

ESTIMATING REFERENCE EVAPOTRANSPIRATION FOR THE CLIMATIC CONDITIONS OF SOUTH-EASTERN ALBANIA

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SUMMARY - In this paper we compare measured reference evapotranspiration (ET_0) with calculated reference evapotranspiration in the experimental field of the Soil Science Institute of Tirana, close to the city of Korça (south-eastern Albania, 41° 35' N 20° 46' W, and 899 m above sea level). The reference crop was grass 0.08-0.15 m high. We used a drainage lysimeter to measure ET_0 , and we calculated ET_0 by four different equations: Penman, FAO-24 Penman, Penman-Monteith and a modified Penman equation. We used data from 1982 to 1992, averaged on a ten-day basis, for making linear regression analysis, using measured ET_0 as dependent variable and calculated ET_0 as independent variable. Results showed that the Penman-Monteith model fitted the calculated values better. The Penman and modified Penman equations tended to overestimate the measured ET_0 , whereas the FAO-24 Penman equation tended to underestimate it.

Key words: reference evapotranspiration, drainage lysimeter, Albania.

INTRODUCTION

Studies on evapotranspiration play a major role in both the design and management of irrigation systems and the calculation of crop water requirements. It is known that the crop evapotranspiration (ET_c) can be either measured or estimated from the reference evapotranspiration (ET_0) and the use of crop coefficients, K_c (Doorenbos and Pruitt, 1977). There are different methods based on meteorological data for the estimation of ET_0 (Jensen et al., 1990). Direct measurements of ET_0 in the field require installations not available in most cases. Therefore ET_0 is usually calculated. One of the crucial aspects in this calculation is the choice of the empirical equation that gives best results for the environmental conditions in the area (Pruitt and Doorenbos, 1977). This makes the local evaluation of the ET_0 estimating methods a task of priority interest.

In this paper, we show the evaluation procedure and results of four combination equations for calculating ET_0 in Korça (south-eastern Albania) as compared to ET_0 measured on a ten-day basis in a drainage lysimeter covered by grass.

MATERIALS AND METHODS

The experimental site was located close to the city of Korça (south-eastern Albania, 41° 35' N, 20° 46' W, 899 m above sea level). Measurements of ET_0 were made from 1982 to 1992, for the period of April to September, by using a drainage lysimeter (1.0 x 1.0 x 1.2 m depth) in which the water table level was maintained at 0.7 m depth. The lysimeter was placed in a 3 ha plot covered by grass (*Festuca arundinacea*, cv. Manande). Water and fertilizers were applied to optimal levels, and crop height was maintained between 0.08 and 0.15 m.

Meteorological data were recorded in a weather station placed in the experimental plot. Hourly data of solar radiation, air and dew point temperatures, vapour pressure and air humidity, and wind speed were recorded in an automatic weather station MILOS 500 placed in the experimental plot. These data were used for the daily calculation of ET_0 by four different equations:

i) Penman equation, ET_0 -P (Penman, 1963):

$$\lambda ET_0 = \frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\gamma}{\Delta + \gamma} 6.43 W_f (e_s - e_a) \quad (1)$$

where λ is the latent heat of vaporization (MJ kg^{-1}), Δ is the slope of the vapour pressure curve versus temperature ($\text{kPa } ^\circ\text{C}^{-1}$), γ is the psychrometric constant, R_n is the net radiation ($\text{MJ m}^{-2} \text{d}^{-1}$), G is the heat flux density to the ground ($\text{MJ m}^{-2} \text{d}^{-1}$), e_s is the saturation water vapour pressure (kPa), e_a is the water vapour partial pressure (kPa), and W_i is the wind term. Cuenca and Nicholson (1982) state that the wind term is

$$W_i = 1.0 + 0.53 u_2 \quad (2)$$

where u_2 is the wind speed (m s^{-1}) at 2 m above ground surface. Net radiation was calculated from measured solar radiation, air temperature, and ratio between actual measured and possible hours of sunshine, using procedures described by Doorenbos and Pruitt (1977). Soil heat flux was estimated using the method described by Wright (1982).

