Evaluation of Four Methods for Estimating monthly Potential Evapotranspiration (PET) for a Semi-Humid Region in Algeria: A Case Study of Staoueli zone

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Abstract

Evapotranspiration is a critical factor in the water balance. However, it is unclear how climate drivers affect its two main components: transpiration and soil evaporation, across the global land surface. This paper uses a well-validated, process-based model to estimate transpiration and soil evaporation [1]. Soil evaporation and transpiration from plants represent the combined evaporation from the soil surface and are not well understood or frequently measured. Actual evapotranspiration is influenced by climatic factors but is constrained by the available moisture in the soil. In contrast, potential evapotranspiration refers to the amount of water that would be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times for the use of the vegetation. This is solely dependent on climate. [2]

Four formulas have been developed to estimate potential evapotranspiration. The objective of this study is to assess methods for estimating evapotranspiration in a sub-humid region, followed by calibration and validation of the most effective method. To achieve this, we utilized a dataset of climate variables, such as temperature, relative humidity, precipitation, sunshine duration, wind speed, and measured evapotranspiration, collected at the Dar El Beida meteorological station from 1990 to 2022 [3]. The methods were compared by evaluating their obtained values with measured evapotranspiration, using various statistical comparison parameters. The findings indicate that the Bouchet model outperforms the other three methods, providing a closer approximation to the measured evapotranspiration.

Keywords: Evapotranspiration, sub-humid region, measured evapotranspiration, Bouchet model.

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introduction:

Several formulas exist for estimating potential evapotranspiration (PET), each with varying complexity and requiring different amounts of meteorological data [4].

To make use of the wealth of meteorological information available, we compared the results obtained from several formulas with the measured evapotranspiration values, both at daily and monthly intervals, using data from the Dar El Beida station spanning from 1990 to 2022 [3].

Evapotranspiration data was measured at the Dar El Beida station in the Wilaya of Algiers [3]. It was then compared to potential evapotranspiration (PET) values estimated using four methods: Thornthwaite (1948) [5], Turc (1961) [6], Blaney-Criddle (1950) [7], and Bouchet (1963) [8].

These estimations were based on meteorological parameters collected from the station, including temperature, relative humidity, theoretical and actual global radiation, and sunshine duration [9].

This comparative analysis enables us to identify the PET estimation methods that closely match the actual measurements. This identification is crucial for accurately estimating the water requirements necessary for crop growth and for applying them safely in regions with climates similar to the humid and sub-humid conditions observed in the Algiers region.

2.Materials and Methods

2.1. Presentation of the Study Area:

The Technical Institute of Horticultural and Industrial Crops (ITCMI) is a public institution focused on scientific and technical research. It is situated in the municipality of Staoueli [10], located in the northwest of Algiers, the capital, bordering the Tipaza region and the Sahelian zones.

The average monthly temperatures range from 11.50 to 26.70°C, while the relative humidity fluctuates between 67% and over 79%. According to Dar El Beida (2022), the highest average temperatures are typically experienced in July and August, while the lowest are in January and February.

The monthly rainfall averages range from 2.40 to over 101.90 mm, with corresponding monthly evapotranspiration averages ranging between 25.10 and over 181.90 mm [3].

Figure 1 : Study Area Location

2.2. Models and parameters

This work evaluates and compares four potential evapotranspiration models: Thornthwaite (1948) [5], Turc (1961) [6], Blaney-Criddle (1950) [7], and Bouchet (1963) [8].

2.2.1 Thornthwaite Formula (1948) :

The Thornthwaite equation expresses a relationship between ET and changes in mean air temperature. It is an empirical equation and can be written as follows: [5]

$$PET = c\,T^{a} = \left(\frac{10}{I}\right) T^{a}\, L_{A} \qquad \text{(eq.1)}$$

PET = potential evapotranspiration, (mm/day)

T = monthly mean temperature (°C).

a, C = constant.

I = heat index.

L or F = proportion of daylight hours.

•The heat index is calculated as follows:

$$I = \sum_{i=1}^{12} \left(\frac{Ti}{5}\right) \qquad \text{(eq.2)}$$

Ti = Average monthly temperature (° C)

The calculated results are displayed in the following table, denoted as Table 1 :

Table 1: Monthly PET calculation using the Thornthwaite formula at the Dar El Beida station

Months / Values	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
T (°C)	11.5	12.1	13.55	15.45	18.8	22.6	25.55	26.7	23.9	20.55	15.45	12.55
i	3.53	3.81	4.52	5.52	7.43	9.81	11.82	12.63	10.68	8.50	5.52	4.03
I	87.80											
a	1.90											
F	0.86	0.85	1.03	1.10	1.22	1.23	1.25	1.17	1.03	0.97	0.85	0.83
PET Thornthwaite (mm/month)	23.03	24.85	37.53	51.41	82.55	118.01	151.36	153.99	110.12	77.88	39.85	26.23

