FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 5, N° 2, 2007, pp. 107 - 113

EFFECT OF WIND SPEED ON ACCURACY OF TURC METHOD IN A HUMID CLIMATE

UDC 551.509.32:631.92(045)=111

Slaviša Trajković[1], Vladimir Stojnić[2]

[1]Faculty of Civil Engineering and Architecture, University of Niš, Serbia
[2]Snowyhydro Limited, Sydney, NSW, Australia

Abstract. *The Turc method is one of the simplest and most accurate empirical equations used for ET0 estimation. The objectives of this study are: first, to investigate the effect of wind speed on accuracy of Turc method; second, to develop the wind speed adjustment factors for the Turc method. The adjusted Turc method provides the quite good agreement with the evapotranspiration obtained by the FAO-56 Penman-Monteith method. It gave reliable estimation at all the locations and it has proven to be the most adjustable to the local climatic conditions. These results recommend the adjusted Turc method for estimating reference evapotranspiration.*

Key words: *Reference evapotranspiration, FAO-56 Penman-Monteith, Turc, adjustment factor.*

1. INTRODUCTION

The Turc method (Turc 1961) is one of the simplest and most accurate empirical equations used to estimate reference evapotranspiration (ET_0) under humid conditions (Jensen et al. 1990).

This equation is expressed on a daily basis as:

$$ET_0 = 0.013 \cdot (23.88 \cdot Rs + 50) \cdot T \cdot (T + 15)^{-1} \quad (1)$$

where ET_0 = reference evapotranspiration (mm day^{-1}); T = average air temperature (^oC); and Rs = solar radiation (MJ m^{-2} day^{-1}).

Jensen et al. (1990) analysed the properties of twenty different methods against carefully selected lysimeter data from eleven stations located worldwide in different climates. The Turc method compared very favourably with combination methods at the humid lysimeter locations. The Turc method was ranked second when only humid locations were considered. The Penman-Monteith method (PM) only performed better than this method.

Received September 1, 2007

The International Commission for Irrigation and Drainage (ICID) and Food and Agriculture Organisation of the United Nations (FAO) have proposed using the FAO-56 PM method as the standard method for estimating reference evapotranspiration, and for evaluating other methods (Allen et al. 1994 a, b).

FAO-56 Penman-Monteith (FAO-56 PM) equation is (Allen et al. 1998):

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (Rn - G) + \gamma \dfrac{900}{T + 273} U \cdot (e_a - e_d)}{\Delta + \gamma \cdot (1 + 0.34U)} \tag{2}$$

where ET_0 = grass reference evapotranspiration (mm d^{-1}); Δ = slope of the saturation vapor pressure function (k Pa $^oC^{-1}$); Rn = net radiation (MJ m^{-2} day^{-1}); G =soil heat flux density (MJ m^{-2} day^{-1}); γ = psychometric constant (k Pa $^oC^{-1}$); T = mean air temperature (^oC); U = average 24-hour wind speed at two meters height (m s^{-1}); (e_a–e_d) = vapor pressure deficit (kPa).

Many studies have indicated the superiority of this equation (Ventura et al. 1999; Pereira and Pruitt 2004; Lopez-Urrea et al. 2006; Gavilan et al. 2007). FAO-56 Penman-Monteith method requires numerous weather data, and those are: maximum and minimum air temperature, maximum and minimum relative air humidity (or the actual vapor pressure), wind speed at 2 meters height, solar radiation (or sunshine hours).

However, the application of the FAO-56 PM approach is limited in many regions due to the lack of required weather data. The Turc method can be used to estimate ET_0 under humid conditions because of the simplicity of the method and moderate weather data requirements.

Trajkovic (2001) evaluated the six empirical methods (FAO-56 reduced-set Penman-Monteith, Thornthwaite, Hargreaves, Priestley-Taylor, Jensen-Haise, and Turc) as compared to FAO-56 PM equation using monthly data from seven Western Balkan's humid locations. The Turc method was ranked first, based on weighted standard error of estimate. The results indicated that wind speed affects accuracy of the Turc method. Introduction of the wind speed adjustment factor could be useful for reliability of this method. The objectives of this study were: first, to investigate the effect of wind speed on accuracy of the Turc method; second, to develop the wind speed adjustment factors for the Turc method.

