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Ranking of wastewater reuse allocation alternatives using a variance-based weighted aggregated sum product assessment method

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Abstract

This study develops a multi-criteria decision-making framework for optimizing the ranking of wastewater reuse allocation alternatives in a water/wastewater supply system. The method of stepwise weight assessment ratio analysis is used for weighting economic, socio-cultural, environmental, and technologic criteria and their 15 sub-criteria. The optimized weighted aggregated sum product assessment (WASPAS) method evaluates the optimal wastewater allocation alternatives. The last framework step performs a sensitivity analysis of the results. The results indicate the environmental alternative with a score of 0.176 is the best alternative, followed by landscape irrigation, industrial reuse, artificial recharge of aquifer, recreational, and agricultural irrigation in decreasing order of merit. The results of the sensitivity analysis show that changing the joint criteria of the alternatives' importance alters the relative importance of the alternatives but does not change their final ranking, thus demonstrating the reliability of wastewater allocations ranking by the optimized WASPAS method.

Keywords Optimal wastewater allocation · SWARA method · Optimized WASPAS method · Sensitivity analysis

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1 Introduction

The water crises that threaten different aspects of socio-economic sustainability and environmental health of many societies are due to numerous factors such as (1) rapid increase in population and the attempt to achieve food security (Wallace, 2000), (2) the occurrence of climatic change and its adverse impacts (Ashofteh et al., 2017; Golfam et al., 2021), (3) economic development of water-scarce regions compounded by the expanding competition among societal sectors for available water resources (Ridoutt and Pfister, 2010), and (4) surface water quality degradation (Singh et al., 2019; Azadi et al., 2019, 2021).

Several strategies to overcome water scarcity have emerged over time that may be called unconventional water resources (Loáiciga, 2015), such as desalination of sea water (Tsiourtis, 2001), construction of underground dams (Onder and Yilmaz, 2005), treatment and reuse of various effluents including municipal sewage, which is herein called wastewater (Angelakis and Durham, 2008), and rainwater harvesting to reduce water stress (Aladenola and Adeboye, 2010). The cited unconventional water sources must be compatible with the capacity and infrastructure of existing water supply systems and must be economically feasible and avoid environmental degradation.

2 Literature reviews

Section 2.1 reviews selected studies on wastewater reuse; Sect. 2.2 reports pertinent applications of MCDM methods to ranking wastewater reuse allocation alternatives.

2.1 Wastewater reuse

Tsadilas and Vakalis (2003) evaluated the benefits of using municipal wastewater treated in Larissa, Greece, for crops irrigation. Urbano et al. (2017) evaluated the physical, chemical, and microbiological effects on the yield of lettuce from (1) irrigation with freshwater and mineral fertilization, and (2) irrigation using treated wastewater and partial amount of mineral fertilization. The results indicated that lettuce irrigation with using treated wastewater preserved the soil, did not generate harmful bacteria, and raised soil nutrients, and weight of produce. Vergine et al. (2017) evaluated the reuse of agro-industrial wastewater treated for irrigation of the Apulia fields in Italy.

2.2 Application of MCDM techniques for ranking the wastewater reuse alternatives

The main challenges militating against wastewater reuse are: (1) determining the loads and frequency of environmental pollutants that are present in wastewater effluents, (2) choosing the treatments and regulations applicable to wastewater reuse, (3) calculating the costs-benefits of economic affecting wastewater reuse, and (4) overcoming the technical and cultural obstacles that may hinder the adoption of wastewater reuse. Multi-criteria decision-making methods can be effective in solving complex multi-dimensional issues surrounding wastewater reuse and for devising sustainable wastewater reuse policies. Multi-criteria decision-making methods are useful for solving complex issues related to water/wastewater systems and wastewater reuse (see, e.g., Golfam et al., 2019a; 2019b).

Chung and Kim (2014) relied on multi-criteria decision-making and applied the weighted sum method (WSM), the technique for order of preference by similarity to ideal solution (TOPSIS), the fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS), and the decision-making method under complete uncertainty (DMCU) to prioritize the sites for wastewater reuse in the Anyangcheon watershed, South Korea, considering climatic uncertainties in the decision-making process. Li et al. (2017) implemented the index system with analytical hierarchy process (AHP), the weighted suitability analysis (WSA), and grey relational analysis (GRA) methods to protect the marine environment of Luoyuan Bay Sea in Fujian (China) from industrial wastewater discharges. Mahjouri and Pourmand (2017) applied a method of social choice (SC) for assessing and ranking treated wastewater allocation scenarios for landscape irrigation, agricultural lands and artificial recharge of aquifers in the Tehran, Iran.

