Assessing the Positioning of Rainwater Harvesting Systems in University Campuses Using Multi-Criteria Decision-Making Methods

ABSTRACT

Multi-Criteria Decision-Making (MCDM) Methods provide an instrumental tool for the investigation of current decision-making procedures. Such a decision-making problem is the process of determining the most suitable position for rainwater harvesting systems. In this short communication, TOPSIS method is suggested as a sample Multi-Criteria Decision-Making method and the main campus of Recep Tayyip Erdoğan University is used as an application of the method for this problem.TOPSIS method results show that the Student Life Center Roof is found as the most suitable location with a similarity coefficient of S_1^*=0.6789 also results show that Multi-Criteria Decision-Making methods can provide a fast and practical technique for determining the position for rainwater harvesting systems in university campuses.

Keywords: Multi-Criteria Decision-Making, TOPSIS, Rainwater Harvesting, Rainwater Management

1. INTRODUCTION

Multi-Criteria Decision-Making (MCDM) methods have been gaining increasing interest from researchers in a variety of fields worldwide in the last couple of decades. Technological developments, especially those that have enabled a swift processing of large amounts of calculations, have been a key factor in the increase in the number of studies on MCDM methods. The structure of current decision-making processes, where there are many alternatives for suppliers, opportunities, etc. and customers have a variety of demands on multiple aspects, requires a detailed procedure for making the optimal decision. The historical process of decision-making, where a single official makes the decision based on his/her views is no longer available today, and MCDM analysis is the pioneering alternative to performing this analysis.

One such decision-making problem is about the determination of optimal rainwater harvesting systems in university campuses. Rainwater harvesting is the provision of water falling to the ground through precipitation as a recyclable and usable resource in order to cope with the increasing water resources problem due to the effects of global climate change. In a world that currently has very limited water resources, rainwater harvesting systems are one of the most important requirements for human health and sustainable use of resources. In recent years, many studies and strategies have been put forward on this subject (Bekiryazıcı, 2023). Low Impact Development (LID), Sustainable Urban Draining Systems (SUDS) and Green Infrastructures (GI) are the leading planning strategies in this regard (Tang vd., 2021; Ferrans vd., 2022).

In this short communication, the use of MCDM methods is exemplified for determining the most suitable rainwater harvesting strategy in a university campus. Data from the main campus (Zihni Derin Campus) of Recep Tayyip Erdoğan University (RTEU) (Rize, Turkey) will be used as a numerical application and TOPSIS method will be used as the MCDM method. TOPSIS, or Technique for Order of Preference by Similarity to Ideal Solution, is a multi-criteria decision-making method that evaluates and ranks alternative solutions based on their proximity to the ideal solution and distance from the worst solution. Its importance lies in providing a systematic and objective approach for decision-makers to choose the most suitable alternative among a set of options, especially in complex decision scenarios involving multiple criteria. The fact that the method evaluates both the ideal and worst solutions at the same time, the ability to implement the method in a variety of areas and its easy application makes TOPSIS one of the most popular MCDM methods in the literature.

Recent studies on TOPSIS method and rainwater harvesting can be summarized as follows. Pandey et al. have analyzed TOPSIS method and its extensions for different applications [1]. Wątróbski et al. (2022) have used a TOPSIS-based approach to study sustainable cities and communities [2]. Rafiei-Sardooi et al. (2021) have used a hybrid method of TOPSIS and machine learning to evaluate urban flood risks [3]. Słyś and Stec (2020) have given a case study on centralized or decentralized rainwater harvesting systems [4]. Huang et al. (2021) have analyzed the contribution of rainwater harvesting to integrated water resource management [5]. Several other MCDM techniques, such as TODIM method [6] can also be used to analyze such decision-making problems. This short communication aims to address the implementation of this methodology to assess three alternative rainwater management strategies for the main campus of RTEU.

2. MATERIAL AND METHODS

TOPSIS method will be used to investigate the decision-making problem of interest. This method analyzes a decision matrix A given as

$$A = \begin{matrix} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \end{matrix}$$

where $a_{ij}, i = 1, \dots, m, j = 1, \dots, n$ denotes the value of alternative A_i according to the criterion C_j. After the criteria are grouped into two as the benefit criteria (J^+) and the cost criteria (J^-), the decision matrix is normalized using