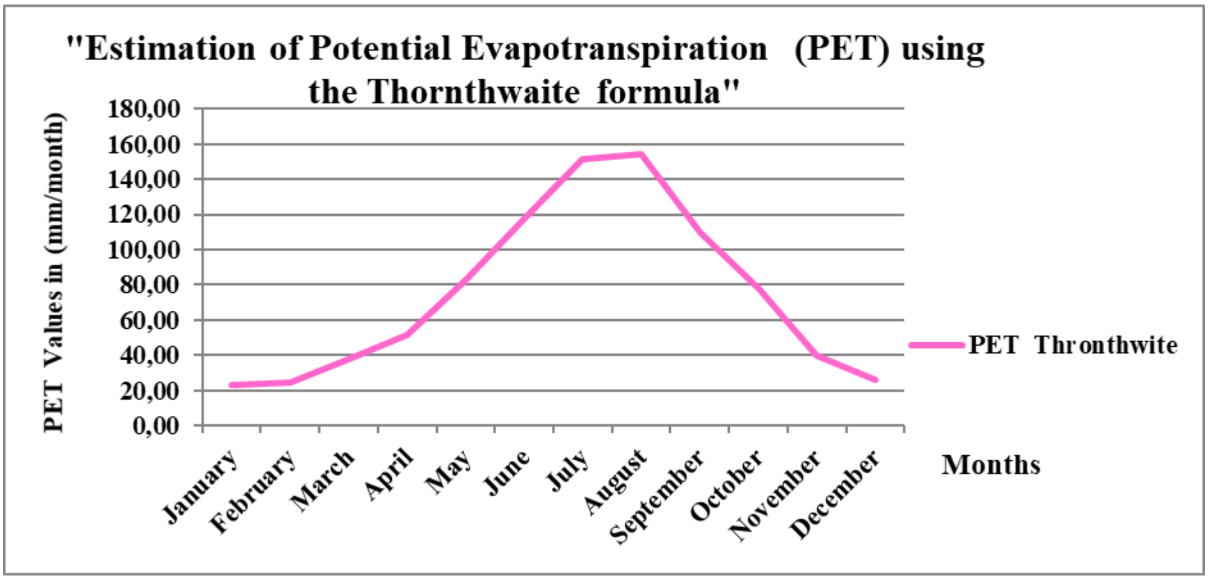


Figure 2: Observed and computed mean monthly evapotranspiration using the Thornthwaite formula at the Dar El Beida station

2.2.2 Blaney – Criddle Formula (1950) :

The Blaney-Criddle method is a simple technique used to calculate reference ET based on temperature changes in a specific region.

The formula for estimating ET using the Blaney-Criddle method is as follows: [7]

$$PET = 25.4\ \frac{K.P}{100}\ (\frac{9}{5}T + 32) \qquad \text{(eq.3)}$$

PET : reference evapotranspiration (mm/month)

T : mean temperature (°C),

P: mean daily percentage of annual daytime hours due to the latitude of region;

K: is monthly consumptive use coefficient; In our case, we set K = 1.

The calculated results are displayed in the following table, denoted as Table 2 :

Table 2 : Monthly PET calculation using the Blaney – Criddle formula at the Dar El Beida station

Months / Values	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
T (°C)	11.5	12.1	13.55	15.45	18.8	22.6	25.55	26.7	23.9	20.55	15.45	12.55
P	0.23	0.25	0.27	0.29	0.31	0.33	0.32	0.30	0.28	0.25	0.23	0.22
K	1.00											
PET Blaney-C (mm/day)	3.03	3.37	3.87	4.46	5.24	6.04	6.41	6.17	5.34	4.38	3.49	3.05
PET Blaney-C (mm/month)	94.00	94.30	119.88	133.75	162.51	181.06	198.63	191.30	160.06	135.81	104.82	94.57

Figure 3 : Observed and computed mean monthly evapotranspiration using the Blaney – Criddle formula at the Dar El Beida station

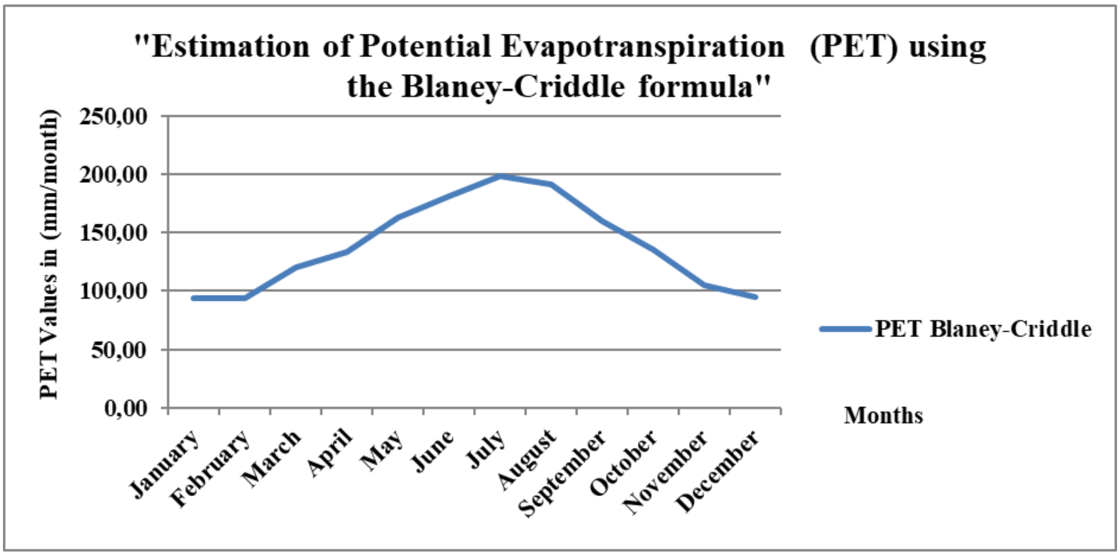


Figure 3 : Observed and computed mean monthly evapotranspiration using the Blaney – Criddle formula at the Dar El Beida station

2.2.3 Turc Formula (1961) :

RH ≥ 50 % (monthly average)

$$PET\ (mm/month) = (0{,}013 \times \text{Number of days in the month considered})\ \frac{Tm}{Tm+15}\ (Rs + 50) \quad (eq.4)$$

•RH <50 %

$$PET\ (mm/month) = (0{,}013 \times \text{Number of days in the month considered})\ \frac{Tm}{Tm+15}\ (Rs + 50)\ \left(1 + \frac{50-RH}{70}\right) \quad (eq.5)$$

were,

PET is the reference evapotranspiration (mm/month) ;

Tm is the mean temperature (°C);

Rs is the solar radiation of the crop surface (MJ m^{-2} day^{-1});

and RH is the relative humidity (%).

Gi or GR represents the actual global radiation in calories per cm2 of horizontal surface per day during the specified period.

