# THE OPTIMIZING MODEL OF POTENTIAL EVAPOTRANSPIRATION IN NORTH SYRIA

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## ABSTRACT

Evapotranspiration (consumptive use) is a key function for estimating irrigation requirement that depends on the climatic conditions.

Evapotranspiration (ETP) can be determined by direct measurements, empirical climatic formulas or by using evaporation measurements as indices. Direct measurement will give the best evaluation of evapotranspiration if it is available.

In the present work, 12 well-known climatic empirical methods have been selected from literature and used for estimating potential evapotranspiration under semi arid areas which is similar to the northern part of Syria.

The original data have been derived and adapted from the meteorological stations (Tel hadya, Jindiress and Breda), thus the purpose of this research is to select a few of the most popular methods for estimating the potential evapotranspiration in semi arid areas. The methods used in this study were compared with the direct measurements methods (Class A Pan, Lysimeter).

Daily and monthly potential evapotranspiration values were calculated and used for the statistical analysis which showed significant differences between the observed and expected values.The latter were calculated from the formulas of both Thornthwaite and Meyer. In conclusion, these two formulas were not applicable for the semi arid areas such as those prevailed in northern Syria. The other ten formulas were not significant and proved to be correct.

**Keywords:** Evapotranspiration, empirical climatic formulas, statistical parameters, arid clima

## INTRODUCTION

Water is very important natural resource with multiple uses and limited availability.

Consumptive use (or Evapotranspiration) is an essential element for estimating irrigation water requirements and for water resource management, espicially under arid conditions, where fresh water is limited.

Evapotranspiration incorporates combined losses by direct evaporation from all surfaces and transpiration from plants. The potential evapotranspiration (ETP) has been defined by Penman as being the evapotranspiration resulting from a homogenous grassy plant cover of a uniform height of 6 to 15 cm, which grows well and shades the whole soil surface, without being affected by any nutritive, physiological or pathological limitation, and which yield fully under the dominant environmental conditions.

Potential evapotranspiration can be determined by direct measurements (lysimeters, field plots, water balances, etc.); by using empirical climatic formulas ( Penman, Blaney- Criddle, Meyer, etc.); or by using evaporation measurements as indices. Direct measurements, if this is available, would actually gave the best estimates of evapotranspiration.

Almost all of ETP formulas are empirical, and depend upon the establishment of known correlations between evapotranspiration and one or more measured climatic variables, such as evaporation, temperature, radiation, humidity, wind speed and percentage of sunshine. However, each of these correlations has been formulated under special environmental conditions in a certain region. Thus, it does not fallow that they could be employed in other regions, due to the differentiation of local climatic factors. Hence, this suggests a change in correlation's variables during application, or seeking the more accurate formulas according to local condition.

This paper presents both an overview and an evaluation of 12 well-known climatic and evaporation methods employed to determine potential evapotranspiration (ETP) under arid conditions. The evaluation will be performed by actual measurements and climatic data obtained from 3 stations in the north of Syria.

## SELECTION OF ESTIMATION METHODS

In the work, suitable methods were chosen for estimating potential evapotranspiration (ETP) from the numerous methods reported in literature. Some of the methods that have received some popularity under arid conditions are listed in Table 1. They are classified as, temperature, relative humidity, radiation, combination or Pan methods.

The temperature methods consist of two different forms of the Blaney-Criddle methods and Thornthwaite method which depend only on temperature. The relative humidity methods utilize only relative humidity (or vapor pressure deficit) and consist of Albrecht and Haude formulas. The combination group includes all methods that related to temperature, sunshine, radiation, wind speed and relative humidity. The radiation classification includes all methods, apart from combination methods that utilize radiation as basic climatic parameter in addition to other parameters, the pan method includes the use of direct measurements of Class A Pan.

**Table 1 Selected methods and their classification**

| Serial No. | Classification | Name of method |
|---|---|---|
| 1<br>2<br>3 | Temperature methods | THORNTHWAITE<br>BLANEY-CRIDDLE<br>modified BLANEY-CRIDDLE |
| 4<br>5 | Relative-humidity methods | ALBRECHT<br>HAUDE |
| 6<br>7<br>8<br>9 | Combination methods | MEYER<br>BLANEY-CRIDDLE (FAO)<br>SCHENDEL<br>IVANOV |
| 10<br>11<br>12 | Radiation methods | TURC<br>MAKKINK<br>PENMAN |
| 13 | Pan methods | CLASS A PAN |

The suitability of each of the above methods of estimating evapotranspiration can be tested by comparing their computed results with actual measurements in the same area. Such a comparison can be achieved by evaluating criteria based on specified statistical parameters.

