FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 14, N° 2, 2016, pp. 247- 255
DOI: 10.2298/FUACE1602247G

EFFECT OF SOLAR RADIATION MODELS ON EVAPOTRANSPIRATION ESTIMATION

UDC 551.573

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Abstract. *The crop evapotranspiration has the great effect on defining and planning of water resources. The estimation of evapotranspiration depends on various climatic parameters. In this study, the analysis of the effect of solar radiation (Rs) on daily reference evapotranspiration (ET_0) was conducted. The FAO-56 Penman-Monteith method (FAO-56 PM) was used for the estimation of ET_0 in Serbia at eight meteorological stations for the period 1980-2010. The Rs was estimated using the ten one-parameter global solar radiation models. The ET_0 with Almorox and Hontoria model 1 had the smallest deviation related to the ET_0 with Angstrőm-Prescott (AP) model, and ET_0 with Toğrul et al. model 2 and Rietveld model had the greatest deviation from ET_0 with AP model.*

Key words: *reference evapotranspiration, solar radiation models, FAO-56 Penman-Monteith method, Serbia.*

1. INTRODUCTION

The water balance represents the relationship between supply and consumption of water. In order to define the water needs, it is necessary to know the water balance. Evapotranspiration (ET) and precipitation represent the major elements of water balance. According to Dalezios et al. (2002), the ET is important component in irrigation and agricultural planning and water resources management.

Food and Agriculture Organization of the United Nations (FAO) and International Commission for Irrigation and Drainage (ICID) proposed the FAO-56 Penman-Monteith method (FAO-56 PM) as the standard method for calculation of reference evapotranspiration (ET_0) (Allen et al., 1994a, 1994b; Allen et al., 1998).

Solar radiation (Rs) is one of important parameters for calculation of the ET_0 using FAO-56 PM method (Trajkovic and Kolakovic, 2009). The values of Rs can be measured or can be determined using empirical methods. There are a plenty of research studies in

Received October 15, 2015 / Accepted March 25, 2016
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which the Rs has been analyzed and applied in ET_0 estimation (Yao et al., 2014; Ouali and Alkama, 2014; Teke and Basak Yildirim, 2014).

Analysis of eleven Rs models and their impact on daily ET_0 were investigated in Tabari et al. (2014). The ET_0 was tested in two climate types (arid and semi-arid) at two stations in Iran. Also, they validated and calibrated some of Rs models according to the measured data. Allen model and Dogniaux-Lemoine model gave the best values of Rs in semi-arid and arid climates, respectively. Samani and El-Sebaii models had the greatest improvements after calibration in arid climate, while the Ertekin-Yaldiz and Glower-McCulloch models were the best ones after calibration in semi-arid climate. Gocic and Trajkovic (2014) analyzed the trends of ET_0 on monthly, seasonal and annual time scales in Serbia. FAO-56 PM and adjusted Hargreaves were used for estimation of ET_0. Approximately 70 % of observed stations were characterized with significant increasing trends for both ET_0 methods.

In this study, the analysis of effect of ten one-parameter global solar radiation models on calculation of reference evapotranspiration was presented.

2. Methods and Materials

The study area is Serbia, which territory is located in Southeastern Europe, and its climate is moderate continental. The average temperature is 10.9 °C in Serbia. January is the coldest month, while the warmest month is July. The average annual precipitation is 896 mm. Annual sunshine hours ranged between 1500 and 2200 hours. Months with the maximum average sunlight are May, June, July, August and September.

The territory of Serbia is observed through the eight meteorological stations. Table 1 shows the geographical characteristics of observed stations. Data required for calculation of solar radiation and reference evapotranspiration were taken from meteorological yearbooks issued by the Republic Hydrometeorological Service of Serbia. The data were taken for the period 1980-2010.