GR = GRA (0.18 + 0.62 (n) / (N)) (eq.6)

GRA is derived from tables and signifies the theoretical global radiation, assuming clear skies at the latitude under consideration (refer to GRA or RA table). [6]

Where:

GRA = 1035 - 9.076 x Lat + (7.050 x Lat + 49.90) x Cos (29.92 x i - 182.5) (eq.7)

H = 362.7 + 0.2101 x Lat + (4.085 x Lat - 80.99) x Cos (30.01 x i - 188.9) (eq.8)

Variables:

GRA: Theoretical global solar radiation (calories/cm^2/day).

h: Measured duration of insolation (hours/month).

H: Theoretical duration of insolation (hours/month).

i: Month number (1 for January, 10 for October, etc.).

Lat: Latitude of the location considered in degrees and minutes. [11]

In our case, the latitude of the aerea study is 36°N 43' or approximately 36.73°."

The calculated results are displayed in the following table, denoted as Table 3 :

Table 3 : Monthly PET calculation using the Turc formula at the Dar El Beida station

Months / Values	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Tm (°C)	11.5	12.1	13.55	15.45	18.8	22.6	25.55	26.7	23.9	20.55	15.45	12.55
RH (%)	79%	78%	76%	73%	73%	69%	68%	67%	71%	73%	76%	79%
Month order (i)	1	2	3	4	5	6	7	8	9	10	11	12
Measured insolation (h/day)	6.6	6.4	6.9	8	8.4	10.4	10.8	10.1	8.3	7.2	6.8	6.2
Measured insolation (h/month)	204.6	179.2	213.9	240	260.4	312	334.8	313.1	249	223.2	204	192.2
H	306.03	327.13	359.83	395.36	424.22	438.66	434.82	413.73	381.04	345.51	316.64	302.18

(cal/cm2/d)												
GRA (cal/cm2/d)	427.65	535.23	687.11	842.86	960.99	1 010.06	977.00	870.60	719.21	563.13	443.93	393.35
GR (cal/cm^2/d)	82.70	102.83	131.85	162.29	184.78	196.66	190.90	169.88	139.17	108.64	85.82	75.81
PET Turc (mm/month)	23.21	24.84	34.78	42.01	52.63	57.82	61.17	56.74	45.33	36.96	26.88	23.10

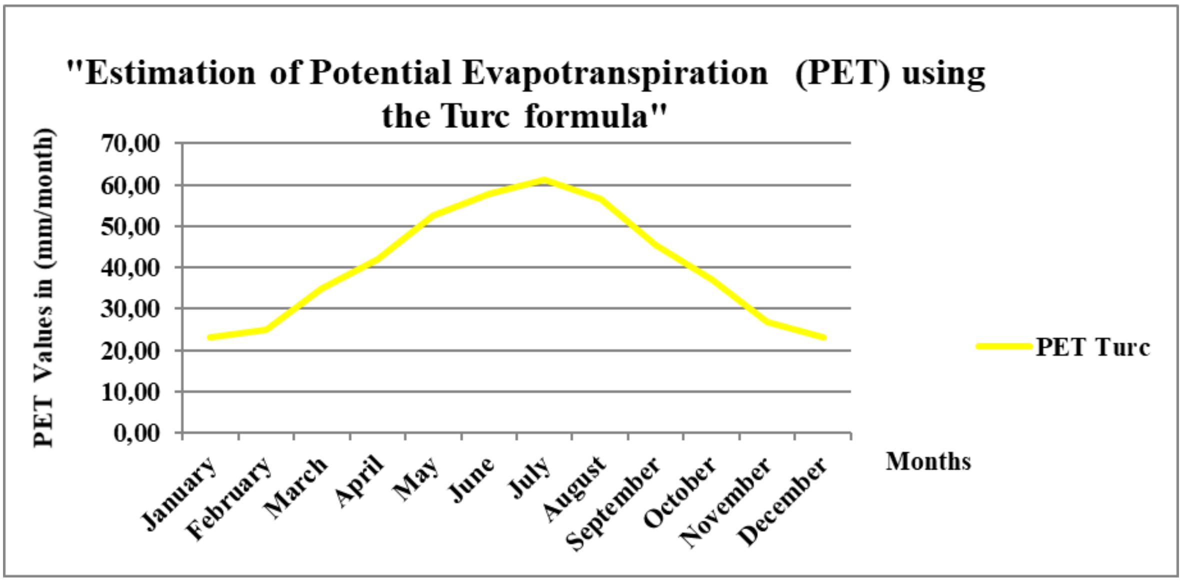


Figure 4 : Observed and computed mean monthly evapotranspiration using the Turc formula at the Dar El Beida station

2.2.4 Bouchet Formula (1963) :

PET = α Ep λ (Θ) (eq.9)

PET= évapotranspiration (mm/day)

Ep = number of millimeters of water evaporated in the Piche in 24 hours.

α = 0.37 when the Piche is positioned in a Stevenson screen 2 meters above ground level.

λ = coefficient dependent on temperature θ (refer to table). [6]

θ = average temperature between air temperature and dew point temperature θr.

Monthly mean temperature $TMean = \frac{(TMax + TMin)}{2}$ (eq.10)

TMean = Average daily temperature.

TMin = Minimum daily temperature.

TMax = Maximum daily temperature.

θr = Dew point temperature.

Assuming dew point temperature equals the minimum temperature (θr = TMin), thus θ

(θ r = TMin) Thus $\theta = \frac{(TMean+Tmin)}{2}$ (eq.11)

Evapotranspiration PET is calculated on a monthly basis (mm/month) due to the availability of monthly meteorological data (Monthly evaporation: Ep, Monthly temperatures: TMax, TMin, TMean) [12].

