FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 8, N° 2, 2010, pp. 163 - 168
DOI: 10.2298/FUACE1002163T

COMPARISON OF SOME EMPIRICAL EQUATIONS FOR ESTIMATING DAILY REFERENCE EVAPOTRANSPIRATION

UDC 556.13:631.43:519.6(045)=111

Slaviša Trajković, Milan Gocić

Faculty of Civil Engineering and Architecture, University of Niš

Abstract. *In this paper, results of certain empirical equations for estimating the daily reference evapotranspiration for the area of southern Italy have been given. Evaluation of the daily values of evapotranspiration of Policoro was conducted by the following equations: FAO-56Penman-Monteith (FAOPM), FAO-24 Penman (FAOPn), FAO-24 Blaney-Criddle (FAOBC), FAO-24 Radiation (FAOR), FAO-24 Pan, Priestley-Tailor (PT) and Hargreaves (HARG). The results strongly support the use of the FAO-24 pan and FAO-56 Penman-Monteith equations for the calculation of daily reference evapotranspiration at the location of Policoro.*

Key words: *Reference evapotranspiration; Penman-Monteith; Class A pan, Policoro*

1. INTRODUCTION

Evapotranspiration (ET) is one of the major processes in the hydrological cycle, and its reliable estimation is essential to water resources planning and management. A common practice for estimating evapotranspiration is to first estimate reference evapotranspiration (ETo) and then apply a corresponding crop coefficient. Reference evapotranspiration is defined in Allen et al. (1998) as "the rate of evapotranspiration from hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance ($70sm^{-1}$) and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water".

There are a number of methods for calculation of reference evapotranspiration. The goal of this paper is comparison of some empirical equations for calculation of daily reference evapotranspiration for the area of southern Italy.

Received May, 2010

2. MATERIALS AND METHODS

For the purpose of this study, daily lysimeter and weather data (minimum and maximum air temperature, minimum and maximum relative humidity, wind speed, sunshine, and pan evaporation) were collected at the experimental field "E. Pantanelli" of Bari University, located in the area of Policoro (Province of Matera), along the Western Ionian Coast, about 3 km from the sea.

The experimental site is characterized with the Mediterranean semiarid climate with 40°17' N, 16°40' E, and altitude 15 m above sea level. The long-term average values of the major weather parameters are presented below : minimum and maximum air temperature are 11.0 and 21.4 °C, respectively; minimum and maximum relative humidity are 52 and 87%, respectively; sunshine is 6 h 36 min; wind speed is 2.3 m s^{-1}; and Class A pan evaporation is 5.2 mm day^{-1} (Caliandro et al. 1990).

The agrometeorological station was equipped with a Class A evaporation pan and a 4 m^2 (2x2 m) wide and 1.3 m deep weighting lysimeter covered by fescue grass. The lysimeter was situated near the center a 60x60 m grass field. The site was maintained under optimal water conditions. The fescue grass was periodically mowed to keep the height between 8 and 15 cm. Irrigations were applied with a frequency from 3 to 5 days.

The various instruments were located about 30 m from the lysimeter. The data for temperature and humidity were gathered by bimetallic thermograph and hair hydrograph, respectively. The wind speed was measured by propeller anemograph 3.5 m above the grass. Bright sunshine duration was gathered by Campbell-Stokes sunshine recorder. The integrity of data was assessed by comparison with a nearby station through "double mass analysis".

The values of solar radiation were tested using the envelope of solar radiation indication the maximum values of solar radiation which can occur on that day. If no measured value of solar radiation does not reach envelope, this suggests malfunction of the instrument and the need to correct the solar radiation values. Allen (1996) described three methods for determining the envelope, and in this paper the simplest method is used, which slightly underestimates the real values of the envelope in the days of highest radiation (3-5 %), but, since, for all practical purposes it does not differ on other days, its accuracy is considered satisfactory.

This method can be expressed in a following way:

$$R_{so} = (0.75 + 2 \cdot 10^{-5} Z) R_a \tag{1}$$

where R_{so} is the solar radiation envelope, Z is the height above seal level of the station, R_a is the extraterrestrial radiation.

