Pol. J. Environ. Stud. Vol. 33, No. 1 (2024), 981-989
DOI: *10.15244/pjoes/172032* ONLINE PUBLICATION DATE: 2023-11-14

Original Research

Estimating Leachate Generation in the Savina Stena Sanitary Landfill through Evapotranspiration Analysis: A Comprehensive Study

Bojana Živković[1], Jelena Đokić[1]*, Maja Petrović[2], Srđan Kovačević[2]

[1]University of Pristina in Kosovska Mitrovica, Faculty of Technical Sciences, Serbia
[2]University of Novi Sad, Faculty of Technical Sciences, Serbia

Received: 30 June 2023
Accepted: 8 September 2023

Abstract

Sanitary landfills pose a significant threat to the environment, primarily due to the presence of leachate. The characteristics of leachate and its detrimental impact on the surrounding ecosystem necessitate a comprehensive and rigorous approach to addressing this problem. Accurate estimation of leachate volume is crucial, and one essential factor for such calculations is evapotranspiration. To calculate evapotranspiration at the „Savina Stena“ sanitary landfill, the Thornthwaite method was employed using data sourced from the FAO AQUASTAT Climate Information Tool, spanning the period from 1990 to 2020. These values were then utilized to determine the average quantity of leachate generated at the landfill. The research findings reveal that the maximum daily amount of leachate recorded is 61.82 m^3, with the highest levels occurring during winter months. Specifically, the leachate production for December was calculated at 61.82 m^3/day, followed by January with 50.52 m^3/day and February with 47.09 m^3/day. Additionally, the study presents a comparison between the evapotranspiration values derived from the Thornthwaite method and those obtained from the FAO AQUASTAT Climate Information Tool over the same 31-year period. This comparison was performed by calculating the root mean square error (RMSE) and relative error (RE).

Keywords: Landfill, precipitation, temperature, evapotranspiration, leachate

Introduction

Sanitary landfills are commonly employed as the primary method for municipal waste disposal. When appropriately constructed and operated in adherence to laws and regulations, these landfills can effectively manage waste. However, it is important to acknowledge that even well-maintained landfills still carry inherent risks to the environment. Landfill leachates represent highly complex and heavily contaminated waters which are formed through a combination of factors, including stormwater infiltration, moisture present in the waste, and the process of waste biodegradation. They can contain various organic and inorganic impurities,

---

*e-mail: jelena.djokic@pr.ac.rs

of which the most attention is paid to hazardous and toxic substances [1]. The composition of leachate is influenced by various factors, with the most significant ones including the waste composition, landfill age, meteorological parameters such as temperature and precipitation, landfill depth, and waste treatment processes conducted prior to disposal [2, 3].

Addressing the issue of leachate from sanitary landfills is of utmost importance due to its profound and detrimental impact when released into the environment. In pursuit of a higher environmental standard and improved quality, it is imperative to collect leachate and transport it to a purification facility, where various treatment processes are employed. Only after meeting legal regulations and ensuring proper purification, can the treated leachate be safely reintroduced into nature [4]. It is worth noting that leachate continues to be generated within the landfill long after its closure, and these later-stage leachates tend to contain elevated concentrations of pollutants [5]. The quantity of leachate in landfills exhibits variability and relies on several key factors. One crucial aspect is the disposal and compaction of waste within the landfill cells. The degree of compaction directly influences the permeability of the waste to water, with well-compacted waste offering less permeability compared to loose waste. This compaction factor plays a pivotal role in determining the flow rate of leachate. Moreover, the presence of landfill covers serves to limit the infiltration of stormwater into the landfill body. These covers, in conjunction with factors such as precipitation levels, infiltration rates, surface flow, temperature, and evapotranspiration, directly impact the volume of leachate generated [6]. In addition, the composition of the waste, waste aging, waste characteristics, biochemical degradation processes, and other related factors also exert significant influence on the formation of leachate [7]. During the planning phase of constructing a sanitary landfill, it is crucial to calculate the volume of leachate as it helps estimate the dimensions of drainage pipes, collectors, and the necessary processing plant. The amount of leachate is influenced by seasonal variations and meteorological conditions [8]. One common approach for estimating leachate is through the calculation of evapotranspiration (ET), which can be obtained empirically using various methods. Meteorological data plays a significant role in modeling ET [9]. Moreover, potential (reference) evapotranspiration holds great importance within the hydrological cycle, particularly concerning hydraulic structures [10]. In 1959, P.E. Rijtema [11] discussed various methods for calculating potential evapotranspiration and highlighted six specific approaches, namely Lysimeter, Pan x red. Factor, Penman, Makkink, Turc, and Haude. Rijtema noted that although these methods required different parameters for calculations, the results obtained from each method did not exhibit significant differences. However, it is important to consider that the accuracy of all evapotranspiration calculation methods is contingent upon their application in the same climatic conditions for which they were originally developed [12].