Pourmand and Mahjouri (2018) reported a fuzzy decision-making methodology named modified fuzzy social choice (MFSC) to find the optimal scenario for allocating effluent of wastewater treatment plants to agricultural regions and recharge aquifers in Tehran. Piadeh et al. (2018) presented a framework to investigate the sustainability of combined wastewater treatment systems by evaluating of possible alternatives and their processes with the modified analytical hierarchy process (MAHP), using 32 indexes (four criteria and eight sub-criteria), five scenarios, and prioritizing alternatives.

Tayebikhorami et al. (2019) implemented the preference ranking organization method for enrichment evaluation (PROMETHEE) decision-making method to specify the best solution in Pareto fronts obtained with the non-dominated sorting genetic algorithm II (NSGA-II) to achieve an optimal and objective allocation of treated wastewater to stakeholders in the eastern part of the Tehran basin, Iran.

Ghorbani Mooselu et al. (2020) applied the Elimination et Choice in Translating to Reality (ELECTRE) technique to achieve the optimal treated wastewater (TW) Tehran Province, Iran. Paul et al. (2020) evaluated the potential of reclaimed-water use for agricultural irrigation in California implementing integrated geospatial analysis with the AHP. Vaseghi et al. (2020) presented a GRA decision-making method to priority the treated wastewater (TWW) for natural resources, urban green space, industry, and agriculture of the Isfahan North Wastewater Treatment Plant, Iran. Zolfaghary et al. (2021) developed Geographic Information System (GIS) and AHP method to define the adaptability of wastewater reuse for the agricultural of the Golestan, Iran.

The previous studies show there are several MCDM methods including outranking approaches such as PROMETHEE (Brans and Vincke, 1985) and ELECTRE (Roy, 1991), distance to ideal point methods such as TOPSIS (Hwang and Yoon, 1981), and pairwise comparison methods such as AHP (Saaty, 1980) and SC, GRA (Deng, 1982) that have been applied to wastewater reuse allocation. The novelty of this work is applying the SWARA method to weigh criteria and sub-criteria for ranking wastewater reuse alternatives. The optimized WASPAS decision-making method is introduced to rank the sewage reuse alternatives, and to choose the best alternative of wastewater allocation to use locations in a water/wastewater supply system in Iran. The key feature of the WASPAS method compared with other multi-criteria decision-making (MCDM) methods is combining the weighted product model (WPM) and the weighted sum model (WSM), which increases the accuracy of the results. This work develops an optimized WASPAS (i.e., determining the optimal joint criterion λ) to select the best alternative for wastewater reuse allocation between six proposed alternatives.

3 Methods

This section describes the methods used in the present study. Section 3.1 describes determination of the criteria, sub-criteria, and alternatives. Section 3.2 describes the AWARA method, and Sect. 3.3 explains the optimization with the WASPAS ranking method.

The main criteria, their sub-criteria, and proposed alternatives for wastewater allocation are determined by the experts group. The weights of criteria and sub-criteria sets are determined with the SWARA method. Wastewater allocation alternatives are prioritized with the optimized WASPAS method. The flowchart of this paper's methodology is displayed in Fig. 1.

3.1 Determining the criteria, sub-criteria, and alternatives

The main criteria set are (1) environmental, (2) economic, (3) technological, and (4) socio-cultural in nature. For each of these criteria, several sub-criteria are defined to represent the types of circumstances specific to each criterion. The environmental, economic, technological, and socio-cultural criteria have five, four, four, and two sub-criteria, respectively (see Fig. 2). Six alternatives are herein defined for allocating wastewater to demand locations. These alternatives are the reuse of wastewater in the following sectors: (1) industrial, (2) groundwater recharge, (3) agricultural irrigation, (4) landscape irrigation, (5) environmental, and (6) recreational.

