submitted: 15.06.2025. *https://doi.org/10.62683/ZRGAF41.4*
Research paper
accepted: 21.06.2025.

ESTIMATION OF EVAPORATION IN URBAN CONDITIONS

Mladen Milanović[1]
Dragan Milićević[2]
Slaviša Trajković[3]

Abstract

Reliable method for estimating pan evaporation is essential for modelling precipitation, different water balance studies and water management, especially in conditions with prominent climatic changes, such are urban conditions. Four empirical equations (Stephens and Stewart, Griffiths, Kohler-Nordenson-Fox and Linacre 1994) are used for modelling pan evaporation in the urban area of Nis, Serbia. Also, all equations are modified using the nonlinear regression technique, and compared with measured Class A pan evaporation data. The results of statistical tests (coefficient of determination – R2, root mean square error – RMSE and mean absolute error – MAE) showed that Griffiths equation (before modification) has the best match with pan evaporation data (R2 = 0.698, RMSE = 1.224 and MAE = 0.956). Stephens and Stewart equation, from all modified equations, achieves the best matching with the measured pan evaporation data (R2 = 0.866, RMSE = 0.787 and MAE = 0.588).

Key words: *Evaporation, Nonlinear Regression, Urban Area of Niš*

1 MSc, Teaching Assistant, Faculty of Civil Engineering and Architecture, Serbia, mmsmladen@gmail.com, 0000-0002-7093-3653
2 PhD, Full Professor, Faculty of Civil Engineering and Architecture, Serbia, drgara@mail.com, 0000-0003-0617-2682
3 PhD, Full Professor, Faculty of Civil Engineering and Architecture, Serbia, slavisa@gaf.ni.ac.rs, 0000-0001-8294-1047

1. INTRODUCTION

Evaporation is one of the main components of the water cycle. Reliable estimation of evaporation is important for water management and irrigation system planning, especially in urban conditions, i.e. in the conditions where the availability of water is scarce. Urban areas have a direct impact on evaporation. The main reasons for this are urban heterogeneity, caused by rapid and unplanned urbanization, and extreme values of meteorological parameters linked with their rapid changes. Different analysis of evaporation in urban areas were conducted [3,9,14].

There are wide variety of calculation techniques (trend analysis, machine learning, adaptive neuro-fuzzy inference system, empirical equations, etc.) which were applied for pan evaporation (Epan) modelling [1,6,7,11]. With a view to achieving as possible adequate Epan data, some of these techniques were additionally modified using methods such as: genetic, firefly, particle swarm and whale algorithms [6,7]. Three machine learning models together with four empirical models were used for the estimation of Epan for the Poyang lake watershed (China) [11]. The authors claimed that, of all the empirical models, the Priestley and Taylor is the most accurate model, while the gradient boosting decision tree model is the most accurate model than other machine learning models. Equations for modelling Epan can be very useful, but only for the conditions for which they were developed. In order to achieve reliable Epan data, researchers modify original equations using the different optimization techniques [4,13]

The paper presents the analysis and modification of evaporation empirical equations for urban area. The modification of equations was conducted using the nonlinear regression method. In order to define the best equation, all equations were compared with the measured data. Statistical indicators were used for defining numerical relationship between modelled and measured Epan data.

2. MATERIAL AND METHODS

2.1. Study Area

The study covers the city of Nis urban area. Nis, located in South-eastern part of Serbia, has a humid subtropical climate with continental influences. The warmest month is July, while the sunniest is August. January is the coldest month. The average annual air temperature for the Nis urban conditions is 11.9 °C.

Several instruments were used for data collection, such as Class A pan evaporimeter, for measurement E_{pan}, and automatic weather station, equipped with sensors for measurement: 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). The management of sensors is done using the datalogger (CR1000 Measurement and Control Datalogger, Campbell Scientific). Instruments are located in the Nis urban area (43°19’ N, 21°56’ E) with elevation of 197.2 m a.s.l. The study covers the period, on the daily level, from 17th July 2022 to 30th November 2022 and from 1st April 2023 to 30th November 2023.

2.2. Evaporation Equations

Empirical equations for modelling pan evaporation were selected, and their methodology is presented below:

Radiation based equations are presented with the Stephens and Stewart (S-S) equation [15]:

$$E_{pan} = (a + bT_a)\ R_s \quad (1)$$

where: E_{pan} – pan evaporation (mm/day), T_a – mean air temperature (°C), R_s – solar radiation (mm/day), a and b – fitted coefficients (original values are 0.1 and 0.027, respectively).