The most common methods for calculating evapotranspiration are: the Thornthwaite method, established in 1948, based on the length of the canopy and the mean air temperature [13]. In 1961, Turcov established a method based on air temperature (T), solar radiation (Ig) and maximum monthly duration of sunbathing (H) [14]. The Blaney-Criddle formula, established in 1950, uses the average monthly temperature (Tm ºC) and the maximum daily insolation factor (p) as a percentage of the annual sum to estimate evapotranspiration [12]. Albrecht's formula for calculating evapotranspiration was established in 1950 and involves the use of saturated vapor pressure (Es) and monthly mean vapor pressure (e). In 1952, Haudet's formula for evapotranspiration was presented as the product of the proportionality factor for the annual day length (f) and the difference in saturation and water vapor pressure at 14 h (Es14, e14) [12].

Apart from the above, various modified equations adapted to different climatic regions and available parameters are used to calculate evapotranspiration. According to Zotarelli et al., the Penman formula from 1948 was modified by combining it with the Monteith method from 1965, and is widely represented as the Penman-Monteith equation [15]. Trajković [16] introduced a simple empirical formula for estimating reference evapotranspiration, which is a modified version of the Hargreaves formula from 1985.

Evapotranspiration is closely linked to temperature and precipitation, and its patterns are directly influenced by changes in these climatic factors. Particularly, during periods of drought, evapotranspiration undergoes significant alterations [17]. Precipitation strongly affects evapotranspiration. Some equations for calculating evapotranspiration directly include them, such as the Hargreaves equation modified by Allen 2003, which includes the monthly sum of precipitation [18]. Precipitation determines some other parameters on the basis of which evapotranspiration is calculated, such as water vapor content and soil water content [17]. Cui et al. also point out that rainfall intensity is very important for evapotranspiration because it determines surface runoff and evaporation [19]. Snyder et al. [20] corroborated the relationship between evapotranspiration and temperature, affirming its significance. However, they highlighted that other factors, such as wind speed and air humidity, also exert considerable influence on evapotranspiration. In a study conducted in Turkey, from October 2018 to September 2019, Kuzai et al. [21] confirmed that temperature and evapotranspiration are directly proportional. Their results show the highest evapotranspiration values in July (2018-191 mm/month; 2019-175 mm/month), when the temperature was also 7-8ºC higher than in the previous months. Haggag et al. [22] demonstrated the strong correlation between evapotranspiration and temperature in their extensive study spanning 46 years. Additionally, Haggag et al.

[22] confirmed the compatibility between precipitation and evapotranspiration (ET), indicating a positive relationship, except during the summer months spanning from June to September. In a study conducted by Nastos et al. [23] in Greece, the assessment of reference evapotranspiration (ETo) in relation to global warming revealed compelling results. The study indicated a substantial projected increase in ETo, nearly doubling its current levels, as a consequence of global warming. These findings underscore the potential impacts of climate change on water loss processes, suggesting a significant intensification of evapotranspiration rates in the future. Chaouche et al. [24], in their research, did not observe a straightforward dependence of evapotranspiration (ET) solely on temperature. However, they employed the Penman-Monteith formula to calculate ET, which takes into account not only temperature but also relative humidity, solar radiation, and wind speed. Their findings emphasized that these additional factors, such as relative humidity, solar radiation, and wind speed, exhibited a significant influence on ET. Prăvălie [25] corroborated the previous research by highlighting the influence of multiple factors on evapotranspiration (ET), extending beyond air temperature alone. In their study, they noted that ET can be affected by anthropogenic factors as well. Using China as an example, Prăvălie pointed out that air pollution can lead to a reduction in daily sunlight duration, thereby impacting ET rates.