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}}.$$

Tables should be explanatory enough to be understandable without any text reference. Double spacing should be maintained throughout the table, including table headings and footnotes. Table headings should be placed above the table. Footnotes should be placed below the table The weight vector W and the normalized decision matrix $R = (r_{ij})_{m\times n}$ are multiplied to obtain the weighted normalized decision matrix $T = (t_{ij})_{m\times n}$ such that $t_{ij} = r_{ij} \times w_j, i = 1, \dots, m, j = 1, \dots n$. The positive and negative ideal solutions are determined from the matrix $T = (t_{ij})_{m\times n}$. The positive ideal solution A^+ maximizes the benefit and minimizes the cost. Similarly, the negative ideal solution A^- minimizes the benefit and maximizes the cost. Each alternative is assessed in relation to their distances to the positive and negative ideal solutions, d_i^+ and d_i^-. The optimal alternative is determined by ranking the similarities to the worst solution $S_i^*, i = 1, \dots, m$ calculated as follows.

$$S_i^* = \frac{d_i^-}{d_i^- + d_i^+}.$$

The alternative with the highest S_i^* is determined to be the best alternative.

3. RESULTS AND DISCUSSION

The main campus, Zihni Derin Yerleşkesi (Campus), of RTEU is located in Rize city center in the northeastern coast of Turkey. The outline of the campus and the study area are shown in the figure below (Figure 1).

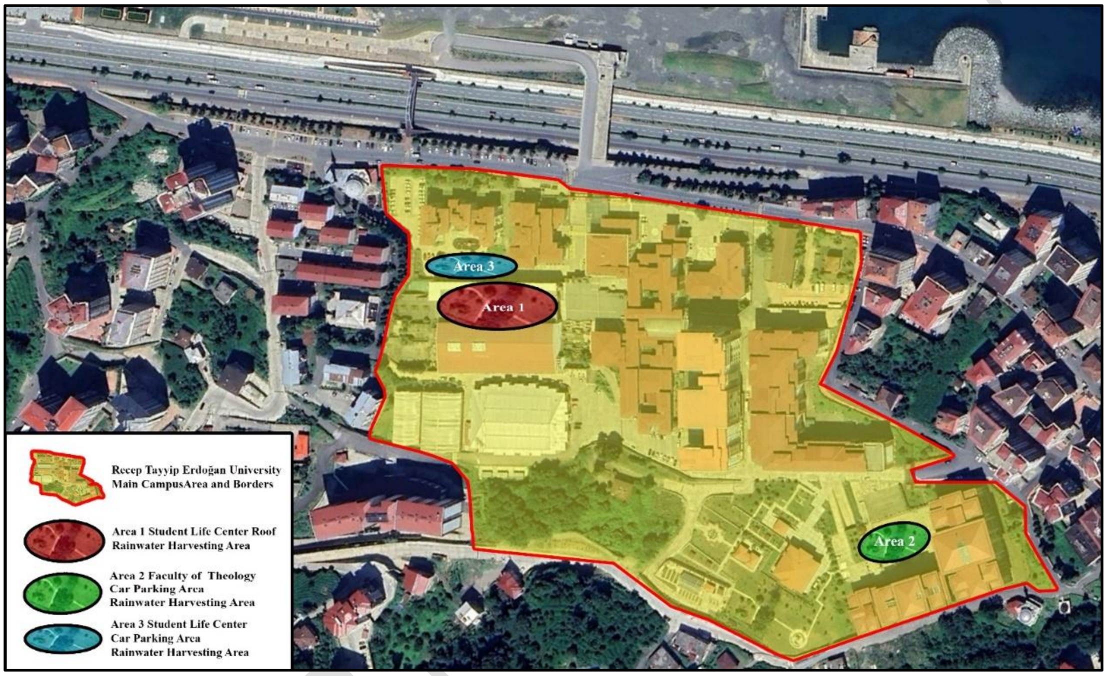

Fig. 1.Zihni Derin Campus of RTEU and main sectors of campus

The main campus is about 93000 m^2 and the three rainwater harvesting areas are proposed within the campus, namely:

"A1: Student Life Center Roof" (about 1500 m^2),

"A2: Faculty of Theology Car Parking Area" (about 750 m^2)

and

"A3: Student Life Center Car Parking Area" (about 600 m^2).

These alternatives are assessed using six criteria as

"C1: Surface Cover Permeability",

"C2: Slope",

"C3: Rainfall",

"C4: Cost",

"C5: Plant Biodiversity"

and

"C6: Area Size"

where C1, C5 and C6 are benefit criteria and the rest are cost criteria. The weight vector is defined as follows.

$$W = [0.30 \quad 0.15 \quad 0.15 \quad 0.10 \quad 0.10 \quad 0.20].$$

The decision matrix A is given as follows.

