doi.org/10.62683/SINARG2025.102

Research paper

SENSITIVITY ANALYSIS OF REFERENCE EVAPOTRANSPIRATION TO KEY CLIMATE VARIABLES IN AN URBAN AREA

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Abstract

Evapotranspiration is a key parameter of the agrohydrological systems and is critical factor for water resources planning. The objective of the study is to analyze the sensitivity of the monthly reference evapotranspiration (ET_0) to climate variables. Data were used for Nis urban conditions, for the period from July 2022 to December 2024. Sensitivity analysis was based on the calculation of sensitivity coefficients for four meteorological parameters: minimum and maximum air temperature (T_{min} and T_{max}), wind speed (U_2) and solar radiation (R_s). The ET_0 values were defined using the FAO 56 Penman-Monteith method. The results of the sensitivity coefficients showed that the two variables – R_s and T_{max} have the greatest influence on ET_0, with the values of coefficients of 0.423 and 0.374, respectively. The analysis showed that T_{min} has the lowest influence on ET_0, in defined conditions.

Key words: *Reference Evapotranspiration, Sensitivity Analysis, Urban Area*

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1. INTRODUCTION

Evapotranspiration is one of the most important components of the balance between water and energy in urban conditions. Its importance is especially recognized at green infrastructure solutions, where it represents part of an effective strategy for negative urbanization consequence mitigation. Reference evapotranspiration (ET_0) depends on meteorological parameters and location, i.e. only meteorological variables have a direct impact on ET_0 [1].

According to [1], the Food and Agriculture Organization at the United Nations strongly recommends the FAO 56 Penman-Monteith equation (P-M) for defining ET_0. This equation belongs to a combined group of methods, i.e. a group of physically based methods that combines energy and mass transfer. The method is reliable for defining ET_0 in different climatic conditions, and this fact is confirmed by using the P-M method for the calibration of other methods, especially those with a limited number of input data [2-4].

The spatial variability of the land cover causes different microclimatic conditions, especially in an urban area. These conditions usually include a change in the surface heat flux and complex wind patterns. Urban vegetation heterogeneity and different structures, together with the variability of meteorological parameters, affect accurate urban ET_0 estimation [5]. For these reasons, it is necessary to define the degree of meteorological parameter influence on ET_0, i.e. it is necessary to conduct a sensitivity analysis.

The sensitivity analysis is used for the identification of the most important variables in the model and for the establishment of the error effect of the input data on the model outputs. There are different types of methods for defining the sensitivity analysis, i.e. there is no general procedure for the estimation of sensitivity, so the interpretation and comparison of the results from literature can be a challenge [6-9].

Sensitivity analyses for the ASCE Penman-Monteith equation were done for several meteorological factors (wind speed, air temperatures, vapour pressure deficit and solar radiation) in the different regions of the United States [10]. The daily basis was the level for the calculation of sensitivity coefficients. Authors concluded that ET_0 was mostly sensitive to changes of the vapour pressure deficit, while it was not sensitive to minimum temperature changes, at all locations. Also, the analyses of other variables showed significant variations of sensitivity between locations.

The analysis of reference evapotranspiration to the changes of climatic parameters, based on the daily data, was conducted in China (Jiangsu province) [11]. The analyzed area was covered with 60 stations, and the data covered a period from 1961 to 2015. Overall, authors indicated that actual vapour pressure was the most important parameter for ET_0. Wind speed was separated as the parameter to which ET_0 is not sensitive. The analysis of the seasonal influence of the parameters on ET_0 revealed that it was the most sensitive to changes of air temperature and sunshine hours during the summer period.

The monthly analysis of the sensitivity of climatic factors to ET_0 trends was performed in Iran by using a qualitative detrend method [12]. The territory of Iran was observed by five synoptic stations for the period between 1963 and 2007. The main factor which affected the significant positive trend of ET_0 was relative humidity, i.e. relative humidity and sunshine hours at Tabriz station, and minimum temperature, relative humidity and wind speed at Mashhad.

The paper covers the sensitivity analysis of reference evapotranspiration to the key meteorological variables (air temperature, wind speed and solar radiation) using the sensitivity coefficients and sensitivity curve method.