## DATA and GEOGRAPHICAL LOCATION

The climatic data, as well as the actual measurements that used in the present study, where obtained from full climatic observation stations (in North of Syria) for last 3 years. The location of these stations are listed in Table 2.

**Table 2. Observation stations**

| Name of station | Coordinates | | Elevation meter above sea level | average precipitation |
|---|---|---|---|---|
| | Latitude | Longitude | | |
| Tel Hadya | $36^0$ 01’N | $36^0$ 56’E | 284 m | 330 mm |
| Jindiress | $36^0$ 24’N | $36^0$ 44’E | 210 m | 447 mm |
| Breda | $35^0$ 56’N | $37^0$ 10’E | 300 m | 278 mm |

In general, North Syria climate can be sorted as warm and dry in Summer, mild and humid in Winter. Table 3 shows the measured climatic data in ICARDA climatic station (Tel hadya, 30 km south of Aleppo). Table 4 shows the calculated climatic data for the Tel Hadya station.

**Table 3 Climatic data in Tel hadya climatic station (first year)**

| DATA | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| tmax $^0$C | 34.3 | 28 | 20.1 | 11.2 | 7.8 | 8.5 | 15.9 | 23.9 | 28 | 32.7 | 34.9 | 37.6 |
| tmin $^0$C | 17.1 | 13.2 | 6.8 | 2.5 | -1.5 | -0.3 | 1.2 | 5.6 | 10.5 | 15.5 | 18.8 | 21.1 |
| t $^0$c | 25.7 | 20.6 | 13.5 | 6.9 | 3.2 | 4.1 | 8.6 | 14.8 | 19.3 | 24.2 | 26.9 | 29.4 |
| RH (max) % | 73.8 | 76.4 | 92.9 | 96.2 | 92.8 | 96.4 | 90.3 | 93.4 | 93.0 | 80.9 | 74.5 | 74.8 |
| RH (min) % | 27.1 | 30.2 | 44.1 | 59.8 | 60.7 | 59.6 | 35.2 | 30.0 | 33.6 | 28.0 | 26.9 | 25.3 |
| RH % | 50.6 | 53.3 | 67.8 | 78.0 | 77.1 | 78.0 | 62.7 | 61.7 | 63.7 | 53.4 | 50.7 | 50.1 |
| u m/s | 3.6 | 2.08 | 1.66 | 2.37 | 2.26 | 2.71 | 2.72 | 2.81 | 2.14 | 3.36 | 5.2 | 4.29 |
| n hr | 10.9 | 7.4 | 6.0 | 3.2 | 4.0 | 3.2 | 6.6 | 9.2 | 8.8 | 11.9 | 12.9 | 12.1 |
| P mm | 0 | 73 | 25.2 | 74.0 | 62.3 | 75.4 | 15.8 | 0.4 | 23 | 3.5 | 0 | 0 |
| E Pan A mm | 11.6 | 5.9 | 2.5 | 1.3 | 1.2 | 1.4 | 3.9 | 6.8 | 7.4 | 12.6 | 15.2 | 14.4 |
| | | | | | | | | | | | | |
| t m$^0$ C | 25.8 | 19.5 | 12.5 | 7.8 | 6.5 | 7.8 | 11.0 | 15.9 | 20.7 | 25.6 | 28.7 | 28.9 |
| Pm mm | 0.5 | 24.5 | 48.5 | 53.8 | 60.9 | 50.2 | 43.8 | 28.4 | 14.2 | 3.0 | 0 | 0.1 |

