COMPARATIVE ANALYSIS OF METHODS FOR THE CALCULATION OF THE PAN COEFFICIENT

Mladen Milanovic[1]
Slavisa Trajkovic[2]
Milan Gocic[3]

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Summary: *Evapotranspiration and evaporation represent important parameters for a successful water resource management and other activities related to water and agricultural production. The pan evapotranspiration method is a method for the calculation of reference evapotranspiration (ET_0), i.e. a method which directly links evaporation and ET_0. This method uses the pan coefficient (K_p) and pan evaporation (E_{pan}). It is widespread because of its simplicity, ease of data interpretation and application and suitability for locations with a limited availability of meteorological data. In this paper, six methods for K_p are compared with the tabular values of K_p proposed by Doorenbos and Pruitt. Six statistical tests were used for the comparison of methods. Based on the results of the statistical tests, the Snyder model has the greatest similarity to the K_p values, while the Abdel-Wahed and Snyder model has the greatest deviation.*

Keywords: *reference evapotranspiration, pan coefficient, Snyder model, Abdel-Wahed and Snyder model.*

1. INTRODUCTION

Processes such as evaporation and evapotranspiration represent the major components of the hydrologic cycle. Therefore, these components have an important role in agricultural production and planning, design of irrigation and drainage systems and hydro-meteorological studies. There are numerous methods for estimating the reference evapotranspiration (ET_0), and one of them is the FAO-24 Pan method. This method does not require numerous climatic parameters, and represents the comparison between evaporation from a pan with water and evapotranspiration from grass, and the pan coefficient (K_p) is used for that purpose [1]. Furthermore, reliable estimation of ET_0 using pan evaporation (E_{pan}) depends on the accurate determination of K_p [2].

[1] Mladen Milanovic, MSc, University of Nis, Faculty of Civil Engineering and Architecture, Nis, Serbia, tel: 064 2415752, e-mail: mmsmladen@gmail.com
[2] Prof. Dr Slavisa Trajkovic, University of Nis, Faculty of Civil Engineering and Architecture, Nis, Serbia, tel: 063 1058673, e-mail: slavisa@gaf.ni.ac.rs
[3] Dr Milan Gocic, University of Nis, Faculty of Civil Engineering and Architecture, Nis, Serbia, tel: 064 1479423, e-mail: mgocic@yahoo.com

Doorenbos and Pruitt (1977) proposed the values for K_p for various ground cover types surrounding the pan [1]. According to Trajkovic et al. (2000), the main problem in defining K_p is the lack of a clearly defined scope of input parameters [3].
There are several models which can be used for the determination of K_p, and they are usually based on wind speed, relative humidity and fetch length conditions. Many authors have used these models to investigate the behavior of ET_0 in deferent climates [2,4-6]. In addition, some authors have used various models to define new models for K_p.
Trajkovic et al. (2000) used an artificial neural network, i.e. the radial basis function (RBF) network, to estimate the K_p [3]. They compared the values of the new K_p with the tabular values given by Doorenbos and Pruitt (1977), and also analyzed other regression equations. Their results showed that the new model, based on the RBF network, best fits with the tabular values of all the observed models. Ditthakit and Chinnarasri (2012) developed new K_p equations for Class A pan and Colorado sunken pan under green and dry fetch conditions using the M5 model tree based on the soft computing technique [7]. They concluded that the M5 model tree is more accurate in estimating K_p values, and that the equations for K_p can be reliably used.
This paper presents a comparative analysis of six methods for the calculation of the pan coefficient. The values of K_p given by Doorenbos and Pruitt (1977) were used as reference values in this study.

2. MATERIALS AND METHODS

Doorenbos and Pruitt (1977) presented one of the methods for the indirect estimation of reference evapotranspiration, which is based on E_{pan} and K_p [1]:

$$ET_o = K_p \cdot E_{pan} \tag{1}$$

Doorenbos and Pruitt (1977) gave the values of K_p for different weather conditions, for different areas where the pan can be placed and for the different class of pan, Table 1. [1].