The values of solar radiation obtained by Ansgstrom's formula on the basis of the measured values of sunshine hours are presented in the Figure 1 where one may observe that the points lie below the envelope and that a correction must be accomplished. In this paper the factor 1.12 was used for correction, and the modified values of solar radiation were presented in the Figure 2. The obtained value minimally differs from the value of 1.11 presented in Todorovic (1999). Calculation of evapotranspiration was conducted with the new, corrected values of solar radiation.

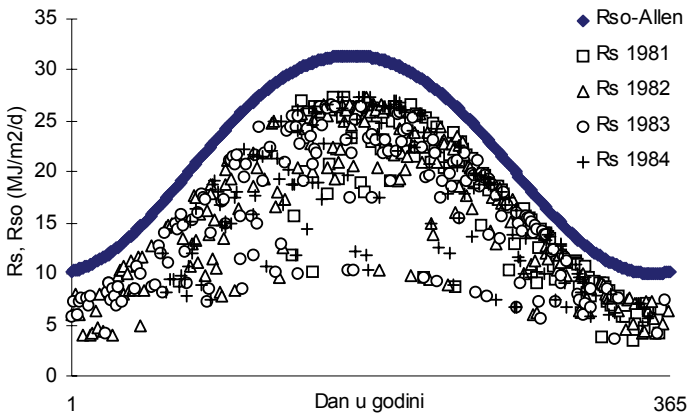

Fig. 1. Solar radiation calculated from sunshine hours; Policoro (Italy, 1981/84)

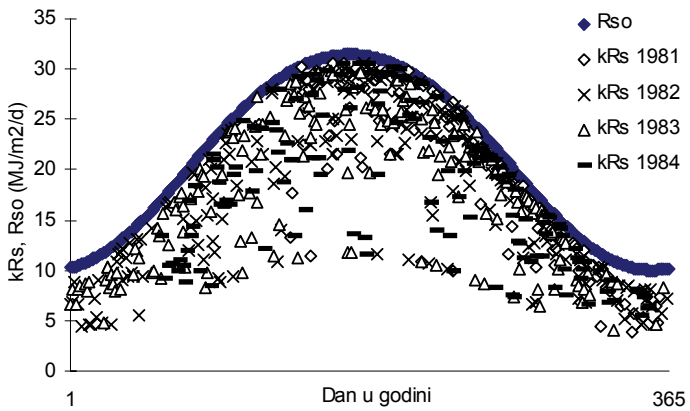

Fig. 2 Corrected solar radiation calculated from sunshine hours; Policoro (Italy, 1981/84)

The raw data set included lysimeter and weather data from May 15, 1981 to December 18, 1984 (Caliandro, personal communication, 2000). However, problems existed on some days, so not all days were selected for analysis. Days with irrigations or rainfall, grass cuttings, and problems associated with irrigations or equipment were omitted from analysis. The final data set used in this study had a total of 497 patterns distributed over all seasons.

Evaluation of daily values of evapotranspiration of Policoro was performed with the methods: FAO-24 Penman-Monteith (FAOPM), FAO-24 Penman (FAOPn), FAO-24 Blaney-Criddle (FAOBC), FAO-24 Radiation (FAOR), FAO-24 Pan, Priestley-Tailor (PT) and Hargreaves (HARG). These methods were listed in Allen et al. (1994) as methods which should be used for estimation of evapotranspiration with the exception of FAO-24 Penman method.

3. RESULTS AND DISSCUSION

The obtained results were compared to the measured lysimeter values and presented in Table 1. Data comparison has been done with the following statistic values: maximal error (MXE), mean absolute error (MAE), mean square error (MSE), correlation coefficient (R) and the relation of evapotranspirations obtained by calculation and measurement (ET_{eq}/ET_{ly}). According to all the statistics, the best results are obtained by FAO-24 Pan and FAO-56 Penman-Monteith, while the weakest statistics are obtained by FAO-24 Penman i Priestley-Taylor.