The calculated results are displayed in the following table, denoted as Table 4 :

Table 4 : Monthly PET calculation using the Bouchet formula at the Dar El Beida station

Months / Values	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
TMin (°C)	5.8	6.7	7.5	9.2	12.8	16.3	19.4	20.4	18	14.5	9.8	7
TMax (°C)	17.2	17.5	19.6	21.7	24.8	28.9	31.7	33	29.8	26.6	21.1	18.1
TMean (°C)	11.5	12.1	13.55	15.45	18.8	22.6	25.55	26.7	23.9	20.55	15.45	12.55
θ (°C)	8.65	9.40	10.53	12.33	15.80	19.45	22.48	23.55	20.95	17.53	12.63	9.78
λ Bouchet	2.39	2.40	2.55	2.73	3.03	3.51	3.99	4.21	3.76	3.29	2.77	2.51
PET Bouchet (mm/month)	24.91	36.89	70.70	102.76	147.85	212.35	268.30	259.99	163.50	93.92	40.59	23.33

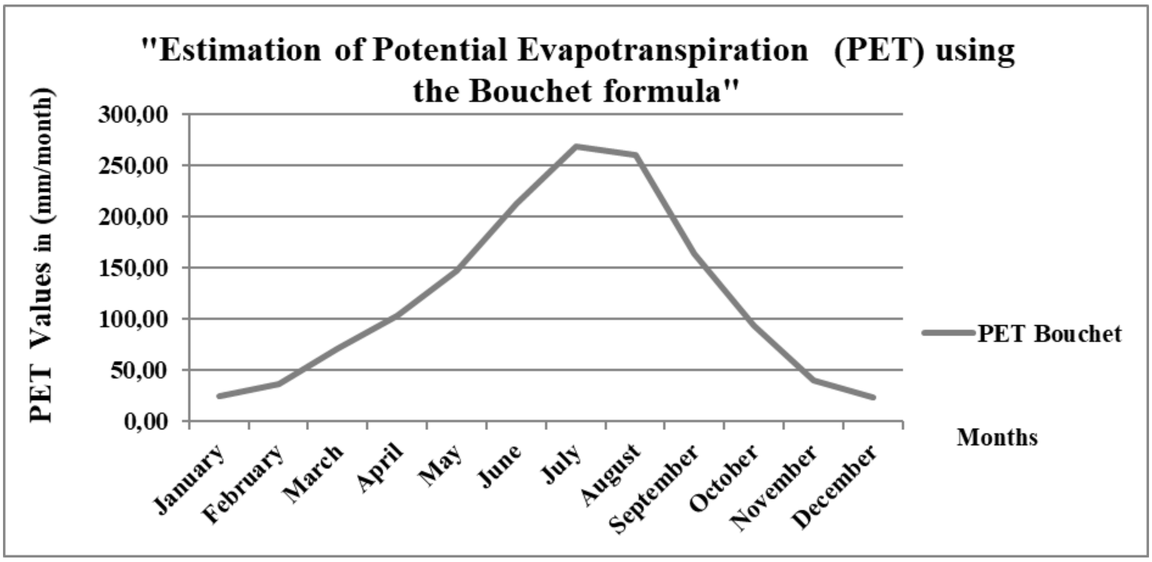


Figure 5 : Observed and computed mean monthly evapotranspiration using the Bouchet formula at the Dar El Beida station

3.Results and Discussion

3.1. Comparison of Different Methods for Estimating Evapotranspiration (Annual Scale):

The results obtained from various approaches to estimate PET during the period (1990-2022) are summarized in the table below, denoted as Table 5 :

Table 5 : Comparison of Results Obtained for Monthly PET Using the Four (04) Studied Formulas at Dar El Beida Station

Months / Values	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Measured evapotranspiration (mm/month)	28.2	41.6	74.9	101.7	131.9	163.4	**181.9**	167	117.4	77.1	39.6	25.1
Thornthwaite (mm/month)	23.03	24.85	37.53	51.41	82.55	118.01	151.36	**153.99**	110.12	77.88	39.85	26.23
Blaney-Criddle (mm/month)	94.00	94.30	119.88	133.75	162.51	181.06	**198.63**	191.30	160.06	135.81	104.82	94.57
Turc (mm/month)	23.21	24.84	34.78	42.01	52.63	57.82	**61.17**	56.74	45.33	36.96	26.88	23.10
Bouchet	24.91	36.89	70.70	102.76	147.85	212.35	**268.30**	259.99	163.50	93.92	40.59	23.33

(mm/month)												

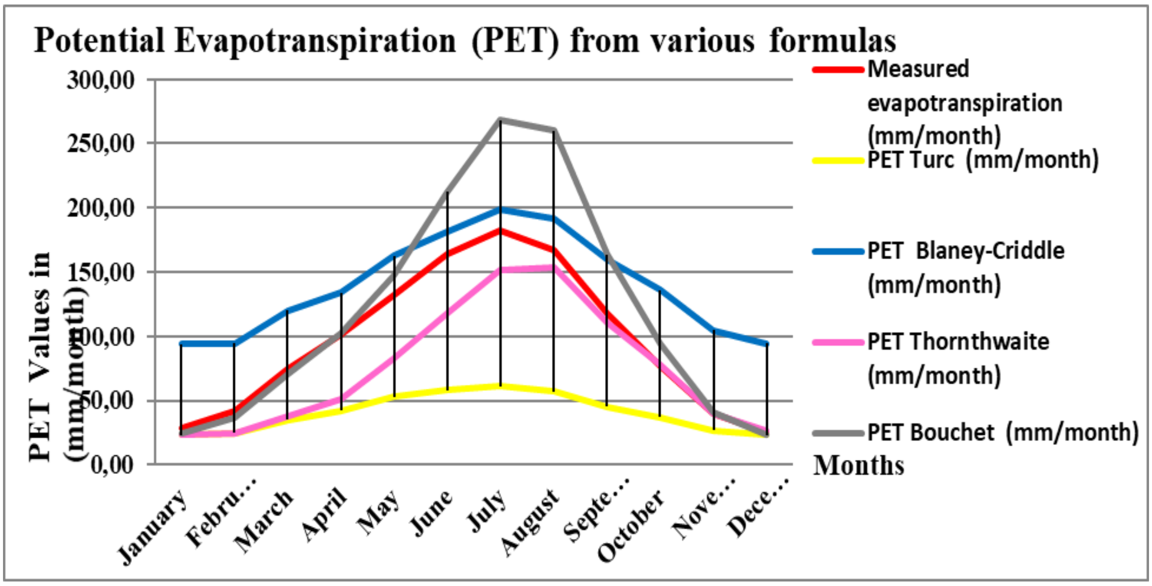


Figure 6 : Observed and computed mean monthly evapotranspiration values of estimated evapotranspiration (04formulas) and measured evapotranspiration PET at the Dar El Beida station

The analysis of monthly potential evapotranspiration was conducted over a thirty-two-year period at the Dar El Beida station using four formulas: Thornthwaite, Blaney-Criddle, Turc, and Bouchet.