**Table 4 Calculated climatic data in Tel hadya station (3ed year)**

| DATA | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra -- | 13.1 | 10.6 | 8.0 | 6.6 | 7.4 | 9.4 | 12.1 | 14.7 | 16.4 | 17.2 | 16.7 | 15.4 |
| u Bft | 3.6 | 2.6 | 2.3 | 2.9 | 2.7 | 3.1 | 3.1 | 3.2 | 2.6 | 3.45 | 4.5 | 4.05 |
| p -- | 0.278 | 0.253 | 0.231 | 0.219 | 0.232 | 0.245 | 0.269 | 0.295 | 0.316 | 0.327 | 0.322 | 0.31 |
| Es m bar | 32.1 | 24.22 | 15.5 | 9.95 | 7.68 | 8.21 | 11.2 | 16.8 | 22.51 | 30.19 | 35.45 | 40.96 |
| Es14 m bar | 54.1 | 37.8 | 23.52 | 13.3 | 10.57 | 11.07 | 18.06 | 29.65 | 37.8 | 49.37 | 55.95 | 64.8 |
| e m bar | 16.24 | 12.9 | 10.5 | 7.76 | 5.92 | 6.4 | 7.0 | 10.36 | 14.34 | 16.12 | 17.97 | 20.52 |
| e 14 m bar | 14.66 | 20.89 | 10.37 | 7.95 | 6.42 | 6.59 | 6.36 | 8.89 | 12.7 | 13.82 | 15.0 | 16.39 |
| N hr | 12.4 | 11.3 | 10.3 | 9.7 | 10.0 | 11.0 | 11.9 | 13.1 | 14.0 | 14.6 | 14.3 | 13.5 |
| n / N -- | 0.88 | 0.65 | 0.58 | 0.33 | 0.4 | 0.29 | 0.55 | 0.7 | 0.63 | 0.82 | 0.9 | 0.9 |
| s /( s+y) -- | 0.748 | 0.693 | 0.599 | 0.509 | 0.453 | 0.468 | 0.537 | 0.621 | 0.678 | 0.733 | 0.76 | 0.783 |
| k -- | 0.7 | 0.7 | 0.8 | 0.75 | 0.75 | 0.8 | 0.75 | 0.75 | 0.75 | 0.7 | 0.7 | 0.7 |
| C -- | 0.8 | 0.8 | 0.85 | 0.9 | 0.9 | 0.9 | 0.85 | 0.85 | 0.85 | 0.8 | 0.8 | 0.8 |

## ANALYSIS

Statistical analysis was applied on the results that turn up from study period. Chi$^2$ (Chi Test $x^2$) was applied in order to decide upon the compatibility between the actual and estimated values, that calculated from the above of the 12 methods, where each of

these method was considered as mathematical formula. Depending on these formulas the nil hypothesis ($H_0$) which suggests the compatibility between the actual and estimated values. The aim of this is to decide weather to accept or reject the nil hypothesis ( $H_0$ ) in order to have accurate results as much as possible. Also more tests were investigated in this research, using the same style of Penman method instead of measurement method as a basis for comparison in order to get the best results.
Chi square was implied for three periods:

1. For the twelve months (the whole year).
2. For five months (May, June, July, August and September).
3. For seven months,starting with October and ending in April.

## RESULTS

The average monthly potential evapotranspiration (ETP) values for all stations are calculated taken during three years. Table 5 shows estimated ETP values in Tel hadya station for each year. Because of the similarity of results taken from the three stations in question,and for the sake of convenience, only Tel hadya results are demonstrated in the tables.

**Table 5 Yearly estimated ETP values**

| METHOD | | 1st year | 2ed year | 3ed year |
|---|---|---|---|---|
| THORNTHWAITE | (1) | 986 | 1056 | 922 |
| BLANEY & CRIDDLE | (2) | 1539 | 1571 | 1452 |
| BLANEY & CRIDDLE | (3) | 1674 | 1680 | 1618 |
| ALBRECHT | (4) | 2125 | 1916 | 1320 |
| HAUDE | (5) | 2272 | 2210 | 2057 |
| MEYER | (6) | 2829 | 2569 | 2227 |
| TURC | (7) | 1427 | 1360 | 1273 |
| BLANEY & CRIDDLE | (8) | 1834 | 1811 | 1752 |
| SCHENDEL | (9) | 1990 | 1919 | 1726 |
| IVANOV | (10) | 1865 | 1777 | 1618 |
| MAKKINK | (11) | 1859 | 1588 | 1504 |
| PENMAN | (12) | 1947 | 1378 | 1702 |
| Pan A | (13) | 1818 | 1758 | 1507 |
| P mm | | 233 | 290.1 | 352.6 |

ETP values in the third year were lower than other years using all methods, except for Penman formula. However these ETP values obtained in the first year were higher than the other years for all methods, except for temperature methods.

The results reflect considerable variations on the level of methods, months and years. Table 6 shows estimated monthly ETP values within the study years.

The results show that ETP values in the growth season (May - September) were lower in the 3rd year than the other years, whereas the values in the 1st years were higher than the other years. This is due to differences in climatic data (wind speed, temperature, humidity) which the formulas rely on. Wind speed was extremely high in July and August during all the three years, and the average speed was 6 m/s. ETP values within the methods based on wind speed, were much higher than the values obtained from other methods.