Temperature based equations are presented with the Griffiths (G) equation [5]:

$$E_{pan} = a + bT_a + cU \quad (2)$$

where: U – wind speed (m/s), a, b and c – fitted coefficients (original values are -3.504, 0.307 and 0.146, respectively).

Mass transfer based equations are presented with the Kohler-Nordenson-Fox (KNF) equation [8]:

$$E_{pan} = 25.4(e_s - e_a)^a\left(b + cU_p\right) \quad (3)$$

where: e_s - e_a – vapour pressure deficit (inches), U_p – wind speed at the standard pan installation (miles/day), a, b and c – fitted coefficients (original values are 0.88, 0.37 and 0.0041, respectively).

Combination based equations are presented with the Linacre 1994 (L1994) equation [10]:

$$E_{pan} = \frac{aT_a - b + cU(T_a - T_{dew})}{d + \frac{e}{S}} \quad (4)$$

where: T_{dew} – mean dew point temperature (°C), S – slope of the psychrometric curve (mbar), a, b, c, d and e – fitted coefficients (original values are 21, 166, 6, 28 and 46, respectively).

2.3. Nonlinear Regression Method

For a purpose of defining a suitable relationship between variables, nonlinear regression approach was applied. Multiple nonlinear regression, one of the nonlinear regression techniques based on the least square approach, is used for establishing quantitative relationship between dependent variable and independent variables, i.e. observed data are modeled using the function, which represents the nonlinear combination of model parameters [2,12]. The function directly depends on the independent variables. The multiple nonlinear relation is expressed as:

$$Y = \alpha_0\left(X_1^{\alpha_1}\right)\left(X_2^{\alpha_2}\right) \dots \left(X_1^{\alpha_n}\right) \quad (5)$$

where: Y – dependent variable, α_0, …, α_n – equation parameters for the nonlinear relation, X_1, …, X_n – independent variables

2.4. Evaluation Criteria

Three statistical indicators (coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE)) were used for defining the performances of the analyzed equations.

$$R^2 = \frac{\left(\sum_{i=1}^{n}(c_i-\bar{c})(m_i-\bar{m})\right)^2}{\sum_{i=1}^{n}(c_i-\bar{c})^2\sum_{i=1}^{n}(m_i-\bar{m})^2} \tag{6}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i-m_i)^2} \tag{7}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|c_i-m_i| \tag{8}$$

where: c_i – the ith calculated value, $\bar{c}$ - the average value of the calculated data, m_i – the ith measured value, $\bar{m}$ - the average value of the measured data, n – the total number of the data.

3. RESULTS AND DISCUSSION

3.1. The Performances of the Proposed Equations

The analysis of statistical indicators, before modification, reveals that the G equation achieves the best matching with measured E_{pan} values, i.e. the values of indicators are: R^2 = 0.698, RMSE = 1.224 and MAE = 0.956. The worst matching with measured pan data was observed at KNF equation (R^2 = 0.776, RMSE = 2.438 and MAE = 2.143). Figure 1 stands out the S-S and G equations from the other equations as the usually closest to the observed data, i.e. the S-S overestimate the observed data during the summer months for both years, while the G equation underestimate observed data during the period november 2022 to june 2023 and for november 2023. Equations KNF and L1994 have a similar pattern of behavior, overestimate the measured E_{pan} data for the entire analyzed period.