The results indicate that the Turc and Thornthwaite formulas tend to underestimate PET when compared to measured evapotranspiration. The Thornthwaite formula closely matches the measured evapotranspiration curve for specific months, including January, February, March, April, November, and December.

In contrast, the Blaney-Criddle and Bouchet formulas tend to overestimate ETP compared to measured evapotranspiration. However, the Bouchet formula shows a close alignment with the measured evapotranspiration curve, particularly during October, November, and December. The analysis indicates a consistent trend in evapotranspiration values converging towards measured evapotranspiration.

Therefore, the Thornthwaite and Blaney-Criddle formulas are the most suitable methods for estimating potential evapotranspiration. These formulas produce PET values that closely match the trend and seasonal variation observed in measured evapotranspiration throughout the year.

It is important to note that the Blaney-Criddle formula produces higher evapotranspiration values than measured data, but it accurately captures the overall trend.

Among the peak months, July has the highest potential evapotranspiration for the Blaney-Criddle, Bouchet, and Turc formulas, while August exhibits the peak for the Thornthwaite formula.

In contrast, the Turc formula consistently records the minimum values across all months compared to the other formulas.

Therefore, the new plotting area should be adjusted accordingly.As a result, the new plotting area should be adjusted accordingly :

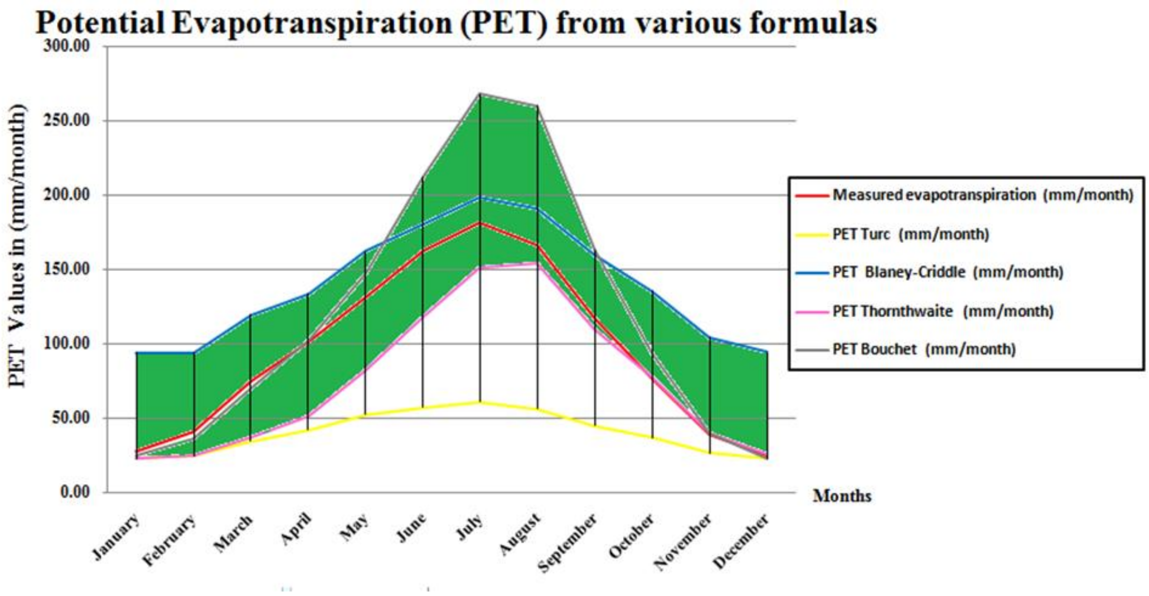


Figure 7 : Revised plotting area for evapotranspiration from different formulas

After plotting the new comparison area, we identified three formulas that are better suited to our measured evapotranspiration component: The degree of alignment with measured evapotranspiration decreases in the following order for these three formulas: Thornthwaite, Blaney-Criddle, and Bouchet. Bouchet, Blaney-Criddle, and then the Thornthwaite formula.

3.2. Relative Error between measured evapotranspiration and estimated PET :

The comparison between the measured PET and the results obtained from various monthly PET estimation approaches was based on the Relative Error (RE) values.

It is important to note that RE is defined as:

$$RE = \frac{PET - PETi}{PET} x100\ (\%) \quad (eq.12)$$

PET: Measured evapotranspiration.

PETi: PET calculated by the methods of Thornthwaite (i=1), Blaney-Criddle (i=2), Turc (i=3), Bouchet (i=4).

RE: Relative error (%).[13]

Lower values of "RE" indicate a more satisfactory estimation of PET by the method.

The results obtained by applying different approaches to estimate PET during the period (1990-2022) are summarized in the table above, denoted as Table 6 :

Table 6: Relative error between the various methods of estimating PET and the measured evapotranspiration.

RE (%) / Months	RE Thornthwaite) (%)	RE Blaney-Criddle (%)	RE Turc (%)	RE Bouchet (%)
January	18.34	-233.35	17.71	11.66
February	40.26	-126.68	40.29	11.33
March	49.89	-60.06	53.56	5.61
April	49.45	-31.51	58.69	-1.05
May	37.42	-23.20	60.10	-12.10
June	27.78	-10.80	64.61	-29.96
July	16.79	-9.20	66.37	-47.50
August	7.79	-14.55	66.03	-55.68
September	6.20	-36.34	61.39	-39.27
October	-1.01	-76.14	52.07	-21.82
November	-0.63	-164.70	32.13	-2.49
December	-4.52	-276.75	7.98	7.06
RE Min (%)	-4.52	-276.75	7.98	-55.68
RE Max (%)	49.89	-9.20	66.37	11.66

Here's a comparative analysis of PET values:

3.2.1.Thornthwaite Formula:

Relative Error: Ranges from -4.52% to 49.89%

The Thornthwaite formula displays a relatively moderate error range, encompassing both negative and positive values. Despite some disparities, it shows a reasonable capability to estimate PET across diverse conditions. While adjustments could enhance accuracy, it demonstrates a degree of reliability overall.

