FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 6, N° 2, 2008, pp. 187 - 192
DOI:10.2298/FUACE0802187T

SIMPLE DAILY ET_0 ESTIMATION TECHNIQUES

UDC 626.85 (045)=111

Slaviša Trajković[1], Vladimir Stojnić[2]

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

Abstract. *A reliable estimation of the reference evapotranspiration (ET_0) is of critical importance for irrigation systems' design. The goals of this research are: firstly, comparison of the evaporation methods, and secondly, analysis whether the evaporation of a Class A pan can be used as a substitution for FAO-56 PM method. In the paper, a comparison of the evaporation methods is done on the basis of the daily data from the Griffith station, Australia. It can be concluded that the Christiansen method is in better agreement with the FAO-56 PM method than the FAO-24 pan method. One of the reasons for a better agreement is a larger number of climatic parameters used than in FAO-24 pan method. The research has demonstrated that the evaporation data can be used as a substitution for FAO-56 PM ET_0.*

Key words: *Reference evapotranspiration, Class A pan, FAO-56 Penman-Monteith, FAO-24 Pan, Christiansen*

1. INTRODUCTION

A reliable estimation of the reference evapotranspiration (ET_0) is of critical importance for irrigation systems' design. There are numerous methods of ET_0 estimation. According to the Food and Agricultural Organization (FAO), Penman-Monteith (FAO-56 PM) method, that requires numerous climatic parameters, achieves better agreement with the lysimeter ET_0 measurements compared to all other known methods (Allen et al. 1998).

In some cases, continuous daily measurement of required climatic parameters is not possible for various reasons, so simple techniques such as the Class A pan evaporation are more suitable. These pans are used worldwide for estimation of ET_0 because of the simplicity of the method and the straightforward data interpretation (Grismer et al. 2002, Irmak and Haman 2003, Stanhill 2002).

The goals of this research are: firstly, comparison of evaporation methods, and secondly, analysis whether the evaporation of a Class A pan can be used as a substitution for FAO-56 PM method.

Received June 22, 2008

2. MATERIALS AND METHOD

In this research, the estimation of the reference evapotranspiration for the Griffith area, New South Wales, Australia; latitude 34° 19' S, longitude 146° 04' E, altitude 126.0 m, which is in the center of a large arid area, and where irrigation makes possible an intensive agricultural production. The data for this station are available since 1962, but with long interruptions in measuring of some climatic parameters. Most often, the missing data are those of the wind speed and the actual duration of sunshine. For the purposes of this research, the data from the period 1970/75 are used. This period was chosen because of the small number of days with incomplete measurements. Out of total of 2,191 days, there exist all the required data for 2,108 days, which is more than 96%. The evaporation values range between 0 and 19.6 mm day^{-1}, and the average value is 5.0 mm day^{-1}. Two evaporation methods are being used in this paper for estimation of ET_0: FAO-24 pan method (Doorenbos and Pruitt 1977) and Christiansen method (Christiansen 1968). Their results are compared to FAO-56 PM method.

2.1 FAO-24 pan method

Reference evapotranspiration obtained by the application of this method from the following equation:

$$ET_0 = k_p \cdot Epan \tag{1}$$

where ET_0 = reference evapotranspiration (mm day^{-1}),
k_p = pan coefficient,
E_{pan} = pan evaporation from (mm day^{-1}).

Values of the pan coefficient for the class A pan are presented in Doorenbos and Pruitt (1977).

The values for pan coefficient for the Class A pan are given in Table 1 for different humidity and wind conditions and pan environment.

The Class A pan is circular, 121cm in diameter and 25.4cm deep. It is made of galvanized iron and placed on a wooden frame platform at a height of 15 cm in order to avoid the thermal effect of the soil. The water level in the pan is maintained 5-8 cm below the rim. Estimation of pan factors is performed by a neural network (Trajkovic et al. 2000).