2. METHODOLOGY

2.1. Study Area and Data

The study area in the paper is one urban area in Nis, South-eastern Serbia. The climate in Nis is humid subtropical with continental influences. The main characteristics of this climate are average high temperatures during the summer period and moderately cold winters. The sunniest month during the year is August, while February is the driest month. Moderate precipitation is characteristic of Nis, with an average annual amount of 607 mm. There are approximately 134 days with rain and 40 days with snow cover during the year.

The automatic weather station, installed in the urban area of Nis with coordinates 43°19' N and 21°56' N and an elevation of 197.2 m a.s.l. was used for data collection. The station is equipped with sensors for the measurement of air temperature and relative humidity (HC2S3-L Temperature and Relative Humidity Probe, Campbell Scientific), wind speed and direction (05103-5 Wind Monitor RM Young, Campbell Scientific) and solar radiation (CS300-L Pyranometer, Campbell Scientific). Datalogger (CR1000 Measurement and Control Datalogger, Campbell Scientific) is used for the management and operation of the station. The analyzed period is based on the average daily data on a monthly basis, from July 2022 to December 2024.

2.2. The FAO 56 Penman-Monteith Method

The FAO 56 Penman-Monteith method was used for the calculation of reference evapotranspiration [1]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{1}$$

where:

ET_0 – reference evapotranspiration [mm day^{-1}]

R_n – net radiation at the crop surface [MJ m^{-2} day^{-1}]

G – soil heat flux density [MJ m^{-2} day^{-1}]

T – air temperature at 2 m height [°C]

U_2 – wind speed at 2 m height [m s^{-1}]

e_s – saturation vapour pressure [kPa]

e_a – actual vapour pressure [kPa]

e_s-e_a – saturation vapour pressure deficit [kPa]

Δ – slope vapour pressure curve [kPa °C^{-1}]

γ – psychometric constant [kPa °C^{-1}]

2.3. Sensitivity Analysis

Sensitivity analysis represents the technique that defines the influence of variables on ET_0. For this study, the sensitivity analysis is based on the dimensionless relative sensitivity coefficient [13]:

$$SC = \frac{\Delta ET_0}{\Delta CV}\frac{CV}{ET_0} \qquad (2)$$

where:

ΔET_0 – relative change of ET_0 with respect to variable changes

CV – climate variable, the base value before change

ΔCV – relative change of CV

ET_0 – reference evapotranspiration, the base value before change

The variables analyzed through the sensitivity process are minimum and maximum air temperature (T_{min} and T_{max}), wind speed at 2 m height (U_2) and solar radiation (R_s). The calculation procedure was done by changing one variable in the ET_0 calculation, while the others were fixed. The relative changes of variables cover the range of $\pm$ 20%, with an interval of $\pm$ 5% (-5%, -10%, -15%, -20%, 5%, 10%, 15%, 20%). All the calculations were done on a monthly basis.

The SC value, positive or negative, implies that the ET_0 value will increase or decrease as the CV increases. The relative effect of the analyzed CV will be larger on ET_0, with the larger SC value. In order to have the most precise assessment of sensitivity, the classes of SC values were proposed by [14] according to the degree of sensitivity, table 1.

Table 1. Sensitivity classes

Sensitivity coefficient	Degree of sensitivity
$0.00 \le \|SC\| < 0.05$	small to negligible
$0.05 \le \|SC\| < 0.20$	medium
$0.20 \le \|SC\| < 1.00$	high
$\|SC\| \ge 1.00$	very high

3. RESULTS AND DISCUSSION

The values of monthly sensitivity coefficients for all the analyzed variables are shown in Figure 1. The figure clearly indicates that there are large fluctuations in all variables. Temperature sensitivity coefficients show a similar pattern. The SC values for T_{max} are higher than those for T_{min}, i.e. ET_0 is more sensitive to T_{max} than to T_{min}, which is reasonable because T_{max} values are always higher than T_{min} and have a greater influence on the ET_0 equation. Based on Figure 1, it is obvious that SC(T_{min}) has the lowest values of all the other variables (ET_0 is not sensitive to the changes of T_{min}). This conclusion is supported by the numerical value of the unique SC of 0.087 for the entire analyzed period. The analysis of the average monthly SC values recognizes September as the month with the highest SC(T_{min}) values of 0.142, while February has the lowest values of SC(T_{min}) (0.008). According to the values of average yearly SC for T_{min} and T_{max}, 2022 stands out as the year with the greatest P-M equation sensitivity to temperature changes, i.e. 0.112 and 0.396, respectively. According to the unique SC(T_{max}) value of 0.374, it can be concluded that the ET_0(P-M) equation is highly sensitive to T_{max}. This sensitivity is especially expressed during the autumn months of October and November, with SC(T_{max}) values of 0.465 and 0.458, respectively.