Table 1 Geographical characteristics of the observed meteorological stations

Station name	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
Belgrade	20°28'	44°48'	132
Kraljevo	20°42'	43°43'	215
Loznica	19°14'	44°33'	121
Negotin	22°33'	44°14'	42
Nis	21°54'	43°20'	204
Novi Sad	19°51'	45°20'	86
Palic	19°46'	46°06'	102
Vranje	21°55'	42°33'	432

2.1. Global solar radiation models

The following ten average daily one-parameter models are used for estimation of Rs:
Angstrőm-Prescott model (Angstrőm, 1924; Prescott, 1940)

$$\frac{H}{H_0} = 0.25 + 0.5\frac{S}{S_0} \tag{1}$$

Bahel et al. model 1 (Bahel et al., 1986)

$$\frac{H}{H_0} = 0.175 + 0.552\left(\frac{S}{S_0}\right) \tag{2}$$

Almorox and Hontoria model 1 (Almorox and Hontoria, 2004)

$$\frac{H}{H_0} = 0.2170 + 0.5453\left(\frac{S}{S_0}\right) \tag{3}$$

Jin et al. model 1 (Jin et al., 2005)

$$\frac{H}{H_0} = 0.1332 + 0.6471\left(\frac{S}{S_0}\right) \tag{4}$$

Srivastava et al. model (Srivastava et al., 1993)

$$\frac{H}{H_0} = 0.2006 + 0.5313\left(\frac{S}{S_0}\right) \tag{5}$$

Page model (Page 2003)

$$\frac{H}{H_0} = 0.23 + 0.48\left(\frac{S}{S_0}\right) \tag{6}$$

Rietveld model (Rietveld, 1978)

$$\frac{H}{H_0} = 0.1 + 1.02\left(\frac{S}{S_0}\right) - 0.44\left(\frac{S}{S_0}\right)^2 \tag{7}$$

Bahel et al. model 2 (Bahel et al., 1987)

$$\frac{H}{H_0} = 0.16 + 0.87\left(\frac{S}{S_0}\right) - 0.61\left(\frac{S}{S_0}\right)^2 + 0.34\left(\frac{S}{S_0}\right)^3 \tag{8}$$

Toğrul et al. model 2 (Toğrul et al., 2000)

$$\frac{H}{H_0} = -0.0344\,ln\left(\frac{S}{S_0}\right) + 0.1982 + \left(-0.0201\,ln\left(\frac{S}{S_0}\right) + 0.4562\right)\left(\frac{S}{S_0}\right) \tag{9}$$

Almorox and Hontoria model 5 (Almorox and Hontoria, 2004)

$$\frac{H}{H_0} = -0.0271 + 0.3096e^{\left(\frac{S}{S_0}\right)} \tag{10}$$

where H is average daily global solar radiation (MJ $m^{-2}day^{-1}$), H_0 is average daily extraterrestrial radiation (MJ $m^{-2}day^{-1}$), S is actual sunshine duration (h), S_0 is maximum possible sunshine duration (h).

H_0 can be estimated as (Angstrőm, 1924; Prescott, 1940):

$$H_0 = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \quad (11)$$

where G_{sc} is solar constant (0.082 MJ $m^{-2}min^{-1}$), d_r is inverse relative distance Earth-Sun, ω_s is sunset hour angle, φ is latitude (rad) and δ is solar declination. These elements can be calculated using the following equations:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi J}{365}\right) \quad (12)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (13)$$

where J is the day of year and

$$\omega_s = \arccos[-\tan(\varphi) \tan(\delta)] \quad (14)$$

S_0 can be estimated as

$$S_0 = \frac{24}{\pi} \omega_s \quad (15)$$

2.2. Reference evapotranspiration model

The daily ET_0 values were estimated using FAO–56 PM method (Allen et al., 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 VPD}{\Delta + \gamma(1 + 0.34 U_2)} \quad (16)$$

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

2.3. Methods for comparison

Statistical test methods, mean bias error (MBE), root mean square error (RMSE) and Nash-Sutcliffe equation (NSE), are used to statistically evaluate the performances of ET_0 calculated using different Rs equations:

$$MBE = \frac{1}{n} \sum_{i=1}^{n} (c_i - m_i) \quad (17)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (c_i - m_i)^2} \quad (18)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} (m_i - c_i)^2}{\sum_{i=1}^{n} (m_i - m_a)^2} \quad (19)$$

where c_i is the i-th calculated value, m_i is the i-th measured value and m_a is the average of measured value.