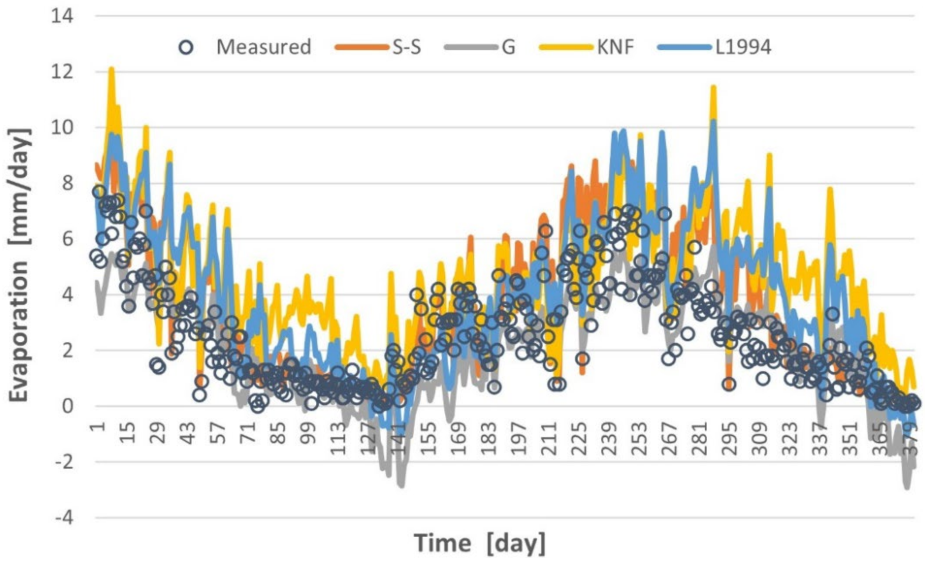

Figure 1. Equations performances before modification

3.2. Comparison of the Modified Equations and Measured Evaporation

A comparative analysis between original and modified equations shows that all equations are improved. The KNF is the most improved equation, i.e. the improvements of R^2, RMSE and MAE are 6.8, 62.2 and 66.8 %, respectively. The modified G equation has the least improvements (4.7, 6.7 and 7.4 % for R^2, RMSE and MAE, respectively) of all equations. Figure 2 displays that there is no significant dispersion at the modified S-S equation, except for the higher E_{pan} values, where equation shows underestimation. Other equations indicate an overestimation for low E_{pan} values, and an underestimation for the high ones.

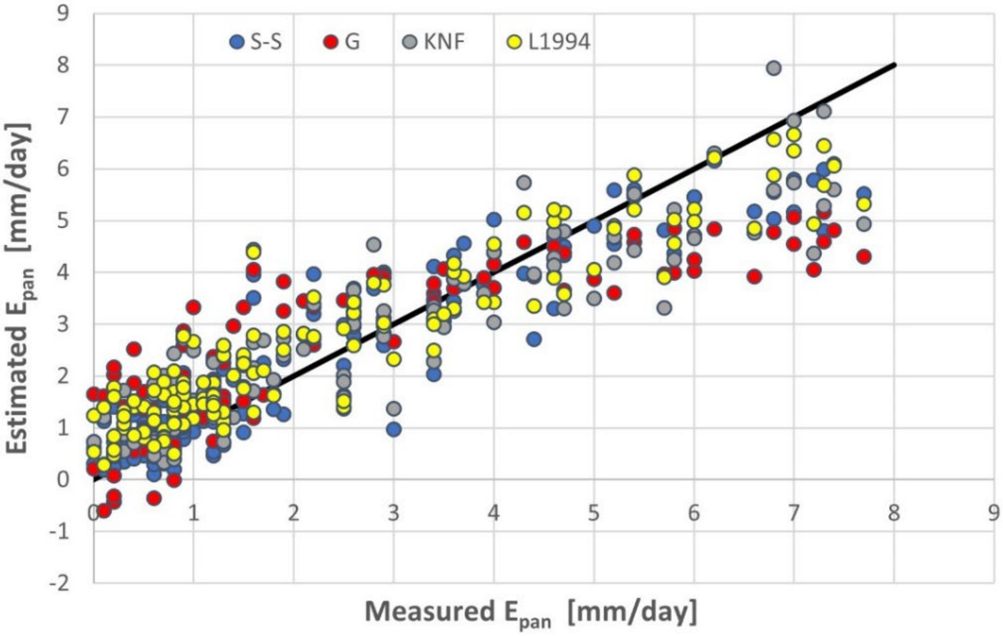

Figure 2. The measured versus the modified Epan values during the validation phase

The results of statistical indicators for the modified equations, compared with the measured E_{pan}, exhibit that equation with the best performances is the S-S equation, while the G is the worst, Table 1. According to Table 1, modified L1994 equations is on the second place. The values of the fitted coefficients for the S-S, a and b are 0.2505 and 0.0102, respectively.