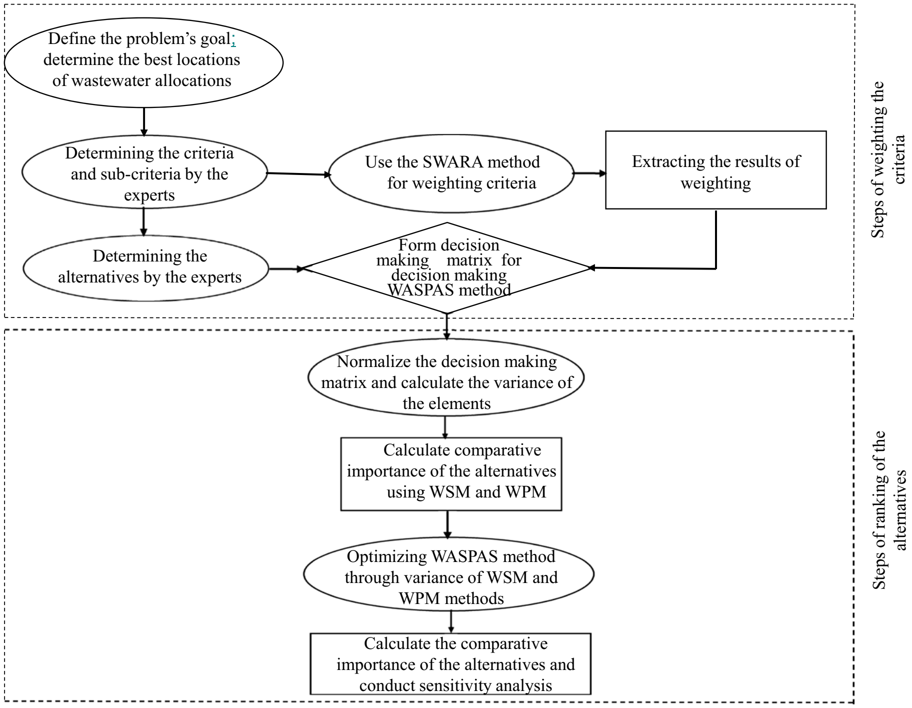

Fig. 1 Flowchart of the SWARA weighting and the optimized WASPAS ranking methods

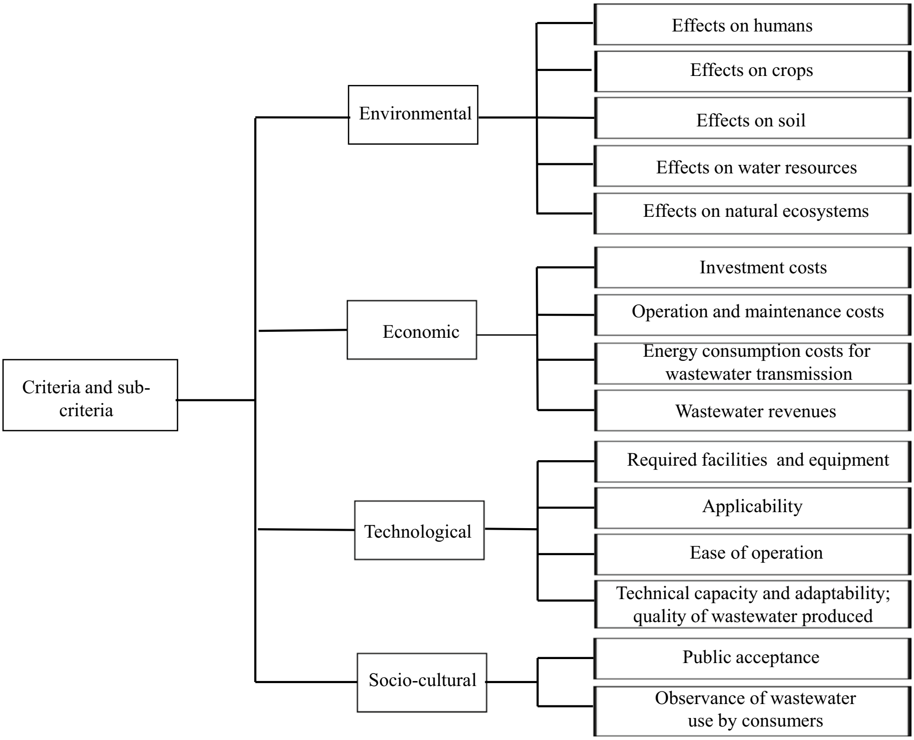

Fig. 2 Tree diagram of criteria and sub-criteria

3.2 The SWARA method

The method of SWARA was presented by Keršulienè et al. (2010), which ranks the decision-making criteria given their expected importance. The most significant advantages of the method are its ability to assess the accuracy of experts during the weighting process, its easiness of implementation, and limited comparisons between criteria. The SWARA method has been proven successful in weighting tasks involving complex and atypical cases (Khodadadi et al., 2017). The steps of the SWARA method are as the following:

- First step: determining the set of independent criteria.

