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Application of the ARCAS group-hybrid decision-making method for wastewater reuse

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Abstract
This work applies a multi-criteria group decision-making (MCGDM) method to select the best treated wastewater reuse allocation alternative for augmenting water supply. The additive ratio compromise assessment (ARCAS) hybrid method is based on the integration of stepwise weight assessment ratio analysis (SWARA) (for weighting the criteria) with the adapted additive ratio assessment (ARAS) multi-criteria decision-making method in a group decision-making framework with new normalization scheme for the decision-making matrix's elements. For this purpose, four main criteria with 15 sub-criteria and six alternatives for treated wastewater reuse, i.e., landscape irrigation, agricultural irrigation, application in the industrial sector, artificial aquifer recharge, recreational sector, and supplying environmental demands are considered. Experts' opinions are gathered and the steps of the ARCAS method are applied. The results show that the agricultural irrigation alternative is top ranked. The final ranking of the treated wastewater reuse alternatives is achieved by evaluating the alternatives and revising the criteria's weights by the experts.

Keywords Treated wastewater allocation · Group decision-making methods · ARCAS hybrid method · SWARA method · ARAS multi-criteria decision-making method

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1 Introduction

Many countries face worsening water shortages that are accentuated by climate change (Azadi et al., 2021; Tsanis et al., 2011), by human activities that contaminate water sources (Rao & Mamatha, 2004), and by lack of or poor integrated management of water resources and consumption (wPahl-Wostl et al., 2008). On the demand side, some factors such as limited allocation of required financial resources for appropriate operation and maintenance of water facilities (Rimi Abubakar, 2016), inadequate patterns of water consumption (Soltanjalilie et al., 2013), and poor adaptation to climate change) exacerbate the water stress (Ashofteh et al., 2019; Iglesias & Garrote, 2015).

2 Literature review

Water stress may lead to adverse consequences on other vital sectors such as diminishing food security (Hanjra & Qureshi, 2010), spreading of disease (Motoshita et al., 2011), reducing the production of some industries, and declining economic output (Park, 2009). Treated wastewater reuse is a useful alternative (Ebrahimzadeh Azbari et al., 2021) because it increases the water supply (e.g., Loáiciga, 2015), and reduces the environmental effects of wastewater discharge (Golfam et al., 2021).

2.1 Reusing treated wastewater

Many publications have investigated the application of wastewater reuse. Papaiacovou, (2001) evaluated the reuse of domestic wastewater in Limassol city, Cyprus, for groundwater recharge, irrigation of public amenity areas, and golf courses. Nasri and Soleimani, (2011) concluded that reusing wastewater for landscape irrigation increased the landscape area. El Moussaoui et al., (2019) showed that reusing domestic wastewater reduced water stress and led to the preservation of natural resources, increased soil fertility, and improved agriculture in the Marrakesh city, Morocco. Baawain et al., (2020) reported that reusing wastewater for non-edible crops irrigation, urban practices, groundwater recharge and industrial activities were suitable options according to public acceptance in Oman. Partyka and Bond, (2022) investigated guidelines governing irrigation with reuse water and recommendations for improving reusing wastewater for produce irrigation to reduce freshwater use. Shrivastava et al., (2022) investigated the necessity and key challenges of reusing wastewater in the food and beverage industry according to increasing water use and associated wastewater discharge. Tampo et al., (2022) evaluated the suitability of unconventional water resources for irrigation and domestic uses. The results showed that treated wastewater was better than groundwater for irrigation according for fertilizer supply and allocation to permissible surface water used based on Water Suitability Indicators for Irrigation Purpose (WSI-IPs) values.

2.2 The role of MCDM methods for ranking treated wastewater

The key challenge in using unconventional water resources is the optimal allocation of those resources to different demand points. The multiplicity of stakeholders with different goals and criteria renders decision-making complex. Optimal water allocation in this instance requires a collaborative effort involving experts from various fields. Multi-criteria group decision-making is particularly well suited to identify optimal resource allocation in this instance. A few multi-criteria decision-making methods that have been applied in water/wastewater systems have been reported. Kalbar et al., (2012) applied the technique for order of preference by similarity to ideal solution (TOPSIS) method to rank wastewater treatment alternatives in Mumbai. The results showed the best wastewater treatment was membrane bio-reactor (MBR). Jing et al. (2013) developed a hybrid stochastic-interval analytic hierarchy process (SIAHP) to select the best wastewater reuse among city moat landscaping, municipal reuse, industrial reuse, and agricultural irrigation. The results showed that industrial reuse was chosen as the best alternative. Kim et al., (2015) developed an iterative framework for robust reclaimed wastewater allocation (IFRWA) in the Anyangcheon basin, Korea, under various climate change scenarios with the TOPSIS method. Gdoura et al. (2015) integrated the analytical hierarchy process (AHP) method with geographic information system (GIS) to select the best area for groundwater recharge with reclaimed water in the Nabeul–Hammamet shallow aquifer, Tunisia. Golfam et al., (2019) applied the AHP and the TOPSIS methods to determine the best scenario for adaptation to climate change effects in the agricultural sector in the Gharanghu basin, Iran. The results showed that 25–15% were the best alternatives according to the AHP and TOPSIS methods, respectively. Paul et al. (2020) integrated GIS with AHP method to investigate the potential of wastewater reuse for agricultural use to reduce the pressure on freshwater sources in California. Karanjeeka and Regulwar (2021) selected the best alternative for wastewater reuse in Aurangabad city by fuzzy analytic hierarchy process (F-AHP) and fuzzy technique for order preference by similarity to ideal situation (F-TOPSIS). The results showed that environmental and recreational reuse and urban reuse were the best alternatives selected by the F-AHP and F-TOPSIS methods, respectively. Savun-Hekimoğlu et al., (2021) combined demand forecasting methods with the FTOPSIS and fuzzy preference ranking organization method for enrichment evaluations (FPROMETHEE) multi-criteria decision-making methods to evaluate five water management alternatives in Istanbul, Turkey. The results showed that reusing graywater is the best alternative for reducing water demand.

