EFFECT OF SOLAR RADIATION MODELS ON EVAPOTRANSPIRATION ESTIMATION

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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 Angström-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

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which the Rs has been analyzed and applied in ET₀ estimation (Yao et al., 2014; Ouali and Alkama, 2014; Teke and Basak Yildirim, 2014).

Analysis of eleven Rs models and their impact on daily ET₀ were investigated in Tabari et al. (2014). The ET₀ 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 ET₀ on monthly, seasonal and annual time scales in Serbia. FAO-56 PM and adjusted Hargreaves were used for estimation of ET₀. Approximately 70 % of observed stations were characterized with significant increasing trends for both ET₀ 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>
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<th>Station name</th>
<th>Longitude (E)</th>
<th>Latitude (N)</th>
<th>Elevation (m a.s.l.)</th>
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<td>43°43'</td>
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<td>121</td>
</tr>
<tr>
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<td>44°14'</td>
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</tr>
<tr>
<td>Nis</td>
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<td>Palic</td>
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</tr>
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<td>21°55'</td>
<td>42°33'</td>
<td>432</td>
</tr>
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</table>
2.1. Global solar radiation models

The following ten average daily one-parameter models are used for estimation of Rs:

- **Angström-Prescott model** (Angström, 1924; Prescott, 1940)
  \[
  \frac{H}{H_0} = 0.25 + 0.5 \left( \frac{S}{S_0} \right)
  \] (1)

- **Bahel et al. model 1** (Bahel et al., 1986)
  \[
  \frac{H}{H_0} = 0.175 + 0.552 \left( \frac{S}{S_0} \right)
  \] (2)

- **Almorox and Hontoria model 1** (Almorox and Hontoria, 2004)
  \[
  \frac{H}{H_0} = 0.2170 + 0.5453 \left( \frac{S}{S_0} \right)
  \] (3)

- **Jin et al. model 1** (Jin et al., 2005)
  \[
  \frac{H}{H_0} = 0.1332 + 0.6471 \left( \frac{S}{S_0} \right)
  \] (4)

- **Srivastava et al. model** (Srivastava et al., 1993)
  \[
  \frac{H}{H_0} = 0.2006 + 0.5313 \left( \frac{S}{S_0} \right)
  \] (5)

- **Page model** (Page 2003)
  \[
  \frac{H}{H_0} = 0.23 + 0.48 \left( \frac{S}{S_0} \right)
  \] (6)

- **Rietveld model** (Rietveld, 1978)
  \[
  \frac{H}{H_0} = 0.1 + 1.02 \left( \frac{S}{S_0} \right) - 0.44 \left( \frac{S}{S_0} \right)^2
  \] (7)

- **Bahel et al. model 2** (Bahel et al., 1987)
  \[
  \frac{H}{H_0} = 0.16 + 0.87 \left( \frac{S}{S_0} \right) - 0.61 \left( \frac{S}{S_0} \right)^2 + 0.34 \left( \frac{S}{S_0} \right)^3
  \] (8)

- **Toğrul et al. model 2** (Toğrul et al., 2000)
  \[
  \frac{H}{H_0} = -0.0344 \ln \left( \frac{S}{S_0} \right) + 0.1982 + \left( -0.0201 \ln \left( \frac{S}{S_0} \right) + 0.4562 \right) \left( \frac{S}{S_0} \right)
  \] (9)

- **Almorox and Hontoria model 5** (Almorox and Hontoria, 2004)
  \[
  \frac{H}{H_0} = -0.0271 + 0.3096e^{\left( \frac{S}{S_0} \right)}
  \] (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).
H₀ can be estimated as (Angström, 1924; Prescott, 1940):

\[
H₀ = \frac{24(60)}{π} Gₛ dₛ \left[ ωₙ \sin(φ) \sin(δ) + \cos(φ) \cos(δ) \sin(ωₙ) \right]
\]  

(11)

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

\[
dₛ = 1 + 0.033 \cos \left( \frac{2πJ}{365} \right)
\]  

(12)

\[
δ = 0.409 \sin \left( \frac{2π}{365} J - 1.39 \right)
\]  

(13)

where \(J\) is the day of year and

\[
ωₙ = \arccos \left[ -\tan(φ) \tan(δ) \right]
\]  

(14)

\(S₀\) can be estimated as

\[
S₀ = \frac{24}{π} ωₙ
\]  

(15)

### 2.2. Reference evapotranspiration model

The daily \(ET₀\) values were estimated using FAO–56 PM method (Allen et al., 1998):

\[
ET₀ = \frac{0.408Δ(Rₙ - G) + γ T + 273 U₂ VPD}{Δ + γ(1 + 0.34U₂)}
\]  

(16)

where \(ET₀\) – reference evapotranspiration (mm day\(^{-1}\)); \(Δ\) - slope of the saturation vapour pressure function (kPa °C\(^{-1}\)); \(Rₙ\) – 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); \(U₂\) – 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 \(ET₀\) calculated using different \(Rs\) equations:

\[
MBE = \frac{1}{n} \sum_{i=1}^{n} (cᵢ - mᵢ)
\]  

(17)

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (cᵢ - mᵢ)^2}
\]  

(18)

\[
NSE = 1 - \frac{\sum_{i=1}^{n} (mᵢ - cᵢ)^2}{\sum_{i=1}^{n} (mᵢ - mₐ)^2}
\]  