The main criteria and sub-criteria, and the independent criteria are chosen and dependent criteria are omitted. A dependent criterion is a criterion whose performance depends on the other criteria.

- Step two: Sorting the criteria by their values.

The criteria are sorted according to their values. The criterion with the highest value receives the top rank, which with the second highest value is second ranked, and so forth.

- Step three: Determining the comparative importance of the average value

Starting from the second criteria, the relative importance of each criterion *j* is determined in relation to the previous criterion *j-1*. This ratio is called the comparative importance of the average value, s_j.

- Step four: Determining the coefficient k_j.

The values of the k_j are calculated with Eq. (1):

$$k_j = \begin{cases} s_j + 1, & j > 1 \\ 1, & j = 1 \end{cases} \tag{1}$$

where k_j is coefficient, and j is criterion.

- Step five: Determining the recalculated weights of the criteria.

The recalculated weight of each criterion is calculated with Eq. (2):

$$w_j = \begin{cases} \frac{x_{j-1}}{k_j}, & j > 1 \\ 1, & j = 1 \end{cases} \tag{2}$$

in which w_j = recalculated weight of each criterion; and x_{j-1} = recalculated weight of the previous criterion.

- Step six: Determining relative weights of the criteria.

The relative weights of the criteria are calculated with Eq. (3):

$$q_j = \frac{w_j}{\sum_{j=1}^{n} w_j} \tag{3}$$

in which q_j = relative weights of criteria j; and n = number of criteria.

3.3 Optimization with the WASPAS ranking method

The WASPAS multi-criteria decision-making method is used to prioritize and select the best wastewater allocation alternative in a water/wastewater supply system which was proposed by Zavadskas et al. (2012). The WASPAS method combines the well-known decision-making methods, i.e., WSM and WPM methods, which makes it accurate compared to the other MCDM methods. Also, it is reliable in that it yields final ranking of alternatives with low reversibility, it applies simple and logical mathematical concepts, and it features multiple capabilities in relation to other multi-criteria optimization methods. The WASPAS steps are as the following:

- Step one: Formation of the initial decision-making matrix.

The decision-making matrix is formed by *m* alternatives and *n* criteria.

$$x = \left[x_{ij}\right]_{m*n} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{4}$$

in which x_{ij} = performance of alternative i regarding to criteria j, A_m = the alternatives set, and C_n = the criteria set.

- Step two: Normalization of the decision-making matrix.

The elements of the decision-making matrix are normalized with the linear normalization method. Equations (5) and (6) normalize the benefits and costs criteria, respectively:

$$\overline{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{5}$$

$$\overline{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{6}$$

in which $\overline{x}_{ij}$ = elements of normalized decision-making matrix; $\max_i x_{ij}$ = the largest element of the decision-making matrix; and $\min_i x_{ij}$ = the smallest element of the decision-making matrix. The cost sub-criteria are the investment, operation and maintenance, and energy consumption costs for wastewater transmission.

- Step three: Calculating the variance of the normalized matrix's elements.

The variance of the normalized matrix's elements is calculated with Eq. (7).

$$\sigma^2(\overline{x}_{ij}) = (0.05\overline{x}_{ij})^2 \tag{7}$$

in which $\sigma^2(\overline{x}_{ij})$ = variance of the normalized decision-making matrix's elements.

- Step four: Calculating the relative significance of alternatives by the WSM method

The WSM method, introduced by Fishburn (1967), is a commonly used multi-criteria decision-making method to determine the relative significance of the alternatives by summing of the criteria weights multiplied by the elements of the normalized decision-making matrix:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x}_{ij} w_j \tag{8}$$

in which $Q_i^{(1)}$ = relative importance of the alternatives is calculated by WSM; and w_j = weights of the criteria.

- Step five: Calculating relative importance of alternatives by the WPM method.

The WPM method (Starr, 1969) calculates the relative significance of the alternatives with the following equation:

$$Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \tag{9}$$

in which $Q_i^{(2)}$ = relative importance of the alternatives by the WPM method.