**Table 6 Monthly estimated ETP values**

| | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | 130.5 | 82.1 | 30 | 8.37 | 3.1 | 2.8 | 15.5 | 47.1 | 90.2 | 176 | 137 | 197 |
| (2) | 180 | 132.3 | 792 | 39.3 | 18.9 | 25.4 | 58.9 | 111 | 154 | 220 | 201 | 231 |
| (3) | 165.6 | 137.6 | 99 | 76.5 | 68.8 | 68.6 | 100 | 131 | 166 | 204 | 188 | 207 |
| (4) | 187.5 | 139.5 | 58.8 | 27.9 | 23.2 | 21 | 51.1 | 76.5 | 100 | 215 | 167 | 251 |
| (5) | 273 | 115.3 | 87 | 36.5 | 28.2 | 27.7 | 79.6 | 180 | 225 | 328 | 298 | 375 |
| (6) | 321 | 192.2 | 76.2 | 40.3 | 32.5 | 31.6 | 77.5 | 117 | 139 | 437 | 276 | 465 |
| (7) | 153 | 98.5 | 57.9 | 25.7 | 17.3 | 19.6 | 62 | 114 | 138 | 205 | 183 | 195 |
| (8) | 210 | 137.3 | 69.6 | 28.5 | 20.4 | 25.2 | 80.6 | 138 | 171 | 284 | 240 | 307 |
| (9) | 243.6 | 191.5 | 95.7 | 44 | 20.4 | 23.5 | 67.8 | 115 | 150 | 263 | 217 | 291 |
| (10) | 228.6 | 174.8 | 85.8 | 40.3 | 32.8 | 33.6 | 75.9 | 109 | 128 | 239 | 203 | 265 |
| (11) | 184.8 | 107.2 | 52.2 | 107 | 25.7 | 27.7 | 80.6 | 134 | 152 | 264 | 222 | 245 |
| (12) | 199.8 | 111.9 | 80.7 | 30.6 | 29.4 | 33.8 | 83.7 | 131 | 148 | 313 | 243 | 285 |
| (13) | 195 | 102.3 | 51 | 27.2 | 25.1 | 28 | 77.1 | 129 | 146 | 263 | 211 | 249 |

The results for Thornthwaite method showed that $\chi^2 = 89.227$ while $\chi^2_{0.99} = 55.99$ at df =33 .It means that the chi-value was less than the calculated value (Table 7). At df =12 for the same method (Table 8) the $\chi^2$ value was $\chi^2 =22.356$ while $\chi^2_{0.99} =26.2$ and $\chi^2_{0.95} = 21$. This means that the calculated $\chi^2$ is higher than $\chi^2_{0.95}$ and less than $\chi^2_{0.99}$ value.This value confirm the significant differences for both cases (1 and 2). According to these results the nil hypothesis ($H_0$) was rejected at 1% level for the first case and at 5% for the second case. This means that Thornthwaite method differs significantly from basic methods (Clas A Pan, Lysimeter). By applying the same arguments for Meyer method, the results showed that there were significant differences between this method and the basic methods. The rest of other methods showed no significant differences between these methods on one hand and the basic method on the other hand,suggesting that the nil hypothesis ($H_0$) must be accepted because the calculated $\chi^2$ values were less than $\chi^2_{0.95}$ value which found in the table.

**Table 7 Results of chi-test for all months of three years**

| | (df=33) | TABLE CHI -VALUES | | | |
|---|---|---|---|---|---|
| | TOTAL | 1 % | 5 % | 10 % | 25 % |
| METHOD | CHI-VALUES | 55.99 | 39.818 | 36.6364 | 31.6364 |
| THORNTHWAITE | 89.22702 | ** | | | |
| BLANEY &CRIDDLE (A) | 5.5109004 | | | | |
| BLANEY &CRIDDLE (B) | 16.29352 | | | | |
| ALBRECHT | 9.218702 | | | | |
| HAUDE | 13.916602 | | | | |
| MEYER | 36.605887 | | | | * |
| TURC | 9.3502183 | | | | |
| BLANEY & CRIDDLE (C) | 2.0577646 | | | | |
| SCHENDEL | 7.8576491 | | | | |
| IVANOV | 5.8134203 | | | | |
| MAKKINK | 2.9750882 | | | | |
| PENMAN | 5.4634256 | | | | |