The sensitivity coefficients for U_2 exhibit an opposite correlation than those for temperature. This statement is supported by the numerical values of SC(U_2) on an average yearly and monthly basis. Yearly SC(U_2) determines 2024 as the year with the highest sensitivity to U_2 (0.168). A monthly analysis of the SC reveals that the winter session is the most sensitive to U_2, especially in February (0.289). The results of SC(U_2), with an average value of 0.157, define U_2 as the parameter with a medium influence on the ET_0 equation.

The behavior of SC(R_s), on a monthly basis, deviates from the other analyzed parameters. According to Figure 1, there are especially noticeable peaks at SC(R_s) during the summer periods, which is reasonable considering the intensity of R_s during this period. The average monthly SC(R_s) exhibits the highest values in June and July, with 0.771 and 0.753, respectively. November is the month with the lowest sensitivity of ET_0(P-M) to the R_s variable (0.060). The results of the average yearly SC(R_s) show that, in 2023, R_s had the highest influence on ET_0 (0.429) of all the other years. It can be concluded that the ET_0 equation has a high sensitivity to R_s, based on the average SC(Rs) of 0.423. The final comparison of the average SC values for the entire analyzed period determines the prominence of R_s as the variable to which ET_0 is the most sensitive, followed by variables T_{max}, U_2 and T_{min}, respectively.

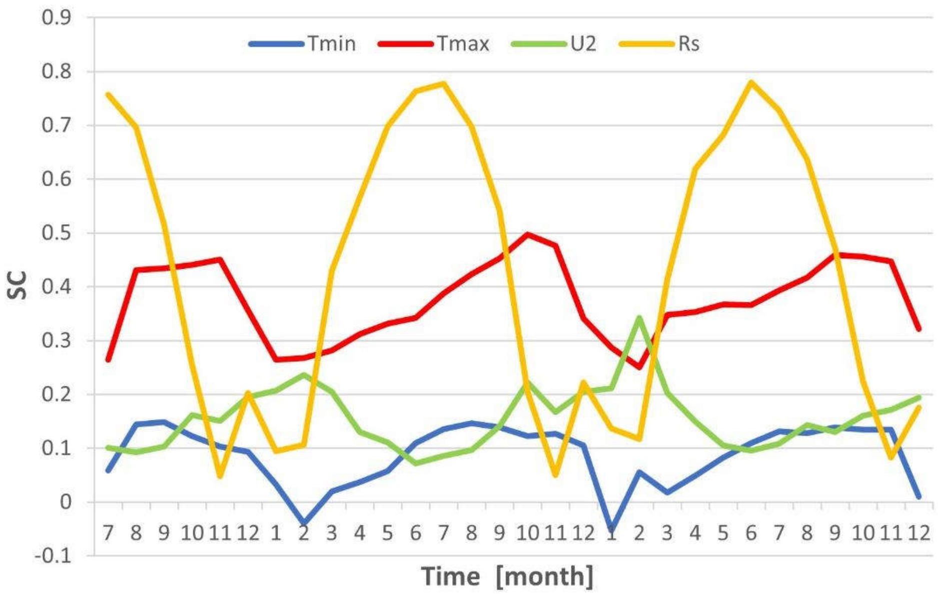

Figure 1. Sensitivity coefficients on a monthly basis

Table 1 represents the percentage change of ET_0 due to the relative change of meteorological variables. The relative change of variables includes T_{min}, T_{max}, U_2 and R_s, used for the calculation of ET_0. The visual relationship between the change of ET_0 and the variables is presented in Figure 2 in the form of the sensitivity curve. According to Figure 2, there is a linear sensitivity relationship, with a positive trend, between the relative changes of ET_0 and the variables. What is more, based on Table 1 and Figure 2, it can be concluded that the changes of T_{max} and R_s have a greater influence on the ET_0 changes than other variables do. The negative relative changes of T_{max} and R_s are almost the same, while there is a small difference between the positive changes. The influence of U_2 change on ET_0 is relatively low, i.e. lower than that of T_{max} and R_s. This result is expected, considering the urban conditions and their impact on U2 (trees, houses and other urban obstacles).