The goal of the research presented in this paper is to evaluate the production of leachate at the Savina Stena sanitary landfill by analyzing evapotranspiration, as well as to compare two methods for calculating evapotranspiration, the Tornthwaite method and the Penman-Monteith method.

Materials and Methods

Study Area

The sanitary landfill "Savina Stena" is located on the territory of the municipality of Zvečan, in the town of Srbovac. It covers an area of 26.6 ha, not far from the highway Raška-Kosovska Mitrovica, with coordinates 42º58′01′′N and 20º49′52′′E, with an elevation of 560 meters. Positioned approximately 300 meters away from the right bank of the river Ibar, the landfill finds itself within a basin surrounded by hills. The slope of the landfill varies, with a gradient of 30%-35% from north to south and 23% from east to west. The facility comprises two cells, with the initial decade of waste disposal planned exclusively in cell "A" (Fig. 1).

The cell has a total area of 2.92 hectares and a capacity to accommodate 350,000 cubic meters of waste. This capacity projection aligns with the ten-year waste disposal requirements for four municipalities: Zvečan, Kosovska Mitrovica, Leposavić, and Zubin Potok. The waste estimation takes into consideration various factors, such as the current waste generation per capita in these municipalities, projected municipal development, and expected population growth. The anticipated waste quantities for the period spanning from 2020 to 2035 are provided in Table 1.

The bottom of the landfill cell has a 5% slope, which facilitates the controlled movement of water within the cell. This slope proves advantageous for the installation and functioning of the landfill's leachate collection system.

Fig. 1. Macrolocation of Savina Stena sanitary landfill.

Table 1. Quantity and volume of disposed waste, for the years 2020-2035.

Year	Waste production (tn/y)	Waste to landfill (m^3/y)	Sanitary Landfill vol./year (m^3)	Total Sanitary Landfill vol. (m^3)
2020	15.233	25.388	29.196,32	162.906,90
2021	15.690	26.150	30.072,21	192.979,11
2022	16.161	26.934	30.974,34	233.953,48
2023	16.645	27.742	31.903,60	255.857,09
2024	17.145	28.575	32.860,71	288.717,80
2025	17.659	29.432	33.864,53	322.564,33
2026	18.189	30.315	34.861,93	357.426,26
2027	18.734	31.224	35.907,79	393.334,05
2028	19.297	32.161	36.985,02	430.319,07
2029	19.875	33.126	38.049,57	468.413,65
2030	20.472	34.119	39.237,41	507.651,06
2031	21.086	35.143	40.414,53	548.065,59
2032	21.718	36.197	41.626,97	589.692,55
2033	22.370	37.283	42.875,78	632.568,33
2034	23.041	38.402	44.162,05	676.730,38
2035	23.732	39.554	45.486,91	722.217,29

Meteorological Data

Due to the unavailability of meteorological stations in the vicinity of the "Savina Stena" landfill, the required meteorological data was obtained from the FAO AQUASTAT Climate Information Tool. The AQUASTAT tool, a global information system on water and agriculture developed by the Food and Agriculture Organization (FAO), offers comprehensive data on various climatic parameters such as precipitation, temperature (minimum, maximum, and average), relative air humidity, insolation, wind speed at a height of 2 meters, and ET_o (reference evapotranspiration) based on the specified coordinates of the study site.

For this research, data from the period between 1990 and 2020 was obtained from the AQUASTAT tool, and the average values of the meteorological parameters are presented in Table 2.