Table 1. Values of K_p for Class A: Pan placed in short green cropped area [1]

U_2 [km/day]	F [m]	RH [%] < 40 (40^*)	RH [%] 40 – 70 (55^*)	RH [%] > 70 (70^*)
< 175 (175^*)	1	0.55	0.65	0.75
	10	0.65	0.75	0.85
	100	0.70	0.80	0.85
	1000	0.75	0.85	0.85
175 – 425 (300^*)	1	0.50	0.60	0.65
	10	0.60	0.70	0.75
	100	0.65	0.75	0.80
	1000	0.70	0.80	0.80
425 – 700 (562^*)	1	0.45	0.50	0.60
	10	0.55	0.60	0.65
	100	0.60	0.65	0.70
	1000	0.65	0.70	0.75

> 700 (700*)	1	0.40	0.45	0.50
	10	0.45	0.55	0.60
	100	0.50	0.60	0.65
	1000	0.55	0.60	0.65

* Representative mean value

U_2 represents the wind speed at the height of 2 m, F is the windward side distance of green crop and RH is the mean daily relative humidity.
Many authors have used the values from Table 1 to develop and calibrate the equations for the calculation of the pan coefficient. The following models have been used for the determination of K_p in this paper:

Snyder model [8]:

$$K_p = 0.482 - 3.76 \cdot 10^{-4} \cdot U_2 + 0.024 \cdot \ln(F) + 4.5 \cdot 10^{-3} \cdot RH \quad (2)$$

Modified Snyder model [9]:

$$K_p = 0.5321 - 3 \cdot 10^{-4} \cdot U_2 + 0.0249 \cdot \ln(F) + 2.5 \cdot 10^{-3} \cdot RH \quad (3)$$

Cuenca model [10]:

$$K_p = 0.475 - 2.4 \cdot 10^{-4} \cdot U_2 + 5.16 \cdot 10^{-3} \cdot RH + 1.18 \cdot 10^{-3} \cdot F - \\ -1.6 \cdot 10^{-5} \cdot RH^2 - 1.01 \cdot 10^{-6} \cdot F^2 - 8 \cdot 10^{-9} \cdot RH^2 \cdot U_2 - 0.1 \cdot 10^{-7} \cdot RH^2 \cdot F \quad (4)$$

Orang model [11]:

$$K_p = 0.51206 - 3.21 \cdot 10^{-4} \cdot U_2 + 0.031886 \cdot \ln(F) + \\ +2.889 \cdot 10^{-3} \cdot RH - 1.07 \cdot 10^{-4} \cdot RH \cdot \ln(F) \quad (5)$$

Allen and Pruitt model [12]:

$$K_p = 0.108 - 3.31 \cdot 10^{-4} \cdot U_2 + 0.0422 \cdot \ln(F) + 0.1434 \cdot \ln(RH) - \\ -6.31 \cdot 10^{-4} (\ln(F))^2 \cdot \ln(RH) \quad (6)$$

Abdel-Wahed and Snyder model [13]:

$$K_p = 0.62407 - 0.0266 \cdot \ln(F) - 2.8 \cdot 10^{-4} \cdot U_2 + 2.26 \cdot 10^{-3} \cdot RH \quad (7)$$

For a comparative analysis of the proposed models, six statistical tests were used (RMSE – Root Mean Square Error, MAE – Mean Absolute Error, MBE – Mean Bias Error, MARE

– Mean Absolute Relative Error, MXRE – Maximum Absolute Relative Error, NE > 4 % - Number of Samples with an Error Greater than 4 %):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(m_i - c_i)^2}{n}} \quad (8)$$

$$MAE = \frac{\sum_{i=1}^{n}|m_i - c_i|}{n} \quad (9)$$

$$MBE = \frac{\sum_{i=1}^{n}(m_i - c_i)}{n} \quad (10)$$

$$MARE = \frac{1}{n} \cdot \sum_{i=1}^{n}\left|\frac{c_i - m_i}{m_i}\right| \cdot 100 \quad (11)$$

$$MXRE = \max\left|\frac{c_i - m_i}{m_i}\right| \cdot 100 \quad (12)$$

$$NE = \left|\frac{c_i - m_i}{m_i}\right| \cdot 100 \quad (13)$$

where m_i represents the i-th observed value and c_i is the i-th estimated value.