- Step six: Determining the variance of the relative importance of alternatives by the WSM method with the following equation:

$$\sigma^2(Q_i^{(1)}) = \sum_{i=1}^{n} w_j^2 \sigma^2(\bar{x}_{ij}) \tag{10}$$

in which $\sigma^2(Q_i^{(1)})$ = variance of relative importance of the alternatives by the WSM method.

- Step seven: Determining the variance of the relative importance of alternatives by the WPM method with the following equation:

$$\sigma^2(Q_i^{(2)}) = \sum_{i=1}^{n} \left[\frac{\prod_{i=1}^{n} (\bar{x}_{ij})^{w_j} w_j}{(\bar{x}_{ij})^{w_j} (\bar{x}_{ij})^{(1-w_j)}} \right] \tag{11}$$

in which $\sigma^2(Q_i^{(2)})$ = variance of the relative importance of the alternatives by the WPM method. The ranking accuracy and effectiveness of the WASPAS method is improved with Eq. (12) proposed by Zavadskas et al. (2006):

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) Q_i^{(2)} \tag{12}$$

- Step eight: Determining the joint criterion for each alternative

This work calculates the optimal value of the joint criterion λ to find the minimum dispersion $\sigma^2(Q_i)$ and assuring maximum accuracy in the estimation of the alternatives. The derivative of Eq. (12) is set equal to zero and solved for λ:

$$2\lambda\sigma^2(Q_i^{(1)}) - 2\sigma^2(Q_i^{(2)}) + 2\lambda\sigma^2(Q_i^{(2)}) = 0 \tag{13}$$

$$\lambda = \frac{\sigma^2(Q_i^{(2)})}{\sigma^2(Q_i^{(1)}) + \sigma^2(Q_i^{(2)})} \tag{14}$$

in which λ = joint criterion.

- Step nine: Calculating the final relative importance of alternatives

The final relative importance of alternatives is calculated with the following equation:

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) Q_i^{(2)}, \quad \lambda = 0, \ldots., 1 \tag{15}$$

in which Q_i = final relative importance of the alternatives.

The alternative with the highest value of Q_i is the best alternative. Evidently Eq. (15) also ranks the alternatives according to their values.

4 Case study

The study region is located in one of the provinces of Iran. This area whose long-term average rainfall (past 32 years) of 120.8 mm is a hot and arid area with limited water resources. There is a rapid growth of urbanization that relies on groundwater extraction for its water use which causes decreasing groundwater storage, especially in recent years. The poor quality of available water in the study area renders it unsuitable for drinking, domestic, and agricultural uses. Water transfer from other areas to the study area is not economically feasible due to geographical and economic factors. Therefore, wastewater reuse is the only option to solve the current water crisis in the study region.

The first phase of building a treatment plant has been completed in the study area with the aim of reusing the treated wastewater for landscape irrigation. It is planned to build other phases in the coming years to deliver higher standards of treatment. Finding the best sectors to reuse the treated wastewater considering regarding all the environmental, economic, technologic, and socio-cultural factors is the goal in this case.

This work relied on the viewpoints of 14 experts. Among them, 5 are experts in water and wastewater operation facilities, 2 are technology experts, 2 are research managers, 1 has expertise in the operation of unconventional water resources, and 4 are experts in the field of water planning.

5 Results and discussion

This section exhibits the results of the methods that were introduced in Sect. 3. Section 5.1 reports the results of the AWARA method. Section 5.2 summarizes the results of the optimized WASPAS ranking method. Sections 5.2.1, 5.2.2, 5.2.3 and 5.2.4 describe the results of the WSM, the WPM methods, determining the optimal λ for final ranking, and the analysis of sensitivity, respectively.

5.1 Results of the SWARA method

The main criteria were identified and questionnaires were answered by the 14 experts producing the relative values of the main criteria (Fig. 3). According to Fig. 3, the environmental criterion had the highest value due to the importance of wastewater for preventing environment pollution, illness, and other adverse impacts with regard to the experts' opinions. The economic criterion was the second best ranked based on the necessity of receiving economic benefits from wastewater; the technological and socio-cultural criteria were ranked third and fourth, respectively. The criteria values by the experts were ranked with the SWARA method to produce their weights, which are listed in Table 1. The SWARA results for the values of the sub-criteria are listed in Tables 2, 3, 4 and 5.