3.2.2.Blaney-Criddle Formula:

Relative Error: Ranges from -276.75% to -9.2%

The Blaney-Criddle formula exhibits an exceedingly wide error range, notably with extremely high negative values, indicating substantial inadequacy compared to measured evapotranspiration. These findings strongly suggest a need for revision or replacement under these specific conditions.

3.2.3.Turc Formula:

Relative Error: Ranges from 7.98% to 66.37%

positive values. While it shows potential to estimate ETo reasonably well under various circumstances, the presence of higher values indicates a tendency to overestimate PET in certain cases. Fine-tuning may enhance its accuracy.

3.2.4.Bouchet Formula:

Relative Error: Ranges from -55.68% to 11.66%

The error range of the Bouchet formula is relatively wide, encompassing both negative and positive values. While more stable than the Blaney-Criddle formula, it exhibits some performance variability. Nevertheless, the positive values suggest a capacity to estimate PET better under certain conditions compared to the Blaney-Criddle formula.

In summary, based on the relative error outcomes, the Thornthwaite formula appears to offer a more stable and relatively better performance. Conversely, the Blaney-Criddle formula displays notably poor performance. The Turc and Bouchet formulas exhibit acceptable performance but may necessitate adjustments to enhance accuracy under specific conditions.

The relative error values ranging between -50% and +50%, or within the interval of -0.5 to +0.5, indicate a good fit and close approximation to the values of the measured evapotranspiration. This criterion signifies a satisfactory performance in estimating evapotranspiration. This is the case for

Thornthwaite: **$E \in [-0.05,+0.50]$,**

3.3. Correlation between measured evapotranspiration and PET estimates:

3.3.1. Values of 'a' and 'b':

When examining the relationship between measured evapotranspiration and estimated PET from various formulas, it is observed that the coefficient 'a' is consistently positive across all tested formulas. This suggests a positive correlation between the estimated PET and the measured evapotranspiration line. However, the coefficient 'b' varies depending on the formula used. The Thornthwaite and Bouchet formulas yield negative values for 'b', indicating that the measured evapotranspiration values exceed the estimated values. In contrast, the Blaney-Criddle and Turc formulas yield positive values for 'b', indicating that the measured evapotranspiration values fall short of the estimated values provided by these formulas.

3.3.2. Quality of regression:

The determination coefficients (R^2) obtained from linear regression between measured evapotranspiration and estimates provided by different evapotranspiration (PET) formulas provide significant insights into the calibration and validation quality of each formula. This analysis presents the results.

3.3.2.1. Thornthwaite Formula:

Determination Coefficient (R^2): 0.88

A determination coefficient of 0.88 indicates a strong correlation between the values estimated by the Thornthwaite formula and the actual measured evapotranspiration. This suggests that this formula offers good calibration and validation compared to the observed data, although there remains some unexplained variability.

3.3.2.2. Blaney-Criddle Formula:

Determination Coefficient (R^2): 0.98

With a determination coefficient of 0.98, the Blaney-Criddle formula shows a very strong correlation between the estimated values and the actual measured evapotranspiration. This indicates excellent precision and very precise calibration compared to the observed data.

3.3.2.3. Turc Formula:

Determination Coefficient (R^2): 0.99

A determination coefficient of 0.99 reveals an exceptionally strong correlation between the estimates from the Turc formula and the actual measured evapotranspiration. This indicates remarkable performance of this formula, offering extremely precise calibration and validation.

3.3.2.4. Bouchet Formula:

Determination Coefficient (R^2): 0.96

The Bouchet formula has a determination coefficient of 0.96, demonstrating a strong correlation between estimated and actual measured evapotranspiration. This indicates high precision and solid calibration compared to the observed data.

Linear regression results show that all formulas have high determination coefficients, indicating a good ability to estimate PET compared to measured evapotranspiration. However, among the formulas evaluated, the Turc formula demonstrated the highest level of effectiveness, followed closely by the Blaney-Criddle and Bouchet formulas. The Thornthwaite formula also exhibited respectable performance, although slightly inferior to the others in terms of calibration and validation precision. It is important to note that a good correlation between two variables does not necessarily indicate a cause-and-effect relationship between them. In the case of the Turc method, the correlation indicates a good result, as demonstrated by a simulation of the two curves, which have the same shape and form:

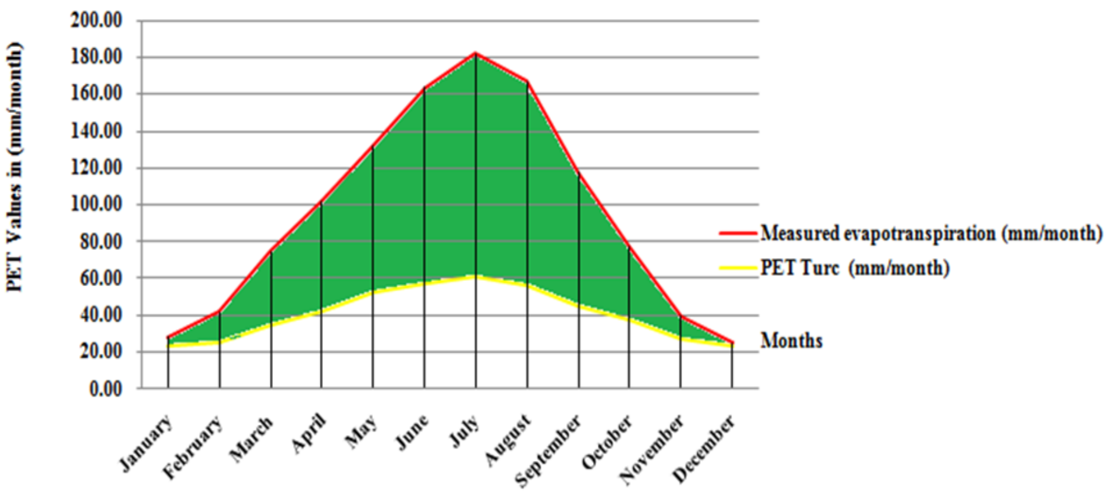
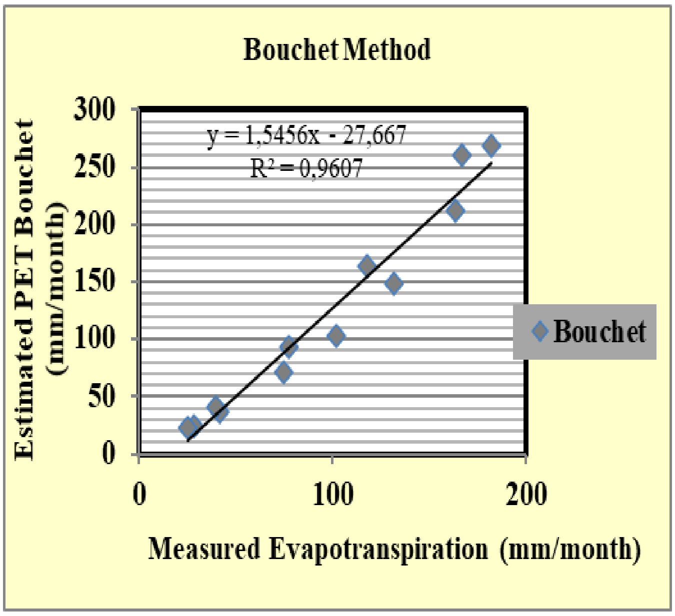


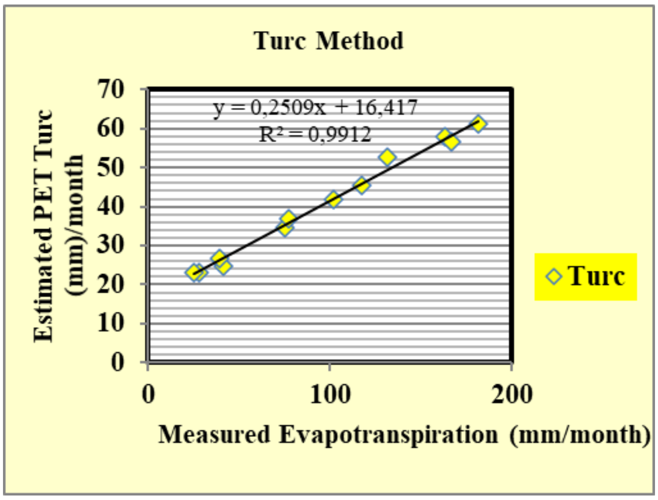
Figure 9 : Correlation between the values of the Turc formula and the measured evapotranspiration.

In statistical terms, the measured evapotranspiration and Turc components exhibit similar value distributions from one month to another. However, in climatic terms, these values are significantly different from each other.

Table 7 : Correlation between measured evapotranspiration and that estimated by various formulas

Relationship	Equation	R^2
ETP (Thornthwaite) ➔Measured PET	PET (TH) = 0.803 Measured PET –2.286 (eq.13)	0.877
ETP (Blaney-Criddle) ➔Measured PET	PET (B-C) = 0.678 Measured PET+74.20 (eq.14)	0.978
ETP (Turc) ➔ Measured PET	PET (TU) = 0.250 Measured PET +16.41 (eq.15)	0.991
ETP (Bouchet) ➔ Measured PET	PET (BO) = 1.545 Measured PET –27.66 (eq.16)	0.960


Bouchet Method
y = 1,5456x - 27,667
R² = 0,9607
Estimated PET Bouchet (mm/month)
300
250
200
150
100
50
0
0
100
200
Bouchet
Measured Evapotranspiration (mm/month)


Turc Method
y = 0,2509x + 16,417
R² = 0,9912
Estimated PET Turc (mm)/month
70
60
50
40
30
20
10
0
0
100
200
Turc
Measured Evapotranspiration (mm/month)

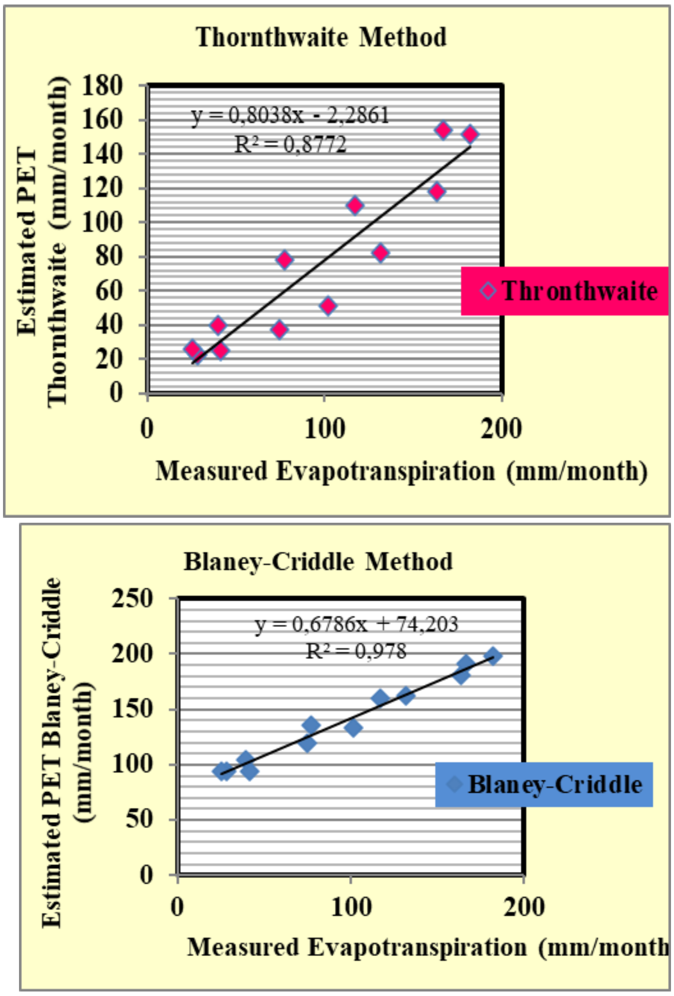


Figure 10 : Correlation curves depicting the results obtained from various methods in comparison to measured evapotranspiration.