2. Estimating ET_0 by Turc Method Using CLIMWAT Data Set

The weather data set used for the development of the wind speed adjustment factors was obtained from CLIMWAT data base (Smith 1993). The data set consists of long-term monthly average values for maximum air temperature, minimum air temperature, mean relative humidity, solar radiation, wind speed and ET_0 estimated with FAO-56 PM equation.

Fifty-two humid locations from seven European countries were selected for this study. These locations cover all the humid latitudes in Europe (from 42 ^oN to 50 ^oN) and a wide range of wind speed was observed at these locations (wind at two meters height varied from 0.51 to 3.16 m s^{-1}).

Table 1 presented the comparison of estimates of monthly ET_0 from the Turc method equation with FAO-56 PM equation for fifty-two CLIMWAT humid stations. This study generally found good agreement between two methods. The SEE varied from 0.10 (Caen) to 0.36 mm d^{-1} (Belgrade), averaging 0.23 mm d^{-1}. Twenty locations gave the SEE value higher than 0.25 mm d^{-1}. The ratio of Turc ET_0 to FAO-56 Pm varied from 0.88 (Orleans) to 1.11 (Torino) for entire year and ranked from 0.90 (Orleans) to 1.06 (Milano) for the peak month. Nineteen locations yielded relative difference between two methods higher than 6%.

The ratios of Turc to FAO-56 PM ET_0 were plotted against long-term average annual values of wind speed to analyze the effects of wind speed on this parameter (Figure 1).

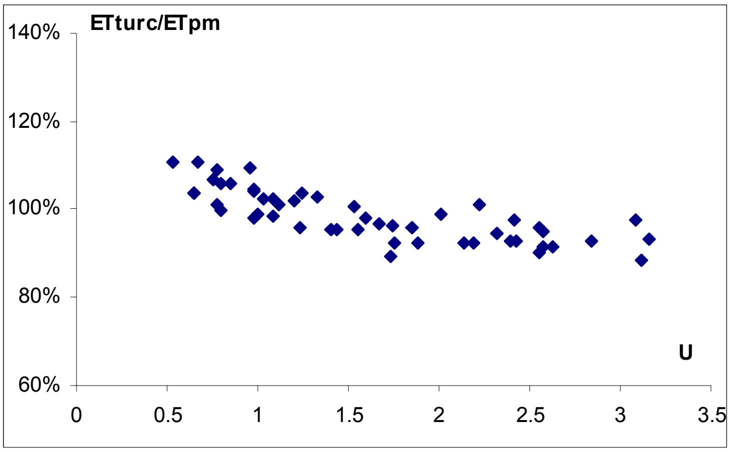

Fig. 1. Ratio of Turc to FAO-56 PM ET_0

Table 1. The statistical summary of Turc ET_0 estimates

Station	State	Latitude (^{o} N)	Altitude (m)	U_2 (m s^{-1})	ETturc/ ETpm	pETturc/ ETpm	SEE (mm d^{-1})
Uccle/Bruxelles	Belgium	50.48	100	2.84	0.93	0.98	0.196
Lille	France	50.34	44	3.16	0.93	0.96	0.206
Rouen	France	49.23	68	1.53	1.01	1.00	0.145
Reims	France	49.18	94	2.63	0.91	0.93	0.262
Caen	France	49.10	66	3.08	0.97	0.98	0.104
Paris Montsouris	France	48.49	75	2.39	0.93	0.93	0.214
Nancy Essey	France	48.42	212	1.67	0.97	1.00	0.226
Strasbourg	France	48.33	149	1.55	0.95	1.00	0.226
Rennes	France	48.04	35	2.22	1.01	0.99	0.106
Orleans	France	47.59	125	3.12	0.88	0.90	0.303
Le Mans	France	47.56	52	2.01	0.99	0.97	0.148
Auxerre	France	47.48	207	2.43	0.93	0.95	0.229
Belfort	France	47.38	422	2.57	0.92	0.99	0.290
Tours St Symph.	France	47.25	96	2.55	0.90	0.92	0.274
Dijon	France	47.16	220	2.19	0.92	0.94	0.259
Nevers	France	47.00	176	2.32	0.95	0.98	0.201