For RMSE the values are always positive, and ideal value is zero. Also RMSE provides information on the short-term performances. MBE provides information on the long-term performances of observed models. As for RMSE and for MBE the ideal value is zero. This statistical test indicates whether a given model has a tendency to overestimate (positive MBE) or underestimate (negative MBE) the base model. For the third statistical test (NSE) the ideal value for observed model is one.

3. Results and Discussion

The results of ET_0 are given as average daily values for eight meteorological stations during the period 1980-2010. Fig. 1 shows the values of ET_0, which are computed using the different Rs models. As the result of these ET_0 calculations, there are ten curves for each station for different Rs models i.e. Angstrőm-Prescott model (ET0 A-P), Bahel et al. model 1 (ET0 B1), Almorox and Hontoria model 1 (ET0 AH1), Jin et al. model 1 (ET0 J1), Srivastava et al. model (ET0 S), Page model (ET0 P), Rietveld model (ET0 R), Bahel et al. model 2 (ET0 B2), Toğrul et al. model 2 (ET0 T2) and Almorox and Hontoria model 5 (ET0 AH5).

The lowest values of ET_0 showed the estimated ET_0 with Rietveld model for Rs for all observed stations. ET_0 with AH5 model for Rs showed the greatest values at all observed stations. Vranje and Negotin stations had the greatest values of ET_0, while Loznica and Kraljevo stations had the lowest values of ET_0. The values of ET_0 obtained from different Rs models were near the same for January, February, March, October, November and December. The values of ET_0 were different for the growing season (April to September), i.e. the differences between ET_0 obtained from different Rs were larger with the increasing values of ET_0 during the year.

ET_0 from Angstrőm-Prescott model for Rs (ET0 A-P) for FAO-56 Penman-Monteith method represents the most reliable way for estimating the values of ET_0 (Allen et al., 1998; Trajkovic and Kolakovic, 2009). For that reason, the ET0 A-P was used as the reference model for comparison with other models of ET_0. Table 2 shows the results of comparison of ET0 A-P with ET_0 estimated with other models for Rs, using the three statistical tests for eight observed stations.

The results of MBE test showed that the best matching with ET0 A-P had the estimation of ET_0 with AH1 model of Rs at six observed stations. Only ET0 J1 and ET0 B2 had the best matching with ET0 A-P with values of 0.015 and 0.002 at Loznica and Kraljevo stations, respectively. According to MBE test, the worst matching had ET0 T2 method. The analysis of RMSE test for ET_0 showed that the Rs estimated with AH1 model had the best matching with the Rs estimated with A-P model at all stations. The ET_0 obtained by Rietveld model and Toğrul et al. model 2 had the worst results of RMSE tests compared to other models for Rs which are used for estimation of ET_0. ET0 AH1, ET0 S and ET0 B1 models had the best results according to NSE test, and ET0 R, ET0 T2 and ET0 AH5 models had the worst. Especially, ET0 AH1 model had the great matching with ET0 A-P model.