**Table 8 Results of chi-test for growth season of three years**

| | (df= 12) | TABLE CHI-VALUES | | | |
|---|---|---|---|---|---|
| | TOTAL | 1 % | 5 % | 10 % | 25 % |
| METHOD | CHI-VALUES | 26.2 | 21 | 18.5 | 14.8 |
| THORNTHWAITE | 22.35599385 | | * | | |
| BLANEY &CRIDDLE (A) | 3.148656667 | | | | |
| BLANEY &CRIDDLE (B) | 7.108083041 | | | | |
| ALBRECHT | 3.907971625 | | | | |
| HAUDE | 10.017908 | | | | |
| MEYER | 31.43953042 | ** | | | |
| TURC | 7.645074781 | | | | |
| BLANEY & CRIDDLE (C) | 1.156708766 | | | | |
| SCHENDEL | 1,573906836 | | | | |
| IVANOV | 1.503994003 | | | | |
| MAKKINK | 0.500680649 | | | | |
| PENMAN | 2.154245059 | | | | |

Using Penman method as basic method, the analysis showed that there were significant differences between this method and the other methods as shown in tables (9 and 10).

**Table 9 Results of chi-test for all months of three years where PENMAN is basic method**

| | (df=33) | TABLE CHI – VALUES | | | |
|---|---|---|---|---|---|
| | | 1 % | 5 % | 10 % | 25 % |
| METHOD | TOTAL CHI-VALUES | 55.99 | 48.18 | 44.33 | 38.28 |
| THORNTHWAITE | 190.9893 | ** | | | |
| BLANEY &CRIDDLE (A) | 24.12287 | | | | |
| BLANEY &CRIDDLE (B) | 49.77056 | | * | | |
| ALBRECHT | 31.18716 | | | | |
| HAUDE | 33.15206 | | | | |
| MEYER | 72.85415 | ** | | | |
| TURC | 31.29805 | | | | |
| BLANEY & CRIDDLE (C) | 11.54637 | | | | |
| SCHENDEL | 24.89903 | | | | |
| IVANOV | 20.99928 | | | | |
| MAKKINK | 11.46777 | | | | |

**Table 10 Results of chi-test for the period (May - September) for the three years where PENMAN is the basic method**

| | (df=12) | TABLE CHI – VALUES | | |
|---|---|---|---|---|
| | | 1 % | 10 % | 25 % |
| METHOD | TOTAL CHI- VALUES | 26.2 | 18.5 | 14.8 |
| THORNTHWAITE | 30.25979059 | ** | | |
| BLANEY &CRIDDLE(A) | 7.997707497 | | | |
| BLANEY &CRIDDLE(B) | 12.95538311 | | | |
| ALBRECHT | 6.553259852 | | | |
| HAUDE | 9.923121714 | | | |
| MEYER | 28.54978836 | ** | | |
| TURC | 13.12971149 | | | |
| BLANEY & CRIDDLE(C) | 2.96056792 | | | |
| SCHENDEL | 3.055402085 | | | |
| IVANOV | 3.648856169 | | | |
| MAKKINK | 2.253184529 | | | |

## CONCLUSION

Rational estimation of potential evapotranspiration is a crucial factor for better conservation of water resources, especially under arid conditions.

In the present work, 12 empirical methods have been selected and classified into five groups according to the utilized climatic elements. These methods have been then evaluated, to test their suitability under semi -arid and arid climates. Statistical comparative analyses have been performed among the results estimated, by different methods in each of the three stations, and in the same methods in different stations.

The influence of site on the estimated ETP values has not been evaluated. The results of these computations have indicated considerable differences in ETP values estimated by each of these methods.

Satisfactory correlation has been noticed for all methods, except for Thornthwaite and Meyer formulas, which reflect doubtful results. The results from these analysis have demonstrated good relation between the monthly ETP values estimated by Class A Pan and other ten methods.

The encouraging results obtained from this work should be investigated further using more sites in the same area, and for longer periods with actual measurements of plants, to determine the plant consumption factor ($K_p$). By using this estimated factor, the real water requirements ETR for plants could have been exactly determined.

## LIST OF SYMBOLS

C = Pan coefficient
E = evaporation
e = vapor pressure
$e_{14}$ = vapor pressure at 14 h
$E_s$ = saturation vapor pressure
$E_{s14}$ = saturation vapor pressure at 14 h
ETP = potential evapotranspiration
ETR = real evapotranspiration
k = coefficient
$K_p$ = crop coefficient
n = hours of bright
N = sunshine duration
n/N = sunshine ratio
p = factor
P = precipitation
$P_m$ = mean monthly precipitation
Ra = solar radiation
RH = relative humidity
$RH_{(max)}$ = max. humidity
$RH_{(min)}$ = min. humidity
t = air temperature
$t_m$ = mean monthly temperature
$t_{(max)}$ = max. monthly temperature
$t_{(min)}$ = min. monthly temperature
u = wind speed
y = psychrometer coefficient

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