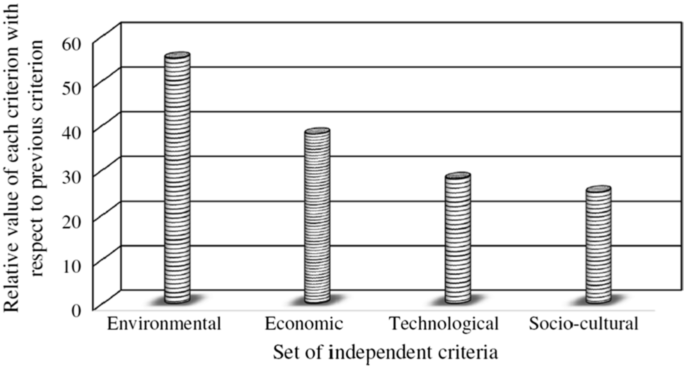

Fig. 3 Relative values of criteria

Table 1 Final weights of the main criteria

Criteria	s_j*	k_j	w_j	q_j
Environmental		1	1	0.314
Economic	0.286	1.286	0.778	0.245
Technological	0.071	1.071	0.726	0.228
Socio-cultural	0.071	1.071	0.678	0.213

*s_j = The comparative importance of the average values of each criterion relative to the criterion listed immediately below it. For example, the s_j of the environmental criterion relative to economic criterion equals 0.286

Sum of the weights = 1

Table 2 Weights of the environmental sub-criteria

Environmental sub-criteria	s_j	k_j	w_j	q_j
Effect on human		1	1	0.271
Effect on water resources	0.214	1.214	0.824	0.223
Effect on crop	0.214	1.214	0.678	0.184
Effect on soil	0.071	1.071	0.633	0.172
Effect on natural ecosystem	0.143	1.143	0.554	0.150

Sum of the weights = 1

Table 3 Weights of the economic sub-criteria

Economic sub-criteria	s_j	k_j	w_j	q_j
Investment costs		1	1	0.375
Wastewater revenues	0.429	1.429	0.7	0.262
Operation and maintenance costs	0.286	1.286	0.544	0.204
Energy consumption costs for wastewater transmission	0.286	1.286	0.423	0.159

Sum of the weights = 1

Table 4 Weights of the technological sub-criteria

Technological sub-criteria	s_j	k_j	w_j	q_j
Applicability		1	1	0.334
Required facilities and equipments	0.214	1.214	0.824	0.275
Technical ability in adaptation and quality of wastewater produced by type of consumption	0.286	1.286	0.641	0.214
Ease of operation	0.214	1.214	0.527	0.176

Sum of the weights = 1

Table 5 Weights of the socio-cultural sub-criteria

Socio-cultural sub-criteria	s_j	k_j	w_j	q_j
Public acceptance		1	1	0.517
Observance of wastewater consumption considerations by consumers	0.071	1.071	0.933	0.483

Sum of the weights = 1

Table 6 Final weights of the environmental, economic, technological, and socio-cultural sub-criteria

Weights of criteria	Sub-criteria	Weights	Final weights
0.314	Effect on human	0.271	0.085
	Effect on water resources	0.223	0.070
	Effect on crop	0.184	0.058
	Effect on soil	0.172	0.054
	Effect on natural ecosystem	0.150	0.047
0.245	Investment costs	0.375	0.092
	Wastewater revenues	0.262	0.064
	Operation and maintenance costs	0.204	0.049
	Energy consumption costs for wastewater transmission	0.159	0.039
0.228	Applicability	0.334	0.076
	Required facilities and equipment	0.275	0.063
	Technical ability in adaptation and quality of wastewater produced by type of consumption	0.214	0.049
	Ease of operation	0.176	0.040
0.213	Public acceptance	0.517	0.110
	Observance of wastewater consumption considerations by consumers	0.483	0.103

The weight of each sub-criterion was multiplied by the weight of the relevant main criterion to produce the final weight of each sub-criterion. Results of the calculations are listed in Table 6, which shows that the most important sub-criteria for the environmental, economic, technological, and socio-cultural criteria were human effects, investment costs, applicability, and public acceptance, respectively. The final weights of each

Table 7 Relative importance of alternatives by the WSM method

Alternatives	Relative importance of alternatives
Industrial	0.850
Artificial recharge	0.778
Agricultural irrigation	0.761
Landscape irrigation	0.856
Environmental	0.857
Recreational	0.769

Table 8 Relative importance of alternatives by the WPM method

Alternatives	Relative importance of alternatives
Industrial	0.828
Artificial recharge	0.764
Agricultural irrigation	0.708
Landscape irrigation	0.834
Environmental	0.846
Recreational	0.734

sub-criterion were applied to the optimized WASPAS multi-criteria decision-making method to prioritize the wastewater reuse alternatives.