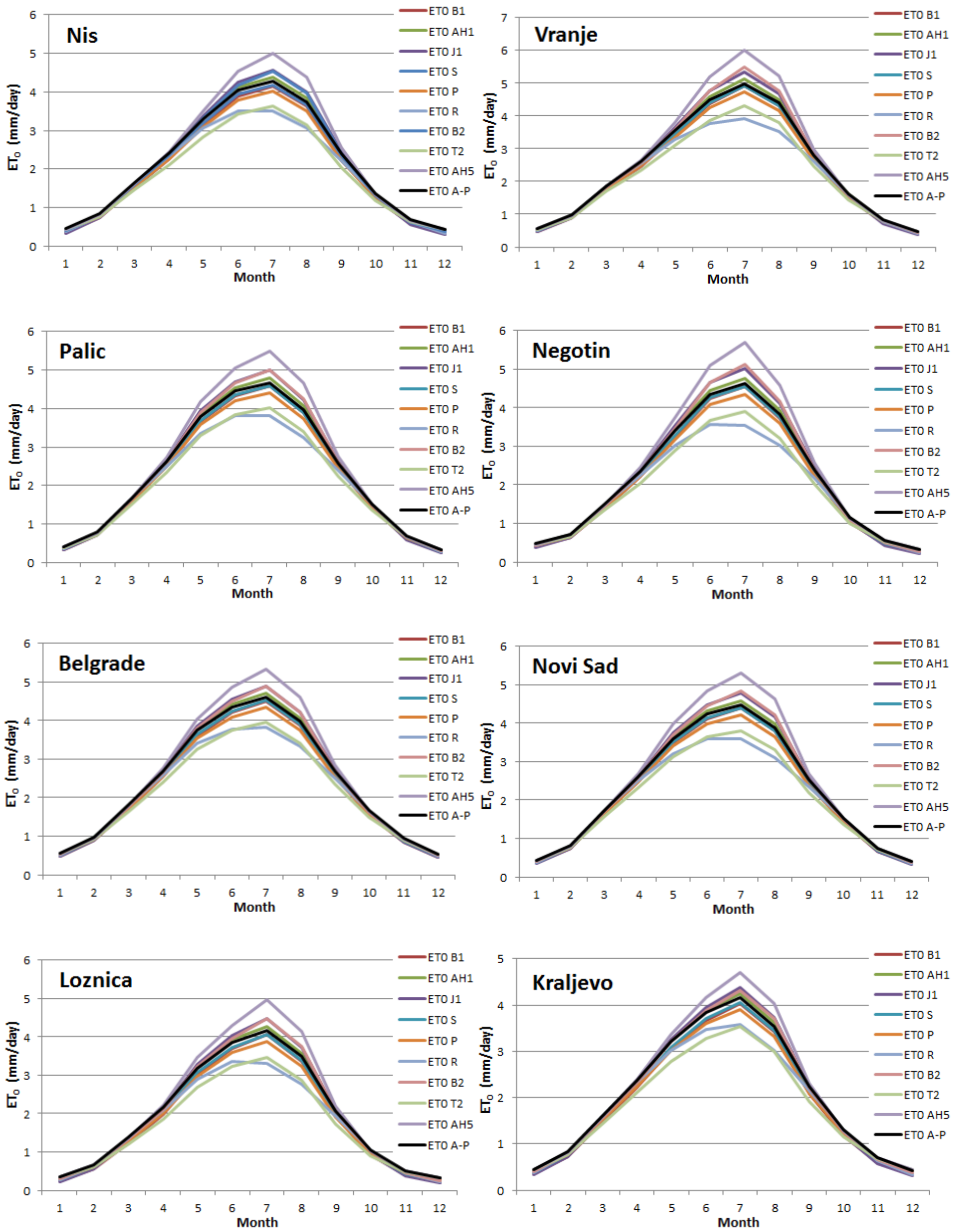

Fig. 1 The average daily values of ET_0 during the period 1980-2010

Table 2 Comparison of ET_0 from different Rs models with ET_0 from Angstrőm-Prescott model

Station name	Statistical indicator	ET0 B1	ET0 AH1	ET0 J1	ET0 S	ET0 P	ET0 R	ET0 B2	ET0 T2	ET0 AH5
Nis	MBE	-0.124	0.016	0.016	-0.091	-0.141	-0.229	0.027	-0.292	0.181
	RMSE	0.127	0.052	0.145	0.094	0.164	0.348	0.111	0.377	0.324
	NSE	0.991	0.998	0.999	0.995	0.986	0.936	0.993	0.925	0.945
Vranje	MBE	-.0.103	0.024	0.044	-0.077	-0.132	-0.283	0.078	-0.286	0.241
	RMSE	0.106	0.061	0.172	0.079	0.155	0.456	0.200	0.373	0.434
	NSE	0.995	0.998	0.988	0.997	0.990	0.914	0.983	0.942	0.922
Palic	MBE	-0.091	0.027	0.057	-0.069	-0.126	-0.262	0.065	-0.281	0.228
	RMSE	0.093	0.057	0.156	0.071	0.151	0.401	0.147	0.366	0.377
	NSE	0.996	0.999	0.990	0.998	0.990	0.933	0.991	0.944	0.941
Negotin	MBE	-0.108	0.028	0.050	-0.081	-0.141	-0.302	0.077	-0.305	0.258
	RMSE	0.110	0.065	0.183	0.083	0.167	0.472	0.195	0.402	0.448
	NSE	0.995	0.998	0.985	0.997	0.988	0.903	0.983	0.930	0.913
Belgrade	MBE	-0.107	0.022	0.037	-0.079	-0.133	-0.231	0.043	-0.286	0.194
	RMSE	0.109	0.052	0.142	0.082	0.158	0.354	0.119	0.369	0.331
	NSE	0.994	0.999	0.990	0.997	0.988	0.940	0.993	0.935	0.947
Novi Sad	MBE	-0.094	0.026	0.051	-0.071	-0.126	-0.264	0.068	-0.280	0.228
	RMSE	0.096	0.057	0.157	0.073	0.152	0.409	0.159	0.366	0.386
	NSE	0.995	0.998	0.988	0.997	0.989	0.921	0.988	0.937	0.930
Loznica	MBE	-0.126	0.016	0.015	-0.092	-0.142	-0.241	0.034	-0.294	0.191
	RMSE	0.128	0.055	0.155	0.094	0.167	0.367	0.131	0.383	0.342
	NSE	0.991	0.998	0.987	0.995	0.985	0.928	0.991	0.921	0.937
Kraljevo	MBE	-0.129	0.007	-0.013	-0.094	-0.131	-0.173	0.002	-0.261	0.125
	RMSE	0.133	0.043	0.122	0.097	0.155	0.260	0.078	0.342	0.237
	NSE	0.990	0.999	0.991	0.994	0.986	0.960	0.996	0.932	0.967