The FAO-24 method makes possible a reliable calculation of reference evapotranspiration provided that the pan is properly installed and regularly maintained (Jacobs et al. 1998). This is the case with the Class A pan in Davis (California, USA) and Kimberley (Idaho, USA) (Jensen et al. 1990). However, in the majority of stations the importance of proper installation and regular maintenance is not fully understood, which in turn causes significant departures from the lysimeter ET_0 values (Hussein and El Daw 1989). The second reason for departures can be that the value of the pan coefficient is very dependent on the local conditions (Chiew et al. 1995) and it is normal that the method gives good results at the locations for which the original values of the pan coefficient have been calibrated (Davis). For implementation of this method, the following parameters are required: evaporation from the Class A pan, mean relative humidity and wind speed at 2 m height.

Table 1. Values of pan coefficient k_p

Wind (km day^{-1}) (1)	Upwind fetch of green crop (m) (2)	Case A: Pan surrounded by short green crop (Doorenbos and Pruitt 1977) Mean Relative Humidity		
		<40% (3)	40-70% (4)	>70% (5)
<175	1	0.55	0.65	0.75
<175	10	0.65	0.75	0.85
<175	100	0.70	0.80	0.85
<175	1000	0.75	0.85	0.85
175-425	1	0.50	0.60	0.65
175-425	10	0.60	0.70	0.75
175-425	100	0.65	0.75	0.80
175-425	1000	0.70	0.80	0.80
425-700	1	0.45	0.50	0.60
425-700	10	0.55	0.60	0.65
425-700	100	0.60	0.65	0.70
425-700	1000	0.65	0.70	0.75
>700	1	0.40	0.45	0.50
>700	10	0.45	0.55	0.60
>700	100	0.50	0.60	0.65
>700	1000	0.55	0.60	0.65

2.2 Christiansen method

Christiansen equation for estimation of ET_0 is presented in (Jensen et al. 1990) in a following way:

$$ET_0 = 0.755 Epan \cdot Ct \cdot Cu \cdot Ch \cdot Cs \tag{2}$$

where ET_0 = is a reference evapotranspiration (mm a day^{-1}),
E_{pan} = measured evaporation from a Class A pan (mm a day^{-1}).
Coefficients are dimensionless.

$$Ct = 0.862 + 0.179 \left(\frac{T}{T_0}\right) - 0.041 \left(\frac{T}{T_0}\right)^2 \tag{3}$$

where T = is mean temperature (^{o}C) and T_0 = 20^{o}C.

$$Cu = 1.189 - 0.240 \left(\frac{U}{U_0}\right) + 0.051 \left(\frac{U}{U_0}\right)^2 \tag{4}$$

where U = is the mean wind speed at 2 m height (km h^{-1}) and U_0 = 6.7 km h^{-1}.

$$Ch = 0.499 + 0.620 \left(\frac{H}{H_0}\right) - 0.119 \left(\frac{H}{H_0}\right)^2 \qquad (5)$$

where H = mean relative humidity and $H_0 = 0.6$.

$$Cs = 0.904 + 0.008 \left(\frac{S}{S_0}\right) + 0.088 \left(\frac{S}{S_0}\right)^2 \qquad (6)$$

where S = percentage of possible sunshine, expressed decimally and $S_0 = 0.8$.

In order to apply this method, the following parameters are necessary: evaporation from the Class A pan, mean temperature, mean relative humidity, wind speed and actual duration of sunshine.

2.3 FAO-56 PM method

In the paper, the results of the evaporation methods are compared to the FAO-56 PM method. This is a standard procedure when no measured lysimeter data are available (Irmak et al. 2002, Martinez-Cob and Tejero-Juste 2004, Trajkovic 2007).

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

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \dfrac{900}{T + 273} \cdot U_2 \cdot (e_a - e_d)}{\Delta + \gamma \cdot (1 + 0.34 \cdot U_2)} \qquad (7)$$

where ET_0 = reference evapotranspiration (mm day^{-1});
Δ = slope of the saturation vapor pressure function (kPa ^{o}C^{-1});
R_n = net radiation (MJ m^{-2} day^{-1});
G = soil heat flux density (MJ m^{-2} day^{-1});
γ = psychometric constant (k Pa ^{o}C^{-1});
T = mean air temperature (^{o}C);
U_2 = average 24-hour wind speed at 2 m height (m s^{-1}); and
VPD = vapor pressure deficit (kPa).

3. Results and Discussion

Results of comparison of evaporation methods with FAO-56 PM method are presented in the table 2. In this table the statistics ETo,eq/ETo,pm are given (ratio of average ET_0 estimates by evaporation equations and FAO-56 PM estimated ET_0), MAE (mean absolute error) and SEE (standard error of estimate). Statistics are given for the whole year and for the peak month (January).

Table 2. Statistics of evaporation methods

	1970/75			January 1970/75		
	$ET_{0,eq}$ / $ET_{0,pm}$ (%/100)	MAE (mm day^{-1})	SEE (mm day^{-1})	$ET_{0,eq}$ / $ET_{0,pm}$ (%/100)	MAE (mm day^{-1})	SEE (mm day^{-1})
FAO-24 pan	1.12	0.95	1.39	1.11	1.39	2.03
Christiansen	1.05	0.86	1.25	1.03	1.27	1.85

The Christiansen method has better agreement with the FAO-56 PM method in respect to the FAO-24 pan method. This method overestimated the ET_0 by 5% and 3% for entire year and the peak month, respectively. Standard error of estimate of this method is 1.25 mm day^{-1} at a yearly level and 1.85 mm day^{-1} in the peak month (January).

The FAO-24 pan method demonstrates significant departure throughout the whole year in respect to the FAO-56 PM. Values of the ET_0 obtained by this method are in average 12% higher than FAO-56 PM ET_0. Standard error of estimate of this method is 1.39 mm day^{-1} at a yearly level and 2.03 mm day^{-1} in the peak month (January).

Two linear regression models ($y = ax$ and $y = ax + b$) were used to establish the relation between evapotranspiration from the Class A pan and FAO-56 PM ET_0. Parameters of the previously mentioned models, displayed in the equations (8) and (9), are obtained on the basis of the data from the period 1970/75.

$$ET_0 = 0.6402 \cdot Epan \tag{8}$$

$$ET_0 = 0.5435 \cdot Epan + 0.7154 \tag{9}$$

Both regression models yield very similar results. The standard error of estimate is 1.07 and 1.14 mm day^{-1}, respectively. Mean absolute error is 0.77 and 0.78 mm day^{-1}, respectively. As using an additional parameter did not significantly improve the quality of estimation, for further usage the equation (8) is recommended. This approach also follows the concept of pan coefficient, which is present in the evaporation methods.

4. CONCLUSIONS

The paper compares the evaporation methods on the basis of the data from the Griffith (NSW, Australia). It can be concluded that the Christiansen method has better agreement with the FAO-56 PM method in respect to the FAO-24 pan method. One of the reasons for better agreement is usage of more climatic parameter than the FAO-24 pan method.

The research proved that the evaporation data could be used as a substitution for the FAO-56 PM ET_0. The obtained results indicate that both analyzed regression models give satisfactory results. But, due to the less number of required parameters, the simpler regression model has advantage. The obtained results have great practical significance, because the missing values of ET_0, in the days when there are no measurements of all climatic parameters, can be obtained on the basis of this regression model.

REFERENCES

1. Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998). "*Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements.*" FAO Irrigation and Drainage Paper 56, Roma.
2. Chiew, F.H.S., Kamaladasa, N.N., Malano, H. M., and McMahon, T. A. (1995). "*Penman-Monteith, FAO-24 reference crop evapotranspiration and class-A pan data in Australia.*" Agricultural Water Management, 28(1), 9-21.
3. Chin, D. A., and Zhao S. (1995). "*Evaluation of Evaporation-Pan Networks.*" J. of Irr. and Drain. Engrg., ASCE, 121(5), 338-344.
4. Christiansen, J. E. (1968). "*Pan evaporation and evapotra-nspiration from climatic data.*" Journal of Irrigation and Drainage Div. ASCE, 94 (2), 243-265.
5. Doorenbos, J., and Pruitt, W. O. (1977). "*Crop Water Requirments.*" FAO Irrigation and Drainage Paper 24, Roma.
6. Grismer, M. E., Orang M., Snyder R., and Matyac R. (2002). "Pan Evaporation to Reference Evapotranspiration Conversion Methods." J. Irrig. and Drain. Engrg., 128(3), 180 -184.
7. Hussein, A.S.A., and El Daw, A. K. (1989). "*Evapotranspiration in Sudan Gezira Irrigation Scheme.*" J. Irrig. and Drain. Engrg., ASCE, 115(6), 1018-1033.
8. Irmak, S. and Haman, D. Z. (2003). "Evaluation of Five Methods for Estimating Class A Pan Evaporation in a Humid Climate." HortTehnology, 13(3), 500-508.
9. Irmak, S., Haman, D. Z., and Jones J. W. (2002) "*Evaluation of Class A Pan Coefficients for Estimating Reference Evapotranspiration in Humid Location.*" *J. Irrig. and Drain. Engrg.*, 128(3), 153-159.
10. Jacobs, A.F.G., Heusinkveld, B. G., and Lucassen, D. C. (1998). "*Temperature variation in a class A evaporation pan.*" Journal of Hydrology, 206(1-2), 75-83.
11. Jensen, M. E., Burman, R. D. and Allen, R. G. (1990). "*Evapotranspiration and irrigation water requirements.*" ASCE manuals and reports on engineering practice No.70, ASCE.
12. Martinez-Cob, A and Tejero-Juste, M. (2004). "A wind-based qualitative calibration of the Hargreaves ETo estimation equation in semiarid regions." Agricul. Water Management, 64, 251-264.
13. Katul, G. G., Cuenca, R., H., Grebet, P., Wright, J. L., and Pruitt, W. O. (1992). "*Analysis of Evaporative Flux Data for Various Climates.*" J. Irrig. and Drain. Engrg., 118(4), 601-618.
14. Stanhill, G. (2002) "Is the Class A evaporation pan still the most practical and accurate meteorological method for determining irrigation water requirements?" Agricultural and Forest Meteorology, 112, 233-236.
15. Trajkovic, S., Stojnic, V., Todorovic, B., and Stankovic, M. (2000) "*Converting from pan evaporation to evapotranspiration using radial basis function networks*" In: Proceedings of 4th International Conference Hydroinformatics, Paper No. 289, 23-27 July 2000, Cedar Rapids, IA, USA.
16. Trajkovic, S. (2007) "*Hargreaves vs. Penman-Monteith under Humid Condition.*" J. Irrig. and Drain. Engrg., 133(1), 47-52.

JEDNOSTAVNE TEHNIKE PRORAČUNA DNEVNIH VREDNOSTI REFERENTNE EVAPOTRANSPIRACIJE

Slaviša Trajković, Vladimir Stojnić

Pouzdani proračun referentne evapotranspiracije (ET_0) od suštinske je važnosti pri projektovanju hidromelioracionih sistema. Ciljevi ovog istraživanja su: prvo, uporedjivanje evaporacionih metoda i drugo, analiziranje da li evaporacija sa suda klase A može da se koristi kao zamena za FAO-56 PM metod. U radu se vrši uporedjivanje evaporacionih metoda na osnovu podataka sa stanice Griffith. Može se zaključiti da Christiansen metoda ima bolje slaganje sa FAO-56 PM metodom u poredjenju sa FAO-24 pan metodom. Jedan od razloga za bolje slaganje je veći broj korišćenih klimatskih parametara od FAO-24 pan metode. Istraživanje je pokazalo da se podaci o evaporaciji mogu koristiti kao zamena za FAO-56 PM ET_0.

Ključne reči: *Referentna evapotranspiracija, Sud klase A, FAO-56 Penman-Monteith, FAO-24 Pan, Christiansen*