Evapotranspiration and Leachate

Evapotranspiration for a period of 31 years was calculated using the Thornthwaite (1948) formula:

$$ET_o = ET_x * \frac{DT}{360}$$

where: ET_o - potential evapotranspiration, ET_x - corrected potential evapotranspiration

$$ET_x = 16 * \left[\frac{10*Ti}{J}\right]^a$$

where: Ti - mean monthly air temperature, J - annual heat index, a - surface flow coefficient

$$J = \sum_{i=1}^{12} J_i$$

Ji = monthly heat index

$$J_i = 0{,}09 * \sqrt{{T_i}^3};$$

$$a = 0{,}016J + 0{,}5;$$

$$\frac{DT}{360} = 0{,}1217 * P,$$

P - mean daylight hours for latitudes 42° [26]. P values are given in Table 3.

To compare the obtained evapotranspiration values with those calculated by the FAO AQUASTAT Climate Information Tool for the same time period, the Penman-Monteith method is used, as employed by the FAO AQUASTAT tool. The Penman-Monteith method requires several primary data inputs, including the pressure drop of saturated water vapor (Δ), net radiation (Rn), assumed heat flux (G), psychrometric constant (γ), mean air temperature at a height of 2 meters (T), wind

Table 2. Average values of meteorological data for the period 1990-2020.

Average values of meteorological data for the period 1990-2020								
Month	Prc.	Tmp. min.	Tmp. max.	Tmp. Mean	Rel. Hum.	Sun shine	Wind (2 m)	ETo,pm
	mm/m	ºC	ºC	ºC	%	$J\ m^{-2}\ day^{-1}$	m/s	mm/m
Jan	48.54839	-5.16452	3.419355	-0.87419	67.30323	6410034	2.248387	18.22581
Feb	48.77419	-3.95806	5.077419	0.554839	61.1871	9240334	2.493548	27.74194
Mar	65.70968	-1.04839	9.025806	3.983871	54.47742	13746008	2.532258	54.35484
Apr	74.06452	2.974194	13.81613	8.393548	51.77419	18189585	2.348387	80.77419
May	80	7.632258	18.63871	13.12903	53.10968	20849299	2.054839	109.6452
Jun	66.93548	11.54516	22.91935	17.23548	49.75484	23227093	1.835484	130.3871
Jul	53.22581	13.67097	25.55161	19.60968	44.86129	23093986	1.883871	144.2903
Aug	43.70968	13.99032	26.05484	20.02258	42.72903	20949283	1.809677	130.9677
Sep	50.45161	9.867742	20.92258	15.3871	48.21613	15597935	1.964516	86
Oct	48.87097	5.464516	15.77097	10.62581	54.58065	10939965	2.035484	52.48387
Nov	51.96774	0.912903	9.758065	5.33871	62.62258	7153605	2.225806	27.25806
Dec	62.6129	-3.42581	4.26129	0.422581	69.30323	5318668	2.277419	16.58065
Total	694.871							878.7097

Table 3. Mean daylight hours for latitudes 42º for the 15th of the month (P).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	9.3	10.4	11.7	13.2	14.4	15.0	14.8	13.7	12.3	10.8	9.6	9.0

speed at a height of 2 meters (), and water vapor deficit at a height of 2 meters (-).

The formula for calculating evapotranspiration using the FAO 56 Penman-Monteith method is as follows [16]:

$$ETo,\ pm = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U_2(e_a-e_d)}{\Delta+\gamma(1+0.34U_2}$$

To assess the potential deviation of the calculated evapotranspiration values, two measures are used: the root mean square error (RMSE) and the relative error (RE):

$$RMSE=\left[\frac{\sum_{i=1}^{k}(ET_o-ET_{o,pm})^2}{k}\right]^{0,5};\quad RE=\frac{RMSE}{ET_{o,pm}}$$

Following the calculation of evapotranspiration, the amount of leachate in the sanitary landfill was determined by employing the hydrological balance equation:

$$L= P-R-E,$$

Where: P-stands for precipitation, R-coefficient of surface runoff and E-evapotranspiration. It is crucial to highlight that the ingress of leachate into the groundwater, as well as vice versa, is effectively prevented through the implementation of a geosynthetic barrier positioned along the bottom and edges of the landfill cell. Furthermore, the absence of stormwater inflow from the surrounding landfill area is ensured due to the presence of drainage channels designed to handle its discharge.