4. CONCLUSION

The effect of different Rs models on estimation of ET_0 was applied in Serbia during the period 1980-2010. The estimation of ET_0 is conducted using the FAO–56 Penman-Monteith method. For comparison the results of ET_0, three tests were applied (MBE, RMSE and NSE).

The analysis of ET_0 showed that the maximum values of ET_0 occurred in June and July, while the minimum values were in December at all stations. ET_0 with AH5 method for Rs had the greatest values at all eight stations, especially for Vranje station with average daily value of 6 mm/day for July. ET_0 with Rietveld model for Rs had the lowest values of ET_0 at all stations. Using this method, the maximum ET_0 had the value of 3.93 mm/day, also for Vranje station.

The MBE, RMSE and NSE tests showed ET_0 that used Rs estimated from the Toğrul et al. model 2 and Rietveld model had the greatest deviation from ET_0 estimated from Angstrőm-Prescott model. ET_0 with Almorox and Hontoria model 1, with Bahel et al. model 2 and with Srivastava et al. model had the smallest deviation related to the ET_0 with Angstrőm-Prescott model. Especially, the ET_0 with Almorox and Hontoria model 1 showed the great similarity with ET_0 with Angstrőm-Prescott model.

Further research will be oriented to estimate of solar radiation models which gave the worst results in this study. Also original and calibrated formulas for solar radiation will be tested through reference evapotranspiration in different types of climate.

Acknowledgement: *The research presented in the paper is funded by the Ministry of Education, Science and Technological Development, Republic of Serbia (Grant No. TR 37003).*

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EFEKTI UTICAJA MODELA SOLARNE RADIJACIJE NA PRORAČUN REFERENTNE EVAPOTRANSPIRACIJE

Evapotranspiracija useva ima veliki uticaj na definisanje i planiranje vodnih resursa. Proračun evapotranspiracije zavisi od različitih klimatskih parametara. U ovom radu je sprovedena analiza uticaja solarne radijacije (Rs) na dnevne vrednosti referentne evapotranspiracije (ET_0). Za proračun ET_0 je korišćen FAO-56 Penman-Monteith metod (FAO-56 PM) u Srbiji za vremenski period 1980-2010. Rs je određen upotrebom deset jednoparametarskih globalnih solarnih radijacionih modela. ET_0 dobijena korišćenjem Almorox and Hontoria model 1 za proračun Rs daje najmanja odstupanja u odnosu na ET_0 sa Angstrőm-Prescott (AP) modelom a ET_0 izračunanta uz pomoć Toğrul et al. model 2 i Rietveld modela daje najveća odstupanja od ET_0 sa AP modelom.

Ključne reči*: referentna evapotranspiracija, modeli solarne radijacije, FAO-56 Penman-Monteith metod, Srbija.*