Station	State	Latitude (° N)	Altitude (m)	U_2 (m s^{-1})	ETturc/ ETpm	pETturc/ ETpm	SEE (mm d^{-1})
Poitiers	France	46.35	118	2.55	0.96	0.94	0.179
Maribor/Tezno	Slovenia	46.32	275	1.23	0.96	1.02	0.305
Bolzano	Italy	46.30	271	0.65	1.04	1.02	0.240
Sondrio	Italy	46.10	300	0.65	1.04	1.01	0.242
Trento	Italy	46.05	200	0.65	1.04	0.99	0.242
Udine	Italy	46.04	116	0.78	1.02	1.03	0.224
Ljubjana-Bezigrad	Slovenia	46.04	299	0.80	1.00	1.03	0.273
Limoges	France	45.49	282	1.76	0.92	0.97	0.313
Zagreb/Gric	Croatia	45.49	157	1.40	0.95	0.97	0.257
Lyon /Bron	France	45.43	200	2.14	0.92	0.92	0.258
Bergamo	Italy	45.40	238	1.12	1.01	0.99	0.188
Osijek	Croatia	45.33	90	1.03	1.02	1.02	0.268
Milano	Italy	45.28	121	0.78	1.03	1.06	0.265
Verona	Italy	45.26	60	0.67	1.11	1.05	0.295
Padova	Italy	45.24	14	0.76	1.07	1.05	0.240
Novi Sad/Rimski S	Serbia	45.20	84	1.88	0.92	0.96	0.269
Grenoble	France	45.10	223	1.85	0.96	1.00	0.232
Slavonski Brod	Croatia	45.09	95	1.09	0.99	1.00	0.221
Torino	Italy	45.05	238	0.53	1.11	1.03	0.290
Piacenza	Italy	44.55	138	0.98	1.04	1.01	0.244
Ferrara	Italy	44.49	9	1.60	0.98	0.94	0.201
Govone/Asti	Italy	44.48	300	0.98	1.04	1.01	0.237
Parma	Italy	44.48	57	0.80	1.06	1.01	0.262
Belgrade	Serbia	44.48	132	1.73	0.89	0.94	0.365
Banja Luka	Bosnia	44.47	153	0.78	1.01	1.03	0.297
Gourdon	France	44.45	205	1.24	1.04	1.03	0.206
Bologna	Italy	44.30	60	1.09	1.02	0.96	0.211
Agen	France	44.11	59	2.42	0.98	0.94	0.153
Millau	France	44.06	409	1.44	0.95	0.97	0.213
Firenze	Italy	43.46	51	0.96	1.09	1.01	0.262
Kraljevo	Serbia	43.44	225	1.00	0.98	0.99	0.243
Toulouse Blagnac	France	43.37	151	2.57	0.95	0.93	0.188
Siena	Italy	43.31	348	1.33	1.03	0.98	0.198
Nis	Serbia	43.20	201	1.00	0.99	1.01	0.258
Perugia	Italy	43.07	493	0.85	1.06	1.04	0.237
Roma/Coll.Roman	Italy	41.54	17	1.74	0.96	0.95	0.171

Note: ETturc/ETpm = ratio of average annual Turc ET_0 estimates and FAO-56 PM estimated ET_0; pETturc/ETpm = ratio of average peak mothly Turc ET_0 estimates and FAO-56 PM estimated ET_0; and

SEE = standard error of estimate.

It was found that reliability of the Turc method depends on the wind speed. This method overpredicted FAO-56 PM ET_0 estimates at windless locations and generally underpredicted ET_0 at windy locations.

3. ESTIMATING ET_0 BY ADJUSTED TURC METHOD USING CLIMWAT DATA SET

Introduction of the wind speed adjustment factor could be useful for reliability of the Turc method. The adjusted Turc method is:

$$ETo = C \cdot 0.013 \cdot (23.88 \cdot Rs + 50) \cdot T \cdot (T + 15)^{-1} \quad (4)$$

where C = wind speed adjustment factor.

The following regression types were used to compute wind speed adjustment factor: linear, logarithmic, second and third order polynomial, power and exponential. Coefficients for all the regression equations were estimated using the CLIMWAT data set. Results of exponential and linear regression equations were poor, with square correlation coefficients (R^2) that were relatively low (0.61 and 0.62, respectively). The second and third order polynomial equations produced the highest correlation coefficient (R^2 = 0.70 for both cases) and the lowest SEE (3.2%, for both cases). The second order polynomial equation has the following form:

$$C_p = -0.0313 \cdot U^2 + 0.1706 \cdot U + 0.8383 \quad (5)$$

where C_p = adjustment factor; and U = long-term monthly average value for wind speed at two meters height (m s^{-1}).