Table 1. Change of ET_0 (%) considering the change of meteorological variables

	-20%	-15%	-10%	-5%	5%	10%	15%	20%
T_{min}	-1.696	-1.283	-0.863	-0.435	0.443	0.895	1.355	1.825
T_{max}	-7.179	-5.436	-3.660	-1.849	1.888	3.816	5.788	7.806
U_2	-3.161	-2.365	-1.573	-0.785	0.781	1.559	2.334	3.104
R_s	-7.111	-5.333	-3.556	-1.778	1.778	3.556	5.333	7.111

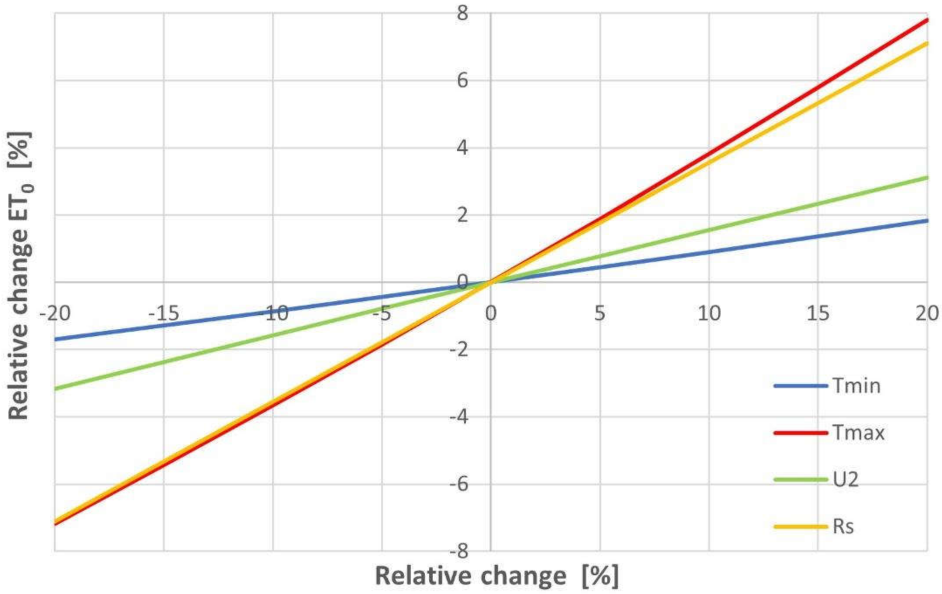

Figure 2. Sensitivity curve for four meteorological variables

4. CONCLUSION

The sensitivity of reference evapotranspiration on key meteorological variables was conducted in one urban area of Nis. Reference evapotranspiration was observed using the FAO 56 Penman-Monteith equation and the mentioned key variables included in the equation calculation, which are T_{min}, T_{max}, U_2 and R_s. The sensitivity analysis was based on the sensitivity coefficients and sensitivity curve method, where the influence of variables was separately analyzed. All the relative changes of variables have demonstrated the linear connection with the relative change of ET_0. The results revealed that the P-M equation is highly sensitive to the changes of T_{max} and R_s, while T_{min} caused the lowest changes, i.e. sensitivity of the equation. The monthly values of SC showed that there is a high variation in the changes of variables, especially in terms of the variations of R_s.

Further study will be oriented towards the connection of the sensitivity analysis with the dependence and uncertainty analysis. Moreover, the urban areas of Nis will be analyzed using the data from more positions.

ACKNOWLEDGMENTS

This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under the Agreement on Financing the Scientific Research Work of Teaching Staff at the Faculty of Civil Engineering and Architecture, University of Niš - Registration number: 451-03-137/2025-03/200095 dated 04/02/2025, as well as the project of the Serbian Academy of Science and Arts, Branch in Nis, grant number 0-15-18.

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