Table 1. The decision matrix A along with the alternatives, criteria and weights

	C1: Surface Cover Permeability	C2: Slope	C3: Rainfall	C4: Cost	C5: Plant Biodiversity	C6: Area Size
	(Benefit) 0.30	(Cost) 0.15	(Cost) 0.15	(Cost) 0.10	(Benefit) 0.10	(Benefit) 0.20
A1: Student Life Center Roof Rainwater Harvesting Area	1000	12	800	40000	3	1500
A2: Faculty of Theology Car Parking Area Rainwater Harvesting Area	425	4	1500	60000	7	750
A3: Student Life Center Car Parking Area Rainwater Harvesting Area	360	6	1700	55000	8	600

For instance, rainfall is a cost criterion with a weight of 0.15 (referring to 15% importance) and its value 1500 for A2 refers to the potential harvested rainwater amount for the second alternative (Faculty of Theology Car Parking Area Rainwater Harvesting Area) for the whole area of the alternative (about 750 m^2).

Results show that the positive ideal solution is

$$A^+ = [0.2621 \quad 0.0429 \quad 0.0499 \quad 0.0441 \quad 0.0724 \quad 0.1684],$$

whereas the negative ideal solution is found as

$$A^- = [0.0944 \quad 0.1286 \quad 0.1061 \quad 0.0662 \quad 0.0272 \quad 0.0674].$$

Hence the similarity coefficients $S_i^*, i = 1, \ldots, 3$ are found as below:

$$d_1^+ = 0.0969, d_1^- = 0.2049 \Rightarrow S_1^* = 0.6789,$$
$$d_2^+ = 0.1797, d_2^- = 0.0969 \Rightarrow S_2^* = 0.3504,$$
$$d_3^+ = 0.2055, d_3^- = 0.0788 \Rightarrow S_3^* = 0.2772.$$

This means that the first alternative, Student Life Center Roof, is the most suitable choice for the positioning of rainwater harvesting systems in RTEU main campus. The distance of A1 to the negative ideal solution is more than twice its distance to the positive ideal solution for this decision-making problem. The rest of the alternatives are closer to the negative ideal solution than they are to the positive ideal solution. Considering the distances to the positive ideal solution $d_i^+, i = 1,2,3$ and the distances to the negative ideal solution $d_i^-, i = 1,2,3$ also provides the same conclusion that positioning the rainwater management application on the roof of the Student Life Center (Area-1 in Figure 1) would provide the best result.

These results show that an assessment of rainwater harvesting systems and their positioning can be swiftly analyzed by the use of Multi-Criteria Decision-Making methods. The current literature contains studies on the design and structure of rainwater harvesting systems that make of rainfall data [7], Geographical Information System (GIS) [8] and remote-sensing based approaches [9]. Although there are multicriteria-backed approaches to determining the optimal sites for rainwater harvesting as well [10], this study extends the current literature with its focus to a university campus based on the data from RTEU main campus.

Some studies in the literature have supported our work by demonstrating that rainwater harvesting systems, similar to sustainable drainage systems, contribute to urban infrastructure and are effective in preventing adversities caused by heavy rainfall. In the studies conducted by Wang et al. (2017), sustainable drainage systems related to rainwater harvesting were designed. Jayasooriya et al. (2018) focused on the use of green infrastructure in rainwater methods in industrialized areas, with a case study in Melbourne. Haider et al. (2019) examined the evaluation of rainwater harvesting in dry regions within their flood risk method. Chiu et al. (2020) conducted studies on rainwater harvesting systems.

4. CONCLUSION

In this study, data from Zihni Derin Yerleşkesi, the main campus of Recep Tayyip Erdoğan University (RTEU) which is located in Rize, Turkey is used to give an application of a Multi-Criteria Decision-Making (MCDM) approach to determining the most suitable locations of rainwater harvesting systems in university campuses. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is used as the MCDM method to analyze three alternative locations for placing the rainwater harvesting systems are proposed and based on current data of the study area, the best alternative is determined. Area-1: Student Life Center Roof is found as the most suitable location with a similarity coefficient of $S_1^*=0.6789$, whereas the other alternatives "Area-2: Faculty of Theology Car Parking Area" and "Area-3: Student Life Center Car Parking Area" have similarity coefficients $S_2^*=0.3504$ and $S_3^*=0.2772$, verifying the result. The study, employing TOPSIS, identifies the Student Life Center Roof (Area-1) as the optimal rainwater harvesting site at Recep Tayyip Erdoğan University's main campus in Rize, Turkey. With a high similarity coefficient (S_1^*) of 0.6789, this approach offers a straightforward solution for campus decision-making, suggesting potential extensions for further refinement.This study can be extended by using a simulation backed approach, a comparison of results from more than one MCDM method and by using more extensive data obtained from GIS. However, the current short note underlines the availability of an accessible, rapid, and uncomplicated procedure for university campuses.

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