5.2 Results of the optimized WASPAS method

The decision-making matrix was formed by the opinions of the experts. The elements of the matrix were normalized. The WSM and WPM methods results were then calculated.

5.2.1 Results of the WSM method

The six alternatives for optimal allocation of wastewater to the demand locations were ranked based on the performance of each sub-criterion relative to each alternative. The decision-making matrix was formed. The relative importance of alternatives was calculated with the WSM method, whose results are listed in Table 7. It is seen in Table 7that the WSM method assigned the environmental alternative the first or best rank with relative importance equal to 0.857; landscape irrigation, industrial use, artificial recharge, recreational, and agricultural irrigation received the second, third, fourth, fifth, and sixth ranks, respectively.

5.2.2 Results of the WPM method

The relative importance of alternatives for optimal wastewater allocation was determined according to the decision-making matrix. The results are listed in Table 8. The WPM method processed the relative importance of alternatives to assign the first or best rank to the environmental alternative; landscape irrigation, industrial use, artificial recharge, recreational irrigation, and agricultural irrigation received the second, third, fourth, fifth, and sixth ranks, respectively.

5.2.3 Determining the optimal λ for final ranking

The optimal λ determines the final relative importance for each alternative and assures the accuracy of the final ranking of alternatives. The value of λ for each alternative was calculated, followed by the determination of the final relative importance and the normalized final relative importance of each alternative, which are listed in Table 9. Table 9 indicates that the environmental alternative with the final relative score equal to 0.176, which is the best alternative for optimal wastewater allocation, would have an important role in decreasing the water stress according to the defined criteria and sub-criteria. Landscape irrigation, industrial use, artificial recharge, recreational irrigation, and agricultural irrigation received the second, third, fourth, fifth, and sixth ranks, respectively.

5.2.4 Sensitivity analysis

Sensitivity analysis evaluates the reliability of the results calculated with the optimized WASPAS method. Sensitivity analysis evaluates changes in the final ranking of the alternatives with respect to the errors of determination of the initial criteria values. The λ parameter is the effective factor determining the final results in a decision-making problem solved with the optimized WASPAS method because it is a function of the decision-making matrix variance, whose elements are based on experts' opinions. Therefore, λ values equal to 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1 were assigned and the alternatives were ranked for each of these λ values. The results are shown in Fig. 4, which shows that changing the joint criterion λ does not change the ranking of the alternatives; therefore, the results from the optimization WASPAS method are reliable.

5.2.5 Comparing the results with two other MCDM methods

A review of the previous studies shows that several multi-criteria decision-making methods with different approaches have been applied to rank wastewater reuse allocation alternatives. Here, using the weight of criteria that was obtained in this study by the

Table 9 Prioritizing the alternatives of optimal wastewater allocation

Alternatives of wastewater allocation	Final relative importance of alternatives	Final normalized relative importance of alternatives
Industrial	0.850	0.174
Artificial recharge	0.778	0.160
Agricultural irrigation	0.761	0.156
Landscape irrigation	0.856	0.175
Environmental	0.857	0.176
Recreational	0.770	0.158

Sum of the relative importance of alternatives = 1

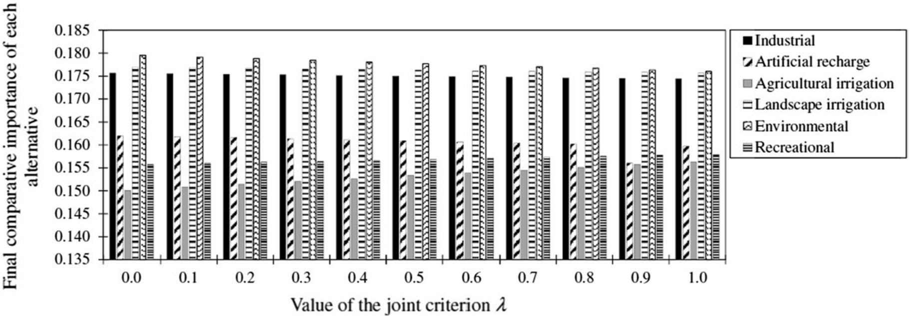

Fig. 4 Results of the sensitivity analysis

SWARA method and using the decision-making matrix of the manuscript, the ranking of the alternatives was obtained by two other MCDM methods.