The data used to calculate potential evapotranspiration and evapotranspiration are shown in Table 4.

Results and Discussion

Evapotranspiration and the Amount leachate

Annual heat index (J), calculated by formula $J=\sum_{i=1}^{12} J_i$, amounts 39.22.

Surface flow coefficient (a), whose value is calculated by the formula a = 0.016J + 0.5, amounts to 1.13.

Surface runoff coefficient (R) has a value of 0.00, which means that all precipitation is lost in the form of abstractions such as infiltration, controlled drainage, and evaporation, that is, there is no precipitation runoff into the landfill cell.

Table 4. Values for calculating corrected potential evapotranspiration and evapotranspiration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	48.55	48.77	65.71	74.06	80.00	66.94	53.23	43.71	50.45	48.87	51.97	62.61
Temperature (Ti)	-0.87	0.55	3.98	8.39	13.13	17.24	19.61	20.02	15.39	10.63	5.34	0.42
Montly heat index (Ji)	0.00	0.04	0.71	2.19	4.28	6.44	7.82	8.06	5.43	3.12	1.11	0.02
Infiltracio mm/month	51.81	46.54	42.70	13.40	0.00	0.00	0.00	0.00	0.00	0.00	25.43	61.21

Table 5. Corrected potential evapotranspiration and evapotranspiration in mm/month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ETx	-2.88	1.76	16.16	37.76	62.72	85.28	98.56	100.80	74.88	49.44	22.72	1.28	547.48
ETo	-3.26	2.23	23.01	60.66	109.91	155.68	177.52	168.06	112.09	64.98	26.54	1.40	898.82

Table 6. Amount of leachate.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
L (m^3/hour)	2.11	1.96	1.86	0.42	0	0	0	0	0	0	1.44	2.58
L (m^3/day)	50.52	47.09	44.61	10.09	0	0	0	0	0	0	34.58	61.82
L (m^3/month)	1515.60	1412.70	1338.30	302.70	0	0	0	0	0	0	1037.40	1854.60

Obtained values of corrected potential evapotranspiration (ETx) and reference evapotranspiration (ETo) for the time period from 1990-2020, are shown in Table 5.

The Thornthwaite method in the calculation of reference evapotranspiration relies on the mean air temperature and heat index. The mean daily air temperature for January is -0.87, which results in a negative value of reference evapotranspiration (-3.26). In relation to the Penman-Monteith calculation, the obtained value is significantly different due to the use of many other input parameters (in relation to Thornthwaite), such as solar radiation, wind speed, water vapor deficit, psychometric constants, etc., which results in obtaining a positive value of evapotranspiration for the same period (18.22).

Quantification of Leachate Production in the Savina Stena Sanitary Landfill

Based on meteorological data and evapotranspiration values, the amount of leachate produced per hour, day and month was calculated (Table 6).

The calculation of leachate generation was performed utilizing the hydrological balance equation, incorporating meteorological data spanning 31 years (1990-2020). The findings revealed that the highest leachate production is anticipated in December, with a daily rate of 61.82 m^3/day, equivalent to 1854.60 m^3 per month or 2.58 m^3 per hour. The results for January and February further validate the winter period as characterized by increased leachate generation. This aligns with the observation that evapotranspiration is at its lowest during these months, confirming the inverse relationship between seepage water and evapotranspiration.

During the months of May, June, July, August, September, and October, the leachate production is not zero in real conditions. It corresponds to the sum of water generated by the biodegradation of organic waste and the water content within the waste, minus the water retained by the waste. The age of the landfill, along with the thickness and composition of deposited waste, can significantly influence this value. However, considering that the „Savina Stena“ sanitary landfill is relatively young, these factors are not expected to exert a substantial impact on leachate production.

Comparison of Evapotranspiration Results Obtained by Different Calculation Methods

Fig. 2 showcases a graphical comparison between the evapotranspiration values obtained from the FAO AQUASTAT Climate Information Tool (ETo,pm) and those calculated using the Thornthwaite method (ETo). It is important to note that these methods utilize different sets of data for their respective calculations, which explains the observed differences in the obtained values.