Due to the complexities of treated wastewater allocation, especially in terms of environmental and economic, natural resources and human health, it is necessary to use a multi-criteria group decision-making method. The ARCAS group decision-making method involves experts who individually rank the management alternatives. In other words, the experts' opinions are not integrated to form a decision-making matrix. Achieving a consensus in group decision-making leads to a final decision that is acceptable to the decision makers (Pérez et al., 2018). Selecting the best method for solving a problem is first and also the most important challenge. Using hybrid multi-criteria decision-making methods solves decision-making problems by specifying the methods for choosing the weighting criteria and ranking the alternatives. Combining several techniques in hybrid decision-making methods can handle stakeholders' preferences, similar or contradicting criteria, and uncertain environments (Zavadskas et al., 2016). In other words, hybrid methods permit the independent evaluation of the experts' opinions, and a final consensus is reached through negotiations between them. It is the key difference between the hybrid MCDM methods and other MCDM methods.

This work develops the ARCAS group-hybrid decision-making method to rank and select the best treated wastewater-reuse allocation alternative. The ARCAS hybrid method integrates the SWARA method for weighting criteria with the adapted multi-criteria decision-making ARAS method into a group decision-making framework. This work introduces a new approach for normalizing the decision-making matrix's elements based on the preferred rating (PR) of stakeholders, which yields results close to the real ideal solution of the stakeholder groups in water/wastewater supply systems. The method herein presented achieves a closer interaction between decision-makers and stakeholders than what is possible with conventional multi-attribute decision-making methods. This permits an effective selection of the best alternative that is compatible with the preferences of stakeholders and decision-makers partaking in treated wastewater-reuse systems. Allocating treated wastewater using various MCDM methods was reported by Afshar and Mariño, (1989), by integrating the AHP method, goal programming (GP), and the Leopold matrix for allocating water reuse to various stakeholders in Najafabad, Iran (Fooladi Dehghani & Khoshfetrat, 2020), by developing the interval type-2 fuzzy TOPSIS method to allocate water and reclaimed wastewater to different sectors (Pourmand et al., 2020). This work presents the first application of the ARCAS hybrid-group for allocating treated wastewater.

3 Methodology

This study develops the ARCAS hybrid-group decision-making method to select the best alternative for reusing treated wastewater. The flowchart of the ARCAS method is displayed in Fig. 1. The ARCAS method includes the SWARA and the adapted ARAS methods. The SWARA and ARAS methods are described first, followed by a review of the ARCAS method. This study's calculation were performed with the Excel spreadsheet.

3.1 The SWARA method

KERšULIENè et al. (2010) introduced the SWARA method for weighting criteria and sub-criteria. The basis of the SWARA method is negotiation between experts for

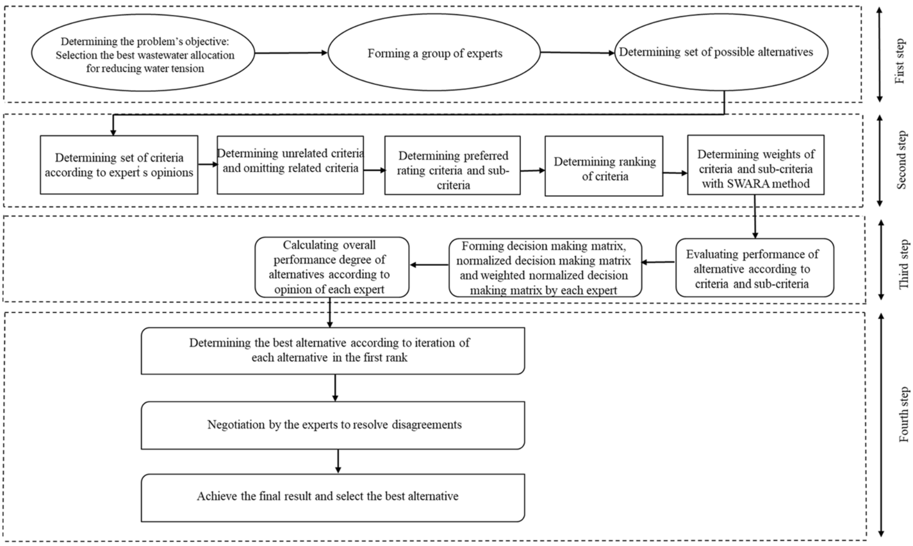

Fig. 1 Flowchart of the ARCAS hybrid method

determining relative importance of criteria j in relation to criteria j-1. The steps of the SWARA method are as follows:

(1) *First step* determining independent criteria and sorting them based on the criteria's values.

The independent criteria are determined and then ranked in descending order based on the values that are assigned by the experts.

(2) *Second step* determining the comparative importance of the average value.

The comparative importance of each criterion is denoted by s_j, which is determined in relation to the previous criterion.

(3) *Third step* determining the coefficient k_j:

The coefficient k_j is determined with Eq. (1) based on the comparative importance of the average value that is determined in step (2):

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

in which k_j = coefficient; and j = criterion.

(4) *Fourth step* determining the initial weights of the criteria.

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

$$q_j = \begin{cases} 1, & j = 1 \\ \dfrac{q_{j-1}}{k_j}, & j > 1 \end{cases} \tag{2}