The approach for determining wind speed adjustment factors (C_p) was selected for using in adjusted Turc equation. Results using the adjusted Turc method (CpTurc) to calculate ET_0 for a number of sites in Europe are presented in Table 2.

The adjusted Turc method gave a better agreement with FAO-56 PM than Turc method. The adjusted equation gave the lower average SEE = 0.211 mmd^{-1}. This equation also yielded less sites with SEE > 0.25 mmd^{-1} (10 sites) or relative difference > 6% (3 sites) than Turc method. The ratios of the adjusted Turc ET_0 to FAO-56 PM ET_0 ranged from 0.93 (Belgrade) to 1.07 (Rennes) for CpTurc, averaging 1.00.

The average ET_0 values for Paris, France as estimated by the FAO-56 PM method (PM), Turc method (Turc), and adjusted Turc method (cTurc) are plotted in Figure 2.

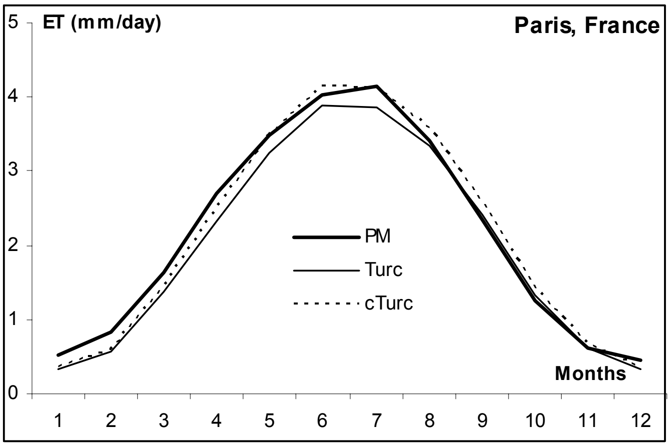

Fig. 2. Average ET_0 estimates for Paris, France

Table 2. The statistical summary of adjusted Turc ET_0 estimates

Station	State	ETturc/ETpm	pETturc/ETpm	SEE (mm d^{-1})
Uccle/Bruxelles	Belgium	0.99	1.05	0.145
Lille	France	0.97	1.02	0.166
Rouen	France	1.03	1.03	0.163
Reims	France	0.98	0.99	0.197
Caen	France	1.04	1.05	0.169
Paris Montsouris	France	0.99	1.00	0.159
Nancy Essey	France	1.00	1.03	0.241
Strasbourg	France	0.98	1.02	0.231
Rennes	France	1.07	1.05	0.200
Orleans	France	0.94	0.96	0.186
Le Mans	France	1.04	1.02	0.176
Auxerre	France	0.99	1.02	0.197
Belfort	France	0.98	1.06	0.295
Tours St Symph.	France	0.97	0.96	0.204
Dijon	France	0.98	1.00	0.221
Nevers	France	1.01	1.04	0.222
Poitiers	France	1.03	1.00	0.163
Maribor/Tezno	Slovenia	0.96	1.02	0.305
Bolzano	Italy	0.97	0.96	0.234
Sondrio	Italy	0.97	0.95	0.251
Trento	Italy	0.97	0.93	0.258
Udine	Italy	1.02	1.02	0.222
Ljubjana-Bezigrad	Slovenia	0.95	0.98	0.252
Limoges	France	0.96	1.01	0.305
Zagreb/Gric	Croatia	0.97	0.98	0.243
Lyon /Bron	France	0.98	0.98	0.194
Bergamo	Italy	1.00	0.98	0.186
Osijek	Croatia	1.00	1.00	0.244
Milano	Italy	1.04	1.01	0.195
Verona	Italy	1.04	0.99	0.200
Padova	Italy	1.02	0.99	0.201
Novi Sad/Rimski S	Serbia	0.97	1.01	0.243
Grenoble	France	1.00	1.04	0.258
Slavonski Brod	Croatia	0.97	0.99	0.217
Torino	Italy	1.02	0.95	0.195
Piacenza	Italy	1.01	0.98	0.220
Ferrara	Italy	1.01	0.97	0.187
Govone/Asti	Italy	1.02	0.99	0.212
Parma	Italy	1.01	0.96	0.229
Belgrade	Serbia	0.93	0.98	0.324
Banja Luka	Bosnia	0.96	0.98	0.270
Gourdon	France	1.04	1.03	0.208
Bologna	Italy	1.01	0.95	0.211
Agen	France	1.04	1.00	0.157
Millau	France	0.97	0.99	0.200
Firenze	Italy	1.06	0.99	0.222
Kraljevo	Serbia	0.96	0.97	0.243
Toulouse Blagnac	France	1.02	1.00	0.142
Siena	Italy	1.04	0.99	0.208
Nis	Serbia	0.97	0.99	0.253
Perugia	Italy	1.02	1.00	0.195
Roma/Coll.Roman	Italy	1.00	0.98	0.116