FAO-24 Pan method has proven in many locations to be insufficiently reliable (Jensen et al. 1990). The values of pan factor used in FAO-24 Pan equation obtained by measurement in Davis and many papers suggest that in other climates they must be used with caution. (Allen and Pruitt 1988, Jensen et al. 1990, Katul et al. 1992, Chiew et al. 1995). However, evaporation pans are used throughout the world because of simplicity of technique, low cost, and ease of data interpretation (Trajkovic i Stojnic 2004, Trajkovic and Stojnic 2008).

Table 1. Comparison of methods for calculation of evapotranspiration

Method (1)	MXE (mm/d) (2)	MAE (mm/d) (3)	MSE $(mm/d)^2$ (4)	R (5)	ET_{eq}/ET_{ly} (%) (6)
FAOPM	3.74	0.524	0.524	0.945	0.975
FAOPan	2.53	0.439	0.373	0.959	0.976
FAOPn	4.15	0.882	1.282	0.942	1.201
FAOR	2.82	0.732	0.851	0.938	1.115
FAOBC	4.15	0.716	0.907	0.929	1.100
HARG	4.56	0.717	0.997	0.887	0.949
PT	3.90	1.002	1.586	0.900	0.780

The first place of FAO-24 Pan equation can be explained by the similar climatic conditions of Policoro and Davis. FAO-56 Penman-Monteith proved to be very reliable, and the obtained results only confirm that FAO and ICID rightfully recommended as a standard for calculation of plant water demand calculation. Some significant departures of FAO Penman-Monteith method which were presented in some previous analyses of lysimetric measuring in the area of the Mediterranean (Caliandro et al. 1990; Rana et al. 1994. and Steduto et al. 1996) can be accounted for by inadequate data on solar radiation, which has been corrected in this paper.

FAO-24 Penman method, which was recommended by Doorenbos and Pruitt (1977) as a standard in calculation of evapotranspiration, overestimates the measured values for over 20% which agrees with the data in the literature which indicate that due to the poorly defined evapotranspiration coefficient c and the inappropriate function of the wind, it is not possibly to appropriately apply FAO Penman method which overestimates the measured values for 10-35 % at all locations (Jensen et al. 1990; Allen et al. 1994).

Poor results of FAO-24 Blaney-Criddle, FAO-24 radiation and Hargreaves method can be justified by the fact that these methods are not intended for the calculation of daily

values of evapotranspiration (Doorenbos and Pruitt 1977; Hargreaves et al. 1985), although there are papers, where they are used for daily periods, with variable success (Jensen et al. 1990; Amatya et al. 1995). Priestley-Taylor method shows extremely high departure from the measured values, which confirms that this method cannot be successfully used for daily calculation of evapotranspiration, which agrees with results presented in Jensen et al. (1990) and Trajkovic and Zivkovic (2009).

4. CONCLUSIONS

The following main conclusions can be drawn:

- The results strongly support the use of the FAO-56 Penman-Monteith equation as the standard method of estimating reference evapotranspiration. The basic obstacle to using this method widely is the numerous required weather parameters. In many areas, the necessary data are lacking, and simpler techniques are required. Evaporation pans are used throughout the world because of simplicity of technique, low cost, and ease of data interpretation.
- The FAO-24 pan equation gives the best daily estimates of ET_0 and it can be used with high reliability for the calculation of daily reference evapotranspiration at the location of Policoro.
- Other equations cannot be recommended for usage at this location.

Acknowledgments. *The authors are particularly grateful to Prof. Angelo Caliandro (University of Bari, Italy) for providing the agrometeorological data of Policoro. The authors would like also to acknowledge and thank Dr. Mladen Todorovic (CIHEAM-Mediterranean Agronomic Institute, Bari, Italy), for his generous support and encouragement.*