These two methods are TOPSIS and additive ratio assessment (ARAS) methods in which both of them are based on the formation of the decision-making matrix in the first step. The approach of the TOPSIS is based on distance to ideal point, but the ARAS is based on a simple comparison to describe complex problems. The ranking of the alternatives based on these methods is shown in Table 10.

Because of the different approach in each MCDM method, the rankings of the alternatives are different. But none of them applies a combination of the results of two MCDM methods except the WASPAS method.

The most important advantage of the WASPAS MCDM method is the combination of two MCDM methods, i.e., WSM and WPM methods that brings together their advantages and improves the accuracy of the results.

The significant advantage of the optimized WASPAS method rather than the normal WASPAS method is determining the optimal λ value, which presents the best combination of the two multi-criteria decision-making methods for obtaining more accurate results. The optimal λ value is calculated based on the practical concept of the variance.

In measuring of the accuracy, the assumption is that the relative importance of an alternative is function of the criteria values and the differences in the relative importance of the alternatives depend on the initial criteria values. The errors for determining

Table 10 Results of comparing the alternatives ranking using TOPSIS and ARAS methods

Alternatives	TOPSIS		ARAS	
	Score	Ranking	Utility degree of an alternative (K_i)	Ranking
Industrial	0.222	1	0.839	3
Artificial recharge	0.205	5	0.765	4
Agricultural irrigation	0.192	4	0.732	6
Landscape irrigation	0.171	2	0.840	2
Environmental	0.110	6	0.849	1
Recreational	0.097	3	0.742	5

the initial values of criteria are stochastic. Using the optimal λ to reach final ranking ensures the minimum estimated variance of the relative importance of each alternative i.

6 Policy and management implications

This paper's approach has been herein demonstrated to be practical for use by experts, decision-makers, and managers involved in the water and wastewater industry who seek to reduce environmental pollution caused by wastewater production and enhance water supply by wastewater reuse. Reuse of treated wastewater based on the priorities for proposed alternatives produces economic, environmental, and health benefits.

7 Conclusions

Reuse of effluent and treated wastewater in various use sectors (except in the drinking use sector) is a growing means of augmenting water supply. However, the complexity of decision-making for optimal wastewater allocation to various users poses challenges given the diversity of stakeholders and their multiple and sometimes conflicting objectives. This paper developed a multi-criteria decision-making method for solving the optimal wastewater reuse allocation problem in a water/wastewater supply system.

This paper's method defined environmental, economic, industrial, and socio-cultural criteria and sub-criteria whose weights were calculated with the SWARA method. The SWARA method assigned weights equal to 0.314, 0.245, 0.228, and 0.213 to the environmental, economic, industrial, and socio-cultural criteria, respectively. The results of the SWARA method demonstrated that the environmental dimension was the most important factor because of its direct impact on health and ecosystems.

The presence of pollutants in the wastewater would pose threats to human health. The optimized WASPAS method ranked the wastewater reuse alternatives according to their final relative importance. Results indicate the environmental alternative with a score of 0.176 was the best alternative for wastewater allocation. The ranking of the other alternatives in decreasing order of value assigned second, third, fourth, fifth, and sixth places to landscape irrigation, industrial use, artificial recharge of aquifer, recreational use, and agricultural irrigation, respectively. Reusing the treated wastewater in fish farming would be beneficial for improving food security in the region and helping to boost employment in spite of the high level of treatment needed.

A sensitivity analysis of the ranking of alternatives was carried out. The optimization concept is to calculate the optimal value of λ to find minimum dispersion $\sigma^2(Q_i)$ and assuring maximum accuracy of the estimation of the alternatives. Therefore, several values of the joint criterion λ were considered because its value is decisive in the final ranking of alternatives. This work's results demonstrated that changing the values of λ did not change the final ranking therefore proving the high reliability of this method in multiple decision-making.

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