(19)

where \(cᵢ\) is the i-th calculated value, \(mᵢ\) is the i-th measured value and \(mₐ\) 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 ET₀ are given as average daily values for eight meteorological stations during the period 1980-2010. Fig. 1 shows the values of ET₀, which are computed using the different Rs models. As the result of these ET₀ calculations, there are ten curves for each station for different Rs models i.e. Angström-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 ET₀ showed the estimated ET₀ with Rietveld model for Rs for all observed stations. ET₀ with AH5 model for Rs showed the greatest values at all observed stations. Vranje and Negotin stations had the greatest values of ET₀, while Loznica and Kraljevo stations had the lowest values of ET₀. The values of ET₀ obtained from different Rs models were near the same for January, February, March, October, November and December. The values of ET₀ were different for the growing season (April to September), i.e. the differences between ET₀ obtained from different Rs were larger with the increasing values of ET₀ during the year.

ET₀ from Angström-Prescott model for Rs (ET0 A-P) for FAO-56 Penman-Monteith method represents the most reliable way for estimating the values of ET₀ (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 ET₀. Table 2 shows the results of comparison of ET0 A-P with ET₀ 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 ET₀ 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 ET₀ showed that the Rs estimated with AH1 model had the best matching with the Rs estimated with A-P model at all stations. The ET₀ 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 ET₀. 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>
<thead>
<tr>
<th>Station name</th>
<th>Statistical indicator</th>
<th>ET0 B1</th>
<th>ET0 AH1</th>
<th>ET0 J1</th>
<th>ET0 S</th>
<th>ET0 P</th>
<th>ET0 R</th>
<th>ET0 B2</th>
<th>ET0 T2</th>
<th>ET0 AH5</th>
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<td>MBE</td>
<td>-0.124</td>
<td>0.016</td>
<td>0.016</td>
<td>-0.091</td>
<td>-0.141</td>
<td>-0.229</td>
<td>0.027</td>
<td>-0.292</td>
<td>0.181</td>
</tr>
<tr>
<td></td>
<td>RMSE</td>
<td>0.127</td>
<td>0.052</td>
<td>0.145</td>
<td>0.094</td>
<td>0.164</td>
<td>0.348</td>
<td>0.111</td>
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</tr>
<tr>
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<td>0.998</td>
<td>0.999</td>
<td>0.995</td>
<td>0.986</td>
<td>0.936</td>
<td>0.993</td>
<td>0.925</td>
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</tr>
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<td>Vranje</td>
<td>MBE</td>
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<td>0.024</td>
<td>0.044</td>
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<td>-0.132</td>
<td>-0.283</td>
<td>0.078</td>
<td>-0.286</td>
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</tr>
<tr>
<td></td>
<td>RMSE</td>
<td>0.106</td>
<td>0.061</td>
<td>0.172</td>
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<td>0.155</td>
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<td>0.988</td>
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</tr>
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<td>0.057</td>
<td>-0.069</td>
<td>-0.126</td>
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<td>0.065</td>
<td>-0.281</td>
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<td>0.999</td>
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<td>0.026</td>
<td>0.051</td>
<td>-0.071</td>
<td>-0.126</td>
<td>-0.264</td>
<td>0.068</td>
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</tr>
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<td>0.015</td>
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<td>0.055</td>
<td>0.155</td>
<td>0.094</td>
<td>0.167</td>
<td>0.367</td>
<td>0.131</td>
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<td>0.998</td>
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<td>0.928</td>
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<td>0.921</td>
<td>0.937</td>
</tr>
<tr>
<td>Kraljevo</td>
<td>MBE</td>
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<td>-0.013</td>
<td>-0.094</td>
<td>-0.131</td>
<td>-0.173</td>
<td>0.002</td>
<td>-0.261</td>
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<td>RMSE</td>
<td>0.133</td>
<td>0.043</td>
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4. CONCLUSION

The effect of different Rs models on estimation of ET₀ was applied in Serbia during the period 1980-2010. The estimation of ET₀ is conducted using the FAO–56 Penman-Monteith method. For comparison the results of ET₀, three tests were applied (MBE, RMSE and NSE).

The analysis of ET₀ showed that the maximum values of ET₀ occurred in June and July, while the minimum values were in December at all stations. ET₀ 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. ET₀ with Rietveld model for Rs had the lowest values of ET₀ at all stations. Using this method, the maximum ET₀ had the value of 3.93 mm/day, also for Vranje station.

The MBE, RMSE and NSE tests showed ET₀ that used Rs estimated from the Toğrul et al. model 2 and Rietveld model had the greatest deviation from ET₀ estimated from Angström-Prescott model. ET₀ 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 ET₀ with Angström-Prescott model. Especially, the ET₀ with Almorox and Hontoria model 1 showed the great similarity with ET₀ with Angström-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.

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REFERENCES

Effect of Solar Radiation Models on Reference Evapotranspiration


**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 (ET₀). Za proračun ET₀ 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 radiacionih modela. ET₀ dobijena korišćenjem Almorox and Hontoria model 1 za proračun Rs daje najmanja odstupanja u odnosu na ET₀ sa Angström-Prescott (AP) modelom a ET₀ izračunana uz pomoć Toğrul et al. model 2 i Rietveld modela daje najveća odstupanja od ET₀ sa AP modelom.

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