Table 1. Statistical indicators of the four modified evaporation equations during the validation phase

Equation	R^2	RMSE (mm/day)	MAE (mm/day)
S-S	0.866	0.787	0.588
G	0.731	1.142	0.886
KNF	0.828	0.922	0.711
L1994	0.874	0.853	0.698

4. CONCLUSION

Four empirical equations were used for defining pan evaporation in urban area. What is more, equations were modified using the nonlinear regression method. Based on the values of the statistical indicators, all equations are improved compared to the original ones. The analysis of evaluation criteria for validation phase indicated that the modified Stephans and Stewart equation achieves the best matching with the measured data. This result differs from the result before modification, where the Griffiths equation stands out as the best equation.

Further study will be oriented towards the analysis of urbanization on evaporation. Also, a comparative analysis will be performed between complicated and simple equations, with minimal number of input data.

ACKNOWLEDGEMENTS

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.

REFERENCES

[1] Azar Naser Arya, Kardan Nazila, Milan Sami Ghordoyee: **Developing the artificial neural network-evolutionary algorithms hybrid models (ANN-EA) to predict the daily evaporation from dam reservoirs**. *Engineering with Computers*, Vol. 39, 1375-1393, 2023.

[2] Bilgili Mehmet: **Prediction of soil temperature using regression and artificial neural network models**. *Meteorology and Atmospheric Phys*ics, Vol. 110, 59-70, 2010.

[3] Fan Defang, Yu Hang, Liu Gan, Yang Rui, Li Xuehui, Wang Long: **Effect of urbanization on the long-term change in pan evaporation: A case study of the Nanpan river basin in China**. *Ecological Indicators*, Vol. 145, 1-12, 2022.

[4] Ghumman Abdul Razzaq, Ghazaw Yousry Mehmood, Alodah Abdullah, ur Rauf Ateeq, Shafiquzzaman Md., Haider Husnian: **Identification of parameters of evaporation equations using an optimization technique based on pan evaporation**. *Water*, Vol. 12, 1-21, 2020.

[5] Griffiths J. F.: **Another evaporation formula**. *Agricultural Meteorology*, Vol. 3, 257-261, 1966.

[6] Ikrem Rana Muhammad Adnan, Jaafari Abolfazl, Milan Sami Ghordoyee, Kisi Ozgur, Heddam Salim, Zounemat-Kermani Mohammad: **Hybridized adaptive neuro-fuzzy inference system with metaheuristic algorithms for modelling monthly pan evaporation**. *Water*, Vol. 14, 1-23, 2022.

[7] Jasmine Mansura, Mohammadian Abdolmajid, Bonakdari Hossein: **On the prediction of evaporation in arid climate using machine learning model**. *Mathematical and Computational App*lications, Vol. 27, 1-14, 2022.

[8] Kohler Max A., Nordenson T.J., Fox W.E.: **Evaporation from pans and lakes**. Weather Bureau, U. S. Department of Commerce al,. *Research paper*: 38, Washington, 1-27, 1955.

[9] Li Jiaqi, Gao Bing: **How urbanization affects pan evaporation in China**. *Urban Climate*, Vol. 49, 1-15, 2023.

[10] Linacre Edward T.: **Estimating U.S. Class A pan evaporation from few climate data**. *Water International*., Vol. 19, 5-14, 1994.

[11] Lu Xianghui, Ju Yan, Wu Lifeng, Fan Junliang, Zhang Fucang, Li Zhijun: **Daily pan evaporation modelling from local and cross-station data using three tree-based machine learning models**. *Journal of Hydrology*. Vol. 566, 668-684, 2018.

[12] Marofi Safar, Tabari Hossein, Abyaneh Hamid Zare: **Predicting spatial distribution of snow water equivalent using multivariate non-linear regression and computational intelligence methods**. *Water Resource Management*, Vol. 25, 1417-1435, 2011.

[13] Mohammadi Mehdi, Salarijazi Meysam, Ghorbani Khalil, Dehghani Amir-Ahmad: **Coastal cities-wide estimation of daily class A pan evaporation from few hydrometeorological variables**. *Urban Water Journal*, Vol. 20, 782-800, 2023.

[14] Ren Chenchen, Ren Gouyu, Zhang Panfeng, Tysa Suonam Kealdrup: **Urbanization significantly affects pan-evaporation trends in large river basins of China mainland**. *Land*, Vol. 10, 1-11, 2021.

[15] Stephens J. C., Stewart E. H.: **A comparison of procedures for computing evaporation and evapotranspiration**. In: *International Union of Geodynamics and Geophysics*, Publication, 62, Berkeley, United States: International association of scientific hydrology, 123-133, 1963.