REFERENCES

1. Allen, R. G., Assessing Integity of Weather Data for Reference Evapotranspiration Estimation, J. Irrig. and Drain. Engrg., ASCE, 122(2), 97-106, 1996.
2. Allen, R. G., Pereira, L. S., Raes, D., and Smith, M., Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irr. and Drain. Paper 56, FAO, Roma, 1998.
3. Allen, R. G., and Pruitt, W. O., Rational Use of the FAO Blaney-Criddle Formula, Closure, J. Irrig. and Drain. Engrg., ASCE, 114(3), 375-380, 1988.
4. Allen, R. G., Smith, M., Perrier, A., and Pereira, L. S., An Update for the Definition of Reference Evapotranspiration, ICID Bulletin, ICID, 43(2), 1-34, 1994.
5. Amatya, D. M., Skaggs, R. W., and Gregory, J. D., Comparison of Methods for Estimating REF-ET, J. Irrig. and Drain. Engrg., ASCE, 121(6), 427-435, 1995.
6. Caliandro, A., Catalano, M., Rubino, P., and Boari, F., Research on the suitability of some empirical methods for estimating the reference crop evapotranspiration in southern Italy, Proc., 1st Congr. of the Eur. Soc. of Agronomy, Session 2 P 65, 1990.
7. Chiew, F.H.S., Kamaladasa, N.N., Malano, H. M., McMahon, T. A., Penman-Monteith, FAO-24 reference crop evapotranspiration and class-A pan data in Australia, Agricultural Water Management, 28(1), 9-21, 1995.
8. Doorenbos, J., and Pruitt, W. O., Crop Water Requirments, FAO Irrigation and Drainage Paper 24, FAO, Roma, 1977.
9. Hargreaves, L. G., Hargreaves, G. H., and Riley, J. P., Irrigation Water Requirements for Senegal River Basin, J. Irrig. and Drain. Engrg., ASCE, 111(3), 265-275, 1985.

10. 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, 1990.
11. Katul, G. G., Cuenca, R., H., Grebet, P., Wright, J. L., Pruitt, W. O., Analysis of Evaporative Flux Data for Various Climates, J. Irrig. and Drain. Engrg., ASCE, 118(4), 601-618, 1992.
12. Rana, G., Katerji, N., Mastrorilli, M., and El Moujabber, M., Evapotranspiration and Canopy Resistance of Grass in a Mediterranean Region, Theor. and Appl. Climatology, 50, 61-71, 1994.
13. Steduto, P., Caliandro, A., Rubino, P., Ben Mechlia, and Snyder, R.L., Penman-Monteith Reference Evapotranspiration Estimates in the Mediterranean Region, Proc. Int. Conf. on Evapotranspiration and Irrig. Scheduling, 357-364, 1996.
14. Todorovic, M., Single-Layer Evapotranspiration Model with Variable Canopy Resistance, J. of Irrig. and Drain. Engrg., ASCE, 125(5), 235-245, 1999.
15. Trajković, S. i Stojnić, V., Estimacija referentne evapotranspiracije evaporacionim metodama, Zbornik radova Gradjevinskog fakulteta u Nišu 20, 189-196, 2004.
16. Trajkovic, S., and Stojnic, V., Simple daily ET_0 estimation techniques, Facta Universitatis, Series: Architecture and Civil Engineering, 6(2), 187-192, 2008.
17. Trajkovic, S., and Zivkovic, S., Effect of actual vapor pressure on estimating evapotranspiration at Serbia, Facta Universitatis, Series: Architecture and Civil Engineering, 7(2), 171-178, 2009.

POREDJENJE EMPIRIJSKIH JEDNAČINA ZA PRORAČUN DNEVNIH VREDNOSTI REFERENTNE EVAPOTRANSPIRACIJE

Slaviša Trajković, Milan Gocić

U ovom radu predstavljeni su rezultati pojedinih empirijskih jednčina za proračun dnevnih vrednosti referentne evapotranspiracije na području Polocoro, Italija i to: FAO-56 Penman-Monteith (FAOPM), FAO-24 Penman (FAOPn), FAO-24 Blaney-Criddle (FAOBC), FAO-24 Radiation (FAOR), FAO-24 Pan, Priestley-Tailor (PT) and Hargreaves (HARG). Dobijeni rezultati snažno podržavaju korišćenje FAO-24 Pan i FAO-56 Penman-Monteith jednačina za računanje dnevnih vrednosti referentne evapotranspiracije na lokaciji Policoro, Italija.

Ključne reči*: referentna evapotranspiracija; Penman-Monteith; Class A pan, Policoro*