 2.98–14.17 mm day^{-1} and 2.16–11.52 mm day^{-1}, respectively. The validity of the daily E_{pan} values estimated by Christiansen method has been revealed through tests with the current climate data for the period of 2021–2022, independent of the climate data for the period of 2012–2020 used in the calibration. The daily measured E_{pan} values ranged from 3.00 to 17.13 mm day^{-1} during the period between 2021 and 2022. For the same period, the E_{pan} values estimated using the original and modified equations of the Christiansen method varied between 3.52–15.46 mm day^{-1} and 2.60–12.61 mm day^{-1}, respectively. Although there are differences between the maximum and minimum points of the measured and estimated daily E_{pan} values for both the periods of 2012–2020 and 2021–2022, it is clearly seen in the graphs in Fig. 3 that they generally move synchronously. R², which is determined as an indicator of the statistical relationship between measured and estimated E_{pan} values, was the same for both the original and modified equations in both periods. R² was determined as 0.89 for the period of 2012–2020 and 0.79 for the period of 2021–2022. It was observed

that the daily E_{pan} values estimated using the modified equation was nearer to the measured values (Fig. 3).
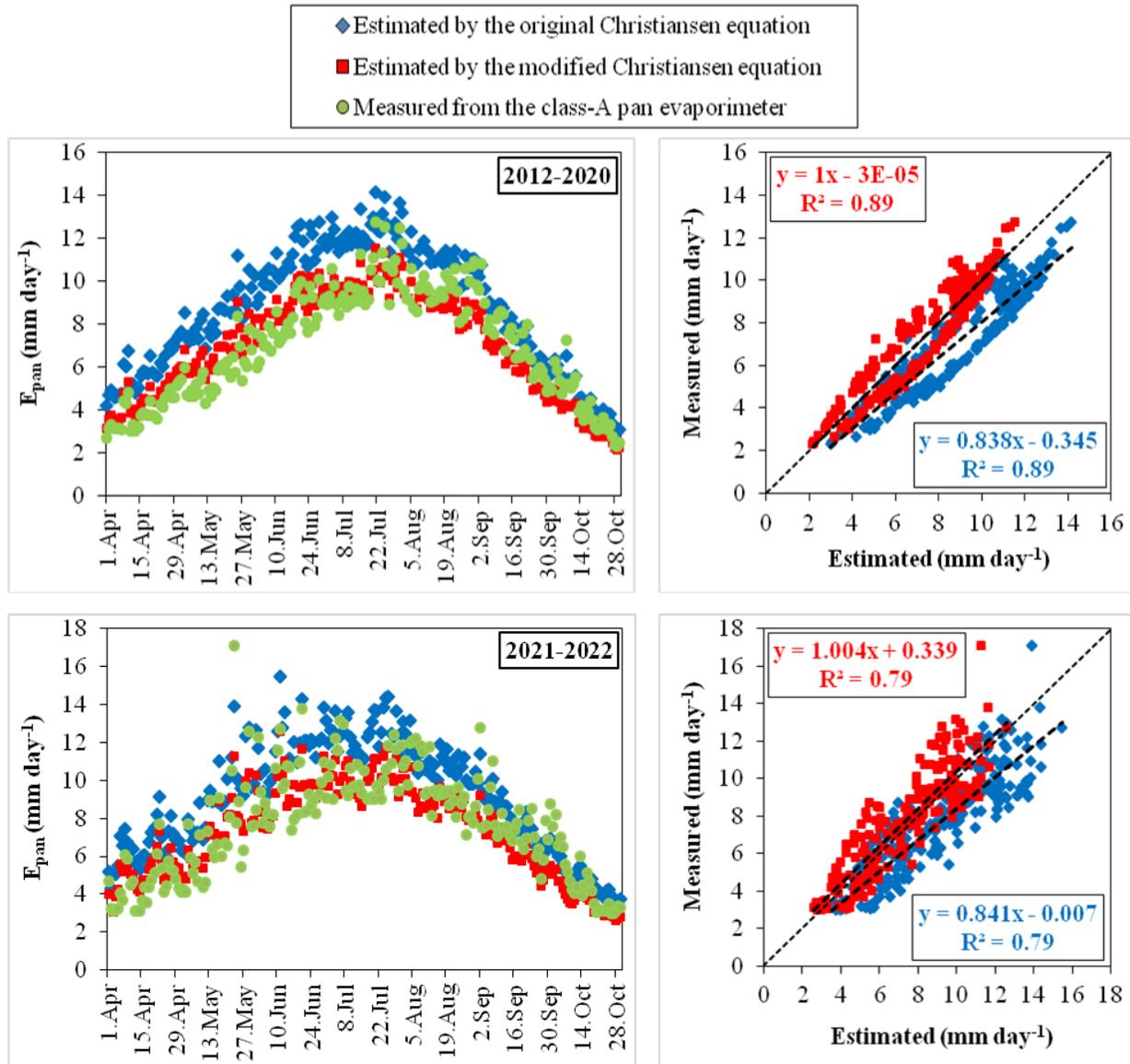