ii) *FAO-24 Penman equation, ET_0 -FAO (Doorenbos and Pruitt, 1977):*

$$ET_0 = c \left[\frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\gamma}{\Delta + \gamma} 2.7 W_i (e_s - e_a) \right] \quad (3)$$

where c is an adjustment factor based on local climatic conditions. It can be calculated from the polynomial equation developed by Frevert et al. (1983). The wind term is

$$W_i = 1 + 0.864 u_2 \quad (4)$$

The vapour pressure deficit ($e_s - e_a$) is calculated from the mean air temperature (T_{mean} , $^\circ\text{C}$) and the mean dew point temperature (T_{dew} , $^\circ\text{C}$):

$$e_s - e_a = e(T_{\text{mean}}) - e(T_{\text{dew}}) \quad (5)$$

iii) *Penman-Monteith equation, ET_0 -PM (Castrignano et al., 1991):*

$$\lambda ET_0 = \frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\gamma}{\Delta + \gamma} \frac{936}{t + 276} u_2 (e_s - e_a) \quad (6)$$

where γ is the corrected psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), given by

$$\gamma = (1 + 0.347 u_2) \gamma \quad (7)$$

iv) *Modified Penman equation, ET_0 -mP (Snyder and Pruitt, 1992):*

The daily reference evapotranspiration (ET_0) for grass as the reference crop is given by

$$ET_0 = \sum E_i \quad (8)$$

where E_i is the hourly reference evapotranspiration. Equation 9 is used for the calculation of E_i during daytime and Equation 10 is used for the calculation during night-time

$$E_i = W_i R_{ni} + (1 - W_i) (e_{ai} - e_{di}) F_{di}, \text{ for } R_{ni} > 0 \quad (9)$$

$$E_i = W_i R_{ni} + (1 - W_i) (e_{ai} - e_{di}) F_{ni}, \text{ for } R_{ni} \leq 0 \quad (10)$$

Variables involved in Eqs (9) and (10) are measured or calculated for the i -th hour of each day. The measured variables are the mean air temperature, t_i ($^\circ\text{C}$), the mean vapour pressure, e_{di} (kPa) the mean wind speed, u_i (m s^{-1}), all of them measured at 2 m above ground level, and the mean solar radiation, R_{si} (W m^{-2}). The calculated variables are

$$W_i = \frac{\Delta_i}{\Delta_i + \gamma_i} \quad (11)$$

where

$$\Delta_i = \frac{e_{ai}}{T_{ki}} \frac{6790.4985}{T_{ki} - 5.02808} \quad (\text{kPa } ^\circ\text{C}^{-1}) \quad (12)$$

$$T_{ki} = 273.16 + t_i \quad (\text{K}) \quad (13)$$

$$e_{ai} = 0.6108 \exp[(17.28 t_i) / (t_i + 237.3)] \quad (\text{kPa}) \quad (14)$$

$$\gamma_i = 0.000646 (1 + 0.000946 t_i) P_b \quad (\text{kPa } ^\circ\text{C}^{-1}) \quad (15)$$

$$R_{ni} = f(R_{sv} t_i) \quad (\text{mm}) \quad (16)$$

$$F_{di} = 0.030 + 0.0576 u_i \quad (\text{mm kPa}^{-1}) \quad (17)$$

$$F_{ni} = 0.125 + 0.0439 u_i \quad (\text{mm kPa}^{-1}) \quad (18)$$

Equation (16) is solved as explained by Jensen et al. (1990). The net radiation R_{ni} is then expressed in millimeters of evaporation after dividing by the latent heat of vaporization:

$$\lambda = 694.5 (1 - 0.000946 t) (W m^2 mm^{-1}) \quad (19)$$

In Eq. (15), P_b is the barometric pressure (kPa). This is estimated from the following equation, given by Doorenbos and Pruitt (1977)

$$P_b = 101.3 - 0.01152 z + 5.44 \cdot 10^{-7} z^2 \quad (20)$$

where z is the elevation (m) above sea level.

Daily ET_o -mP values were computed as follows: During the first three experimental years, equations (9) and (10) were used to calculate the values of E_i during daytime and during nighttime, being the daily totals calculated from both values. Hourly values of E_i were calculated for the rest of the experimental period.

Statistical analysis

The standard errors of the calculated ET_o , averaged on a ten-day basis throughout the experimental period, were calculated by the following equation (Jensen et al., 1990):

$$SEE = \left[\frac{\sum (y_i - \hat{y}_i)^2}{n - 1} \right]^{0.5} \quad (21)$$

where y_i is the average i -th month lysimeter ET_o , \hat{y}_i is the corresponding ET_o calculated by the four different equations, and n is the total number of observations. The calculated SEE has units of $mm d^{-1}$ and $n-1$ degrees of freedom.

Linear regression analysis was made with the ET_o data from the lysimeters as dependent variable and the calculated ET_o data as independent variable. For this analysis, data concerning both measured and calculated ET_o were averaged on a ten-day basis. Two linear equations were used (Jensen et al., 1990):

$$\text{Lysimeter } ET_o = b (\text{calculated } ET_o) \quad (22)$$

$$\text{Lysimeter } ET_o = a + b (\text{calculated } ET_o) \quad (23)$$

Eq. (22) represents regression through the origin, whereas Eq. (23) represents regression with a non zero offset along the ordinate axis. Eq. (22) is the preferred method of evaluating the goodness of fit between calculated ET_o and lysimeter ET_o ,

because calculated ET_o should approach zero as measured ET_o approaches zero. The coefficient b in Eq. (22) can also be used to adjust the calculated ET_o to more closely represent a particular lysimeter ET_o dataset. Regression through the origin by Eq. (22) was justified because, in all cases, the a coefficient was not statistically different from zero (F test with $n-1$ degrees of freedom, $P < 0.05$).