4. CONCLUSIONS

The following conclusions can be drawn:

The Turc method generally yielded good agreement with FAO-56 PM method. It was found that reliability of the method depends on the wind speed. Adjusted Turc method yielded a better agreement with FAO-56 PM than usual Turc method.

The adjusted Turc method provides the quite good agreement with the evapotranspiration obtained by the FAO Penman-Monteith method. It produced reliable estimation at all the locations and it has proven to be the most adaptable to the local climatic conditions. These results recommend the adjusted Turc method for estimating reference evapotranspiration. The FAO-56 is still a guide and researchers should adapt all calculations to their local conditions. The researchers should use their own judgment on the results based on their local experiences and not take the results blindly**.**

REFERENCES

1. Allen, R. G., Smith, M., Perrier, A., and Pereira, L. S. "An Update for the Definition of Reference Evapotranspiration." *ICID Bulletin*, 43(2), 1-34, 1994.
2. Allen, R. G., Smith, M., Perrier, A., and Pereira, L. S. "An Update for the Calculation of Reference Evapotranspiration." *ICID Bulletin*, 43(2), 35-92, 1994
3. Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. "Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements." *FAO Irrig. Drain. Paper 56*, Roma, Italy, 1998.
4. Gavilan, P., Berengena, J., and Allen, R.G. "Measuring versus estimating net radiation and soil heat flux: Impact on Penman-Monteith reference ET estimates in semiarid regions." *Agricultural Water Management* 89, 275-286, 2007.
5. Jensen, M. E., Burman, R. D., and Allen, R. G. "Evapotranspiration and irrigation water requirements." *ASCE manuals and reports on engineering practice No.70*, ASCE, New York, 1990.
6. Lopez-Urrea, R., de Santa Olalla, F. M., Fabeiro, C., and Moratalla, A. "An evaluation of two hourly reference evapotranspiration equations for semiarid conditions." *Agricultural Water Management* 86, 277-282, 2006.
7. Pereira, A. R., and Pruitt, W. O. "Adaptation of the Thornthwaite scheme for estimating daily reference evapotranspiration." *Agricultural Water Management* 66, 251-257, 2004.
8. Smith, M. "CLIMWAT for CROPWAT: A climatic database for irrigation planning and management." *FAO Irrigation and Drainage Paper No. 49*, Rome, Italy, 1993.
9. Trajkovic, S. "Model of estimating maximum discharge in the irrigation system by using minimum number of weather parameters." *Ph.D. thesis*, University of Nis, Serbia (in Serbian), 2001.
10. Turc, L. "Estimation of irrigation water requirements, potential evapotranspiration: A simple climatic formula evolved up to date" (in French). Ann. Agron., 12, 13-49, 1961.
11. Ventura, F., Spano, D., Duce, P., Snyder, R. L. "An evaluation of common evapotranspiration equations." *Irrig. Sci.,* 18, 163-170, 1999.

UTICAJ BRZINE VETRA NA POUZDANOST TURC METODE U HUMIDNOJ KLIMI

Slaviša Trajković, Vladimir Stojnić

Turc metoda je jedna od najjednostavnijih i najpouzdanijih metoda proračuna referentne evapotranspiracije. Ciljevi ovog rada su analiza uticaja brzine vetra na pouzdanost Turc metode i razvoj novog korekcionog koeficijent zasnovanog na brzini vetra koji bi se koristio u izmenjenoj Turc metodi. Dobijeni rezultati pokazuju da izmenjena Turc metoda obezbedjuje sasvim dobro slaganje sa vrednostima referentne evapotranspiracije dobijene primenom FAO-56 Penman-Monteith metode. Izmenjena Turc metoda daje pouzdani proračun na svim lokacijama i pokazala se kao najprilagodljivija lokalnim klimatskim uslovima. Ovi rezultati snažno preporučuju korišćenje izmenjene Turc metode za proračun referentne evapotranspiracije.