Figure 3: Daily measured and estimated pan evaporation values

The seasonal average measured E_{pan} value for the April–October period of 2012–2020 was realised as 7.00 mm day^{-1}. For the same period, the seasonal average E_{pan} values estimated using the original and modified equations of the Christiansen method were determined as 8.77 mm day^{-1} and 7.00 mm day^{-1}, respectively. During the period of 2012–2020, the monthly average measured E_{pan} values reached the highest levels in July (10.02 mm day^{-1}) and August (9.67 mm day^{-1}) when the air temperature increased to maximum levels

(22.20–22.30 °C). These values decreased to minimum levels in April (3.84 mm day^{-1}) and October (4.18 mm day^{-1}) when the relative humidity (%60.44–64.95) and thus the water vapour in the air increased to maximum levels. Similar to the April–October period of 2012–2020, the seasonal average measured E_{pan} value for the period of 2021–2022 was 7.63 mm day^{-1}. The seasonal average E_{pan} values estimated using the original and modified equations of the Christiansen method were determined as 9.14 mm day^{-1} and 7.31 mm day^{-1}, respectively. During the period of 2021–2022, the monthly average measured E_{pan} values reached the highest levels in July (10.40 mm day^{-1}) and August (9.65 mm day^{-1}), when the air temperature increased to maximum levels (20.95–22.13 °C), and decreased to minimum levels in April (4.50 mm day^{-1}) and October (4.65 mm day^{-1}), when the humidity (52.17–60.16%) increased to maximum levels (Table 3).

Table 3: Monthly averages of measured and estimated daily pan evaporation values

Periods	Months	Measured (mm day^{-1})	Estimated (mm day^{-1})	
			Original equation	Modified equation
2012–2020	April	3.84	5.71	4.44
	May	5.67	8.42	6.71
	June	8.11	11.00	8.87
	July	10.02	12.35	10.00
	August	9.67	11.14	9.00
	September	7.36	7.97	6.33
	October	4.18	4.60	3.50
	Average	7.00	8.77	7.00
2021–2022	April	4.50	6.46	5.06
	May	6.90	9.07	7.25
	June	9.53	11.83	9.56
	July	10.40	12.55	10.16
	August	9.65	11.00	8.87
	September	7.70	8.10	6.44
	October	4.65	4.82	3.69
	Average	7.63	9.14	7.31

The seasonal average MAPE and NSE values for daily E_{pan} estimations, made with the original Christiansen equation using daily climate data from the 2012–2020 period, were obtained as 28.17% and 0.37, respectively. Similarly, using the same equation, the seasonal average MAPE and NSE values for the period of 2021–2022 were determined as 25.10% and 0.48, respectively. In both periods, It has been observed that the daily estimated E_{pan} values have a "reasonable" level of accuracy (MAPE= 20–50%) according to the MAPE approach and "satisfying" level of accuracy (NSE= 0.36–0.75) according to the NSE approach. The differences between the means of the data groups consisting of the measured and estimated daily E_{pan} values were statistically significant ($p < 0.05$) in both periods. This result revealed that the daily E_{pan} values estimated by the original

equation of the Christiansen method cannot be used instead of the actual measured E_{pan} values (Table 4). The seasonal average MAPE and NSE values for daily E_{pan} estimations, made with the modified equation of the Christiansen method using daily climate data from the 2012–2020 period, were obtained as 12.15% and 0.89, respectively. Similarly, using the same equation, seasonal average MAPE and NSE values for the period of 2021–2022 were determined as 13.42% and 0.77%, respectively. It has been observed that the daily E_{pan} values estimated using the modified equation have "good" level of accuracy according to both MAPE (MAPE= 10–20%) and NSE (NSE > 0.75) approaches. The differences between the means of the data groups consisting of the measured and estimated daily E_{pan} values were not statistically significant (p > 0.05) in both periods. This result revealed that the daily E_{pan} values estimated by the modified Christiansen equation can be used instead of the measured values (Table 4).

Table 4: The performance of the Christiansen method in estimating daily pan evaporation

Periods	Equations	R^2	P	MAPE (%)	NSE	Accuracy	
						MAPE (%)	NSE
2012–2020	Original	0.89	9.23×10^{-11}	28.17	0.37	Reasonable	Satisfying
	Modified	0.89	1.00	12.15	0.89	Good	Good
2021–2022	Original	0.79	1.93×10^{-7}	25.10	0.48	Reasonable	Satisfying
	Modified	0.79	0.15	13.42	0.77	Good	Good