The regression coefficients b (Eq. 22) were used to adjust the calculated ET_o , being SEEs recalculated afterwards for the adjusted values (i.e. \hat{y} in Eq. 21 was set equal to bET_o). Two SEE values were calculated: (1) the SEE of model estimates versus lysimeters measurements; and (2) the SEE of model estimates adjusted using a coefficient based on a linear regression through the origin, versus lysimeter measurements, ASEE. The use of these two SEEs provided information on accuracy of unadjusted calculated ET_o and on ease with which the model can be adjusted or corrected with a simple coefficient to fit location ET_o . The SEE values were calculated for all months and for months when peak ET_o occurred.

RESULTS AND DISCUSSION

The calculated values of ET_o , averaged on a ten-day basis, were plotted against the values measured with the lysimeter (Fig. 1). For the four equations, most of the plotted values are close to the 1:1 line, indicating a good agreement between their results and the lysimeter measurements. With the ET_o -P and ET_o -mP models, most of the plotted values result below the 1:1 line, indicating the general overestimation of measured ET_o with these two methods. On the other hand, with the ET_o -FAO and ET_o -PM models the highest number of plotted values is above the 1:1 line, indicating a general underestimation of measured ET_o .

Results from the statistical analysis are shown in Table 1. This table includes: the average values of the measured ET_o expressed as percentage of the calculated ET_o , the values of SEE and ASEE, the b and r^2 coefficients from the linear regression through the origin, the weighted values of SEEs, and, finally, the ranking of the different models used, based on the weighted SEE.

Average SEEs for the different ET_o models for all months ranged from 0.854 $mm d^{-1}$ for the Penman-

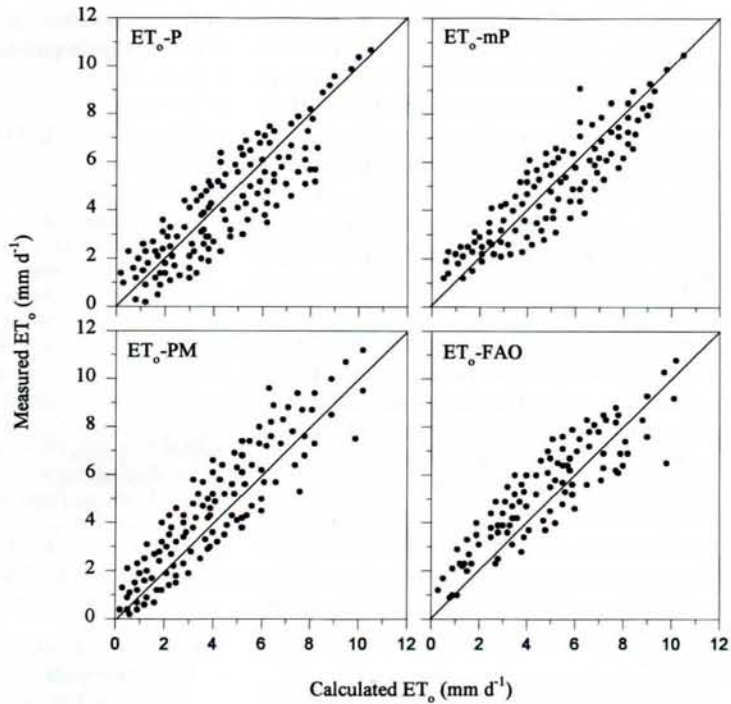


Fig. 1 - Reference evapotranspiration (ET_0) calculated by different models versus the values of evapotranspiration measured in the lysimeter. The points are the values of evapotranspiration for the experimental period, averaged on a ten-day basis (ET_0 -P=Penman; ET_0 -mP = modified Penman; ET_0 -PM = Penman-Monteith; ET_0 -FAO = FAO-24 Penman).

Monteith model to 1.127 mm d^{-1} for the original Penman model. Average SEEs for ET_0 models for the peak months ranged 0.984 mm d^{-1} for the Penman-Monteith model to 1.743 mm d^{-1} for the Modified Penman model.