3.4 Evaluation Metric for Regression Models

(MSE, RMSE, MAE, MAPE) :

3.4.1 Mean Squared Error (MSE) :

Mean squared error is a commonly used metric for regression problems. It calculates the average of the squared differences between the predicted values from the regression model and the actual target values. [13]

In our case :

MSEn :number of observations (eq.17) /$= \sum_{i=1}^{n} \frac{(PET-PETi)^2}{n}$

3.4.2 Root Mean Squared Error (RMSE) :

The Root Mean Squared Error (RMSE) is the square root of the average of the squared differences between the predicted and target values in a regression model. In other words, it is the square root of the Mean Squared Error (MSE). [14]

In our case :

RMSE = $\sum_{i=1}^{n} \sqrt{\frac{(PET-PETi)^2}{n}}$ / n : number of observations (eq.18)

3.4.3 Mean Absolute Error (MAE) :

The Mean Absolute Error (MAE) is calculated as the average difference between the predicted values and the actual values. It is a measure of the accuracy of a predictive model. [14] In our case :

MAE =$\sum_{i=1}^{n} \frac{|(PET-PETi)|}{n}$ / n : number of observations (eq.19)

These three indicators are primarily used to compare our estimation models with a series of observed evapotranspiration data or to compare several methods with each other. Additionally, the following indicator enables comparison between series of deviations.

3.4.4 Mean Absolute Percentage Error (MAPE) :

The model's fitted values and the observed data values are compared using the average absolute percent difference. [15]

In our case :

MAPE= $\sum_{i=1}^{n}\left[\frac{\frac{|(PET-PETi)|}{PET}}{n}\right]x100$ (%) / n : number of observations (eq.20)

Table 8 : Evaluating Regression Models for four formulas

Formules / Regression Models	Thorntwaite	Blaney-Criddle	Turc	Bouchet
MSE	823.83	2 218.56	4 717.89	1 768.85
RMSE	28.70	47.10	68.69	42.06
MAE	21.44	43.41	55.36	26.94
MAPE (%)	21.67	88.61	48.41	20.46

Based on the Regression Models provided in Table 8:

The minimum values from all four methods suggest better adaptation and a closer approximation to the observed values, which is consistent with the analysis of relative errors (RE).

On the other hand, the maximum values consistently indicate poor adaptation and extreme discrepancies.

Additionally, the Thornthwaite formula shows the lowest values for both MAE and MAPE, implying a higher average accuracy of predictions compared to the measured observations.

Similarly, the Bouchet formula demonstrates robust performance with relatively low values for mean absolute error (MAE) and mean absolute percentage error (MAPE), although slightly higher than Thornthwaite's formula.

In contrast, both the Blaney-Criddle and Turc formulas exhibit higher values for mean squared error (MSE), root mean squared error (RMSE), MAE, and MAPE, indicating less precision compared to the measured observations. However, Blaney-Criddle exhibits slightly better performance than Turc.

In conclusion, based on these error measures, Thornthwaite and Bouchet appear to provide better estimates of reference evapotranspiration than Blaney-Criddle and Turc. However, it is important to also consider factors such as data availability and ease of use when selecting the appropriate formula for a specific application.

4. Conclusion :

The objective of this study was to evaluate four empirical methods for estimating potential evapotranspiration (PET) - Thornthwaite, Turc, Blaney-Griddle, and Bouchet - in the Algiers region, using data from the Dar El Beida meteorological station from 1990 to 2022. [3]

The aim was to calibrate and validate the best method against measured evapotranspiration data.

To achieve this, the PET calculated by the tested methods was compared with the measured evapotranspiration. The comparison findings are presented as follows: [17]

On an annual scale:

the Thornthwaite formula provided a good approximation and allowed for a comprehensive simulation of measured evapotranspiration across various statistical indicators, particularly regression models (MSE, RMSE, MAE, and MAPE), and relative error.

The Turc formula showed a strong correlation throughout the year (R2=0.99) due to the similarity between the parameters used in the formula and those used to measure evapotranspiration (temperature and humidity). However, this performance alone is insufficient for determining performance criteria, as it resulted in average to low results with regression models and relative error.

The Bouchet formula demonstrated a strong correlation throughout the year (R2=0.96) and outperformed the other two formulas (Turc and Blaney-Criddle) in regression models.Furthermore,

On a monthly scale:

The Thornthwaite formula provided a satisfactory monthly approximation for the months of August, September, October, November, and December, which are pivotal for estimating water requirements.

Similarly, the Bouchet formula offered a satisfactory monthly approximation for the months of April, November, and December.

In conclusion, three formulas (Bouchet, Turc, and Blaney-Criddle) are deemed most suitable for validation.

The Turc formula showed a slightly higher coefficient of determination (0.99) compared to the Blaney-Criddle (0.98) and Bouchet (0.96) formulas, indicating greater explanatory power over the data variance.

However, the Bouchet formula demonstrated lower values for MSE, RMSE, MAE, and MAPE, signifying superior accuracy and closer alignment with the measured data.

Overall, although the Turc formula displayed a superior coefficient of determination, the Bouchet formula showed better accuracy in aligning with the measured data.

The Bouchet formula demonstrated superior performance in terms of precision and agreement with the measured evapotranspiration data.

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