The data provided by the FAO AQUASTAT Climate Information Tool is specific to its methodology, while

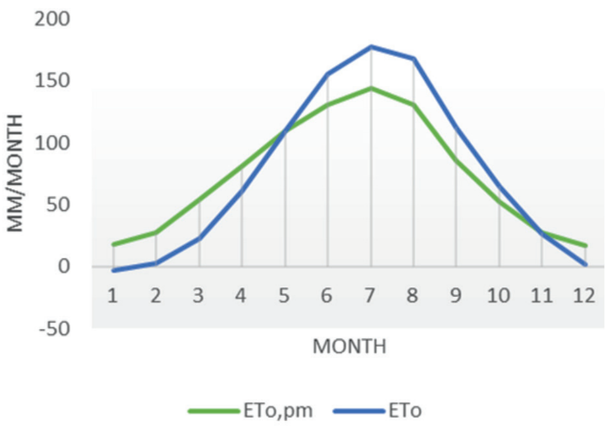

Fig. 2. Graphic representation of ETo,pm (FAO AQUASTAT Climate Information Tool) and ETo (Thornthwaite).

the Thornthwaite method relies on its own set of parameters and calculations. These methodological disparities contribute to the variations in the resulting evapotranspiration values.

By visually representing the comparison in Fig. 2, the graph highlights the distinct patterns and magnitude of the evapotranspiration values derived from each method.

A quantitative evaluation was conducted to compare the Thornthwaite method and the evapotranspiration values obtained from the FAO AQUASTAT Climate Information Tool. This comparison was performed using two error metrics: the root mean square error (RMSE) and the relative error (RE). The values needed for this calculation are shown in Table 2 (FAO AQUASTAT Climate Information Tool -ETo, pm) and Table 5 (Thornthwaite method- ETo).

The calculated RMSE value between the two methods was determined to be 0.807 mm/, indicating the average difference between the calculated and reference evapotranspiration values. This metric provides a measure of the overall accuracy of the Thornthwaite method in estimating evapotranspiration compared to the values obtained from the FAO AQUASTAT Climate Information Tool.

The relative error (RE) value, on the other hand, was determined to be 0.001. This metric represents the discrepancy between the calculated and reference evapotranspiration values, expressed as a percentage of the reference values. A low RE value suggests a relatively small deviation between the calculated and reference evapotranspiration values.

Based on the demonstrated relatively small RE compared to the comparative method, Torthwaite‘s method can be considered suitable for calculating evapotranspiration for the study area. The reasonable agreement of the two compared methods confirms the applied method as effective for areas for which there is not enough input data for other, more complicated methods. The compatibility of these two methods for calculating evapotranspiration was also confirmed by Santos et al. [27], who in their work compared Torthwaite‘s method with the standard PM FAO-56 method, showed the accuracy of this method (d>0.90; EPE<0.72 mm) and ranked it among the best for calculating evapotranspiration for Rio de Janeiro.

Conclusions

The sanitary landfill „Savina Stena“ holds significant importance for the northern region of Kosovo and Metohija. It provides a much-needed solution for proper municipal waste disposal, addressing the inadequate waste management practices in the four municipalities of Kosovska Mitrovica, Zvečan, Leposavić, and Zubin Potok. With its capacity meeting the waste disposal needs of these municipalities for a span of 20 years, the landfill plays a crucial role in ensuring environmental sustainability in the region.

In this study, evapotranspiration was estimated using the Thornthwaite method for the period from 1990 to 2020. Due to the unavailability of a nearby meteorological station, meteorological data were obtained from the FAO AQUASTAT Climate Information Tool based on the coordinates of the landfill site. The potential evapotranspiration (ETo) was calculated, and subsequently, the quantity of leachate expected to be generated within the landfill was determined using a straightforward hydrological balance equation. The results revealed that the highest volume of leachate production would occur in December, reaching 61.82 m^3/day. Similarly, elevated amounts of leachate were observed in January (50.52 m^3/day) and February (47.09 m^3/day), highlighting the winter months as significant contributors to leachate generation. These findings align with the expectation that leachate production is highest during periods of reduced evapotranspiration, which is typically observed during the winter season.