Using the original Christiansen equation, E_{pan} values were estimated with accuracies of 71.83% (MAPE= 28.17%) and 74.90% (MAPE= 25.10%), for the periods 2012–2020 and 2021–2022, respectively. These accuracy rates increased by 22.30% and 15.59% after calibration, respectively. Using the modified equation, E_{pan} values were estimated with accuracies of 87.85% (MAPE= 12.15%) and 86.58% (MAPE= 13.42%), for both periods, respectively. While the original equation overestimated the daily E_{pan} values by 19.79%, the modified equation underestimated them by 4.19%. In tests conducted with the two-year average climate data for the period of 2021–2022, the estimation performance ranking of the original equation from best to worst on a monthly basis is as follows: September (MAPE= 11.38%) > October (MAPE= 17.04%) > August (MAPE= 17.27%) > July (MAPE= 22.94%) > Jun (MAPE= 26.23%) > May (MAPE= 33.60%) > April (MAPE= 47.33%). The monthly basis estimating performances of the modified equation was higher than the original equation. The estimation performance ranking of the modified equation from best to worst on a monthly basis is as follows: August (MAPE= 8.32%) > Jun (MAPE= 11.12%) > July (MAPE= 11.34%) > May (MAPE= 13.18%) > September (MAPE= 15.51%) > October (MAPE= 17.11%) > April (MAPE= 17.58%).

The two-year average monthly and seasonal total amounts of measured and estimated daily E_{pan} values for the period of 2021–2022 are given in Table 5. The seasonal total measured E_{pan} during this period was realised as 1635 mm. The seasonal total E_{pan}

amounts estimated using the original and modified equations of the Christiansen method were determined as 1947.03 mm and 1557.32 mm, respectively. As an indicator of the deviation between the measured and estimated total E_{pan} amounts, the MAPE was obtained as 19.08% for the estimations made with the original Christiansen equation and 4.75% for those made with the modified Christiansen equation. It has been observed that the seasonal total amount of E_{pan} estimated with the original equation has a "good" level of accuracy (MAPE= 10–20%), while the seasonal total amount of E_{pan} estimated with the modified equation has an "excellent" level of accuracy (MAPE < 10%). The estimation performances of the modified equation in April (MAPE= 12.93%), May (MAPE= 0.85%), June (MAPE= 0.33%), July (MAPE= 2.21%) and August (MAPE= 8.17%) are higher than the estimation performances of the original equation in same months. The estimation performances of the original equation in September (MAPE= 5.22%) and October (MAPE= 3.75%) are higher than the estimation performances of the modified equation in same months. It is believed that the original equation can be used for daily E_{pan} estimates in these months without the need for calibration. Therefore, it is recommended to use the modified equation in April, May, June, July and August, and the original equation in September and October for daily E_{pan} estimations.

Table 5: Monthly and seasonal total pan evaporation values and MAPE errors

Months	Measured (mm)	Estimated (mm)		MAPE (%)	
		Original equation	Modified equation	Original equation	Modified equation
April	134.54	193.76	151.94	44.02	12.93
May	222.83	281.08	224.73	26.14	0.85
June	285.94	354.87	286.89	24.11	0.33
July	322.17	388.90	315.05	20.71	2.21
August	299.27	340.88	274.83	13.91	8.17
September	230.93	242.98	193.17	5.22	16.35
October	139.33	144.56	110.73	3.75	20.53
Total	1635.00	1947.03	1557.32	19.08	4.75

NSE is one of the most widely used similarity measures in calibration, method comparison and validation processes within the scope of estimating the most important components of the hydrological cycle such as evaporation and evapotranspiration [40, 41]. In some studies in which various empirical methods used in evaporation and evapotranspiration estimations were evaluated and calibrated under the different climatic and environmental conditions, the accuracy of the methods with "less satisfactory" (NSE < 0.36) and "satisfying" (NSE= 0.36–0.75) levels before calibration increased to "good" (NSE > 0.75) level after calibration [2, 27, 28, 29, 42, 43, 44]. Similarly, in this study in which the Christiansen evaporation estimation method was evaluated

and calibrated under the conditions of Van, the accuracy, which was "satisfying" (NSE= 0.36–0.75) with 0.48 NSE value before calibration, increased to "good" (NSE > 0.75) with 0.77 NSE value after calibration.

4. Conclusion

This study was conducted to evaluate (2012–2020), calibrate, (2012–2020) and further validate (2021–2022) the Christiansen method used to estimate daily evaporation from Class-A pan evaporimeter under the climatic and environmental conditions of Van, Turkey. The performance of this method, which was calibrated using the linear regression method, in daily E_{pan} estimations, was evaluated according to three statistical approaches (R^2, MAPE, and NSE). It has been observed that the Christiansen method is sensitive to changes in air temperature, wind velocity, and relative humidity and its accuracy increased post-calibration. While the original Christiansen equation estimated daily E_{pan} values with an accuracy 74.90% (R^2= 0.79, MAPE= 25.10%, NSE= 0.48), the accuracy increased to 86.58% (R^2= 0.79, MAPE= 13.42%, NSE= 0.77), in estimations made using the modified Christiansen equation. It has been concluded that, for daily evaporation estimations conducted under the conditions of Van using the Christiansen method, it would be more appropriate to use the modified equation in April, May, June, July, and August, and to use the original equation in September and October. The reliability of empirical evaporation estimation methods 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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