Weighting of SEEs values was made by giving 70% of the weight to seasonal values and 30% to peak monthly values. Within each of these two groupings, two-thirds weight was placed on the unadjusted SEE and one-third weight was placed

on the SEE of regression-adjusted estimates. The resulting values of the weighted SEE indicate the ability of models to accurately estimate ET_0 during all months (47% weight), the ability to accurately estimate peak ET_0 (23% weight), and the ability to be corrected using a linear multiplier (30% weight).

Table 1 shows good agreement between the calculated ET_0 by the different models and the lysimeter measurements. The best estimates cor-

Tab. 1 - Summary of statistics and ranking of models for ten-day basis estimates of ET_0 .

Rank	Model	%	SEE	b	r^2	ASEE	W. SEE
1	ET_0 -PM	103	0.854	1.090	0.987	0.564	0.587
2	ET_0 -FAO	106	1.008	1.117	0.963	0.589	0.634
3	ET_0 -mP	98	1.118	0.925	0.948	0.675	0.791
4	ET_0 -P	91	1.127	0.907	0.936	0.714	0.843

% = measured ET_0 expressed as percentage of the calculated ET_0 .

SEE = standard error of estimate without adjustment by regression.

b = regression coefficient (slope) for regression through the origin of lysimeter versus model estimates.

r^2 = Correlation coefficient for regression through the origin of lysimeter versus model estimates.

ASEE = standard error of estimate after regression through the origin.

W. SEE = Weighted SEE.

responded to the ET_0 -PM equation, as indicated by the highest value of the determination coefficient (r^2) and the lowest value of the weighted SEE. Also, the analysis showed that both ET_0 -P and ET_0 -mP equations tend to overestimate ET_c , and ET_0 -FAO and ET_0 -PM models to underestimate.

The fact that the ET_0 -FAO model underestimated ET_0 may be due to the regression equation used to calculate the correction factor C. For the ET_0 -PM equation, the underestimation may be partially due to the empirical expressions of canopy ($rc = 69 \text{ s m}^{-1}$) and aerodynamic ($ra = 200/u_2 \text{ s m}^{-1}$) resistances used in the applied wind function, which needs calibration *in situ*. Moreover, the surface roughness and leaf area index values for grass in the experimental area may be different from those of the sites where the wind function ($(1 + 0.347 u_2)/(1 + rc/ra)$) was calibrated. This enhances the need to standardize the height of the reference crop in the lysimeter, by reducing the tolerance range (0.08 - 0.15 m), and to calibrate the equation with especial emphasis on the wind function.

The overestimation of ET_0 by the ET_0 -mP equation may be caused by the use of daily data instead of hourly data. Thus, diurnal cycles of radiation, temperature, vapour pressure deficit and wind speed cannot be taken into account by the model.

CONCLUSIONS

Under climatic conditions in Korça (south-eastern Albania), the use of the Penman-Monteith model, with the aerodynamic and crop resistances calculated by the proposed formulas, resulted to be a good method for the estimation of reference crop evapotranspiration. The Penman and modified Penman equations tended to overestimate meas-

ured ET_c , whereas the FAO-24 Penman equation tended to underestimate it.

REFERENCES

- CASTRIGNANO A., BARI V. DI RIZZO V. (1991) - Comparison of different forms of Penman equation. Proceedings of the International Symposium on Lysimetry: Lysimeters for Evapotranspiration and Environmental Measurements. Honolulu, Hawaii, July 23-25, pp. 344-352.
- CUENCA R.H., NICHOLSON M.T. (1982) - Application of the Penman equation wind function equation. Journal of Irrigation and Drainage, ASCE (IR1), 13-23.
- DOORENBOS J., PRUITT W.O. (1977) - Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper No. 24, 2nd edition, FAO Rome, Italy, pp. 156.
- FREVERT D.K., HILL R.W., BRAATEN B.C. (1983) - Estimation of FAO evapotranspiration coefficients. Journal of Irrigation and Drainage, ASCE, 109 (IR2), 256-270.
- JENSEN M.E., BURMAN R.D., ALLEN R.G. (1990) - Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70, pp. 332.
- PENMAN H.L. (1963) - Vegetation and Hydrology. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England, pp. 125.
- PRUITT W.O., DOORENBOS J. (1977) - Empirical calibration, a requisite for evapotranspiration formulas based on daily or longer mean climate data. International Round Table Conference on Evapotranspiration, ICID. Budapest, Hungary, pp. 20.
- SNYDER R.L., PRUITT W.O. (1992) - Evapotranspiration data management in California. Proceedings of the Irrigation and Drainage Sessions at Water Forum '92: Irrigation and Drainage. Baltimore, Maryland, August 2-6, pp. 128-133.
- WRIGHT J.L. (1982) - New evapotranspiration crop coefficients. Journal of Irrigation and Drainage, ASCE, 108 (IR2), 57-74.

Received: July 1997

Accepted: January 1998