To validate the accuracy of the calculated evapotranspiration values, a comparison was made with the evapotranspiration values provided by the FAO AQUASTAT Climate Information Tool. This was accomplished by computing the root mean square error (RMSE) and relative error (RE) between the two sets of values. The analysis indicated an RMSE of 0.807 mm/ and an RE of 0.001, demonstrating a relatively small deviation between the calculated and FAO AQUASTAT values.Comparing the results of different methods, including the FAO AQUASTAT tool, using the root mean square error (RMSE) and relative error (RE), highlighted the discrepancies and potential variations caused by different calculation approaches.

These findings emphasize the need for further scientific activities to investigate the impact of climate change on evapotranspiration and leachate generation. Future research should focus on studying the potential effects of climate change on these parameters, enabling adaptation and mitigation strategies to be developed for more sustainable waste management practices in the face of changing climatic conditions. Understanding the implications of climate change will assist in improving waste management infrastructure and enhancing environmental resilience in the region.

Conflict of Interest

The authors declare no conflict of interest.

References

1. KALAMANDA O., VUJČIĆ S. Prečišćene procedne vode regionalne deponije Ramići, Poslovne studije, Purified leachate from the Ramići regional landfill, Business studies, 17 – 18, 47-52, **2017**.
2. HUSSIENY M.A., MORSY M.S., AHMED M., ELAGROUDY S., ABDELRAZIK M.H. Municipal Solid Waste and Leachate Characterization in the Cairo Metropolitan Area. Resources, **11** (11), 102, **2022**.
3. ANTIĆ K., PAP S., NOVAKOVIĆ M., SEKULIĆ M.T., ADAMOVIĆ D., RADONIĆ J. Removal of heavy metal ions from landfill leachate by phytoremediation using Eichhornia crassipes. Ind. Wastewater Treat. Other Top. Remov, 427, **2018**.
4. TAŁAŁAJ I.A. Quality of leachate from landfill with reverse osmosis concentrate recirculation. Journal of Ecological Engineering, **20** (8), 2, **2019**.
5. MORLING S. Landfill leachate, generation, composition, and some findings from leachate treatment at Swedish plants. Vann, **2**, 172, **2007**.
6. RENOU S., GIVAUDAN J.G., POULAIN S., DIRASSOUYAN F., MOULIN P. Landfill leachate treatment: Review and opportunity. Journal of hazardous materials, **150** (3), 468, **2008**.
7. GHIASINEJAD H., GHASEMI M., PAZOKI M., SHARIATMADARI N. Prediction of landfill leachate quantity in arid and semiarid climate: a case study of Aradkouh, Tehran. International Journal of Environmental Science and Technology, **18**, 589, **2020**.
8. KARANAC M., JOVANOVIĆ M., MIHAJLOVIĆ M., DAJIĆ A., STEVANOVIĆ D., JOVANOVIĆ J. Landfill design in Serbia. Recycling and Sustainable Development, **8** (1), 27, **2015**.
9. MORATIEL R., BRAVO R., SAA A., TARQUIS A.M., ALMOROX J. Estimation of evapotranspiration by FAO Penman-Monteith Temperature and Hargreaves-Samani models under temporal and spatial criteria. A case study in Duero Basin (Spain). Natural Hazards and Eatrh system Sciences, https://doi.org/10.5194/nhess-2019-250, **2019**.
10. ABEDI-KOUPAI J., DORAFSHAN M.M., JAVADI A., OSTAD-ALI-ASKARI K. Estimating potential reference evapotranspiration using time series models (case study: synoptic station of Tabriz in northwestern Iran). Applied Water Science, **12** (9), 212, **2022**.
11. RIJTEMA P.E. Calculation methods of potential evapotranspiration. **7**, ICW, **1959**.
12. WEISS O., SCHARF B., PITHA U. Evapotranspiration of technical substrates – methodology for calculating evapotranspiration of technical substrates. Journal of Ecological Engineering, **20** (9), **2019**.