3. RESULTS AND DISCUSSION

The results of the comparative analysis of the models for the determination of the pan coefficient are given in Table 2.

Table 2. Results of comparative analysis of Kp

Model	RMSE	MAE	MBE	MARE [%]	MXRE [%]	NE > 4 %
Snyder	**0.0262**	**0.0212**	**0.0009**	**3.29**	**9.84**	**16**
Modified Snyder	0.0461	0.0372	0.0247	5.43	16.24	31
Cuenca	0.0471	0.0385	-0.0066	6.43	20.00	28
Orang	0.0469	0.0379	0.0286	5.58	15.97	31
Allen and Pruitt	0.0369	0.0299	0.0156	4.46	12.67	24
Abdel-Wahed and Snyder	0.1794	0.1545	0.1151	23.10	42.56	46

The RMSE test, with the value of 0.0262, shows that the Snyder model has the greatest similarity to the tabular values given by Doorenbos and Pruitt [1]. According to this test, the greatest deviation is present in the Abdel-Wahed and Snyder model. The MAE and MBE, just like RMSE test, show that the Snyder model best fits Table 1, with values 0.0212 and 0.0009, respectively. The MARE and MXRE with values of 3.29 % and 9.84 %, respectively, single out the Snyder model as a model which best fits Table 1. Snyder has the following value according to the NE > 4 % test: 16, while the value is 46 in the case of Abdel-Wahed and Snyder. Modified Snyder, Orang and Allen and Pruitt models have mutually similar results. The greatest values of all models are present in the Snyder model, while the Abdel-Wahed and Snyder model has the lowest values of the pan coefficient.

4. CONCLUSION

This paper presents a comparative analysis of six methods for the calculation of the pan coefficient with values given by Doorenbos and Pruitt. The Snyder method stands out as a method with the greatest similarity to the values given by Doorenbos and Pruitt. According to statistical tests, the greatest differences are shown in the Abdel-Wahed and Snyder method, while the Modified Snyder, Cuenca and Orang methods have similar results. The presented results will be used as the starting point for developing a new method for the calculation of the pan coefficient using the artificial neural network.

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UPOREDNA ANALIZA METODA ZA PRORAČUN PAN KOEFICIJENTA

Rezime*: Evapotranspiracija i evaporacija predstavljaju bitne parametre za uspešno upravljanje vodnim resursima i drugim aktivnostima vezanim za vodu i poljoprivrednu proizvodnju. Pan evapotranspiracioni metod je metod za proračun referentne evapotranspiracije (ET_0), tj. metod koji direktno povezuje evaporaciju i ET_0. Ovaj metod koristi pan koeficijent (K_p) i pan evaporaciju (E_{pan}). Ovaj metod je široko rasprostranjen zbog svoje jednostavnosti, lakoće interpretacije podataka i njihove primene i pogodnosti za lokacije sa ograničenom dostupnošću meteoroloških podataka.*
U ovom radu šest metoda za K_p su upoređene sa tabličnim vrednostima K_p predloženih od strane Doorenbos i Pruitt-a. Za poređenje metoda korišćena su šest statistička testa. Na osnovu rezultata statističkih testova, Snyderov model ima najveću sličnost sa vrednostima K_p, dok Abdel-Wahed i Snyder model ima najveća odstupanja.

Ključne reči*: referentna evapotranspiracija, pan koeficijent, Snyder model, Abdel-Wahed i Snyder model.*