13. BEZDAN A., DRAGINČIĆ J., PEJIĆ B., BLAGOJEVIĆ B., MESAROŠ M. Poređenje metoda za izračunavanje referentne evapotranspiracije na području meteorološke stanice Rimski Šančevi. Letopis naučnih radova Poljoprivrednog fakulteta, Comparison of methods for calculating reference evapotranspiration in the area of the meteorological station Rimski Šančevi. Annals of scientific works of the Faculty of Agriculture, **41** (2), 61, **2017**.
14. BAC S., IWANSKI S., KUCHAR L. Porównanie wybranych modeli do szacowania parowania potencjalnego w okresie zimowym dla potrzeb modelowania hydrologicznego. Acta Agrophysica, **12** (2 [162]), **2008**.
15. ZOTARELLI L., DUKES M.D., ROMERO C.C., MIGLIACCIO K.W., MORGAN K.T. Step by step calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method). Institute of Food and Agricultural Sciences. University of Florida, **8**, **2010**.
16. TRAJKOVIĆ S. Jednostavna empirijska formula za proračun referentne evapotranspiracije. Vodoprivreda. A simple empirical formula for the calculation of reference evapotranspiration. Water supply, **39** (229-230), 397, **2007**.
17. WANG L., GUO N., YUE P., HU D., SHA S., WANG X. Regulation of Evapotranspiration in Different Precipitation Zones and Its Application in High-Temperature and Drought Monitoring. Remote Sensing, **14** (24), 6190, **2022**.
18. IDRIZOVIĆ D.F., MATOVIĆ G.S., GREGORIĆ E.N., STRIČEVIĆ R.J. Analiza sedam indirektnih metoda za proračun referentne evapotranspiracije u klimatskim uslovima srbije. Analysis of seven indirect methods for the calculation of reference evapotranspiration in the climatic conditions of Serbia. Journal of Agricultural Sciences, Belgrade, **63** (1), **2018**.
19. CUI Z., WANG Y., ZHANG G.J., YANG M., LIU J., WEI L. Effects of improved simulation of precipitation on evapotranspiration and its partitioning over land. Geophysical Research Letters, **49** (5), e2021GL097353, **2022**.
20. SNYDER R.L., MORATIEL R., SONG Z., SWELAM A., JOMAA I., SHAPLAND T. Evapotranspiration response to climate change. In XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on **922**, 91, **2011**.
21. KUZAY M., MUSTAFA T.U.N.A., TOMBUL M. Determining the relationship of evapotranspiration with precipitation and temperature over Turkey. Journal of Agricultural Sciences, 35, **2022**.
22. HAGGAG M., KALISA J.C., ABDELDAYEM A.W. Projections of precipitation, air temperature and potential evapotranspiration in Rwanda under changing climate conditions. African Journal of Environmental Science and Technology, **10** (1), 18, **2016**.
23. NASTOS P., KAPSOMENAKIS J., KOTSOPOULOS S., POULOS S. Present and future projected reference evapotranspiration over Thessaly plain, Greece, based on regional climate models' simulations. Eur. Water, **51**, 63, **2015**.
24. CHAOUCHE K., NEPPEL L., DIEULIN C., PUJOL N., LADOUCHE B., MARTIN E., CABALLERO Y. Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change. Comptes Rendus Geoscience, **342** (3), 234, **2010**.
25. PRĂVĂLIE R. Analysis Of Temperature, Precipitation And Potential Evapotranspiration Trends In Southern Oltenia In The Context Of Climate Change. Geographia Technica, **9** (2), **2014**.

26. ALLEN R.G., PEREIRA L.S., RAES D., SMITH M. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, Italy, **300** (9), **1998** [In English].
27. SANTOS A.A.R., LYRA G.B., LYRA G.B., LIMA E.P., DE SOUZA J.L., DELGADO R.C. Evapotranspiração de referência em função dos extremos da temperatura do ar no estado do Rio de Janeiro. Irriga, **21** (3), 449, **2016**.
28. AQUASTAT Climate Information Tool. Available online: https://aquastat.fao.org/climate-information-tool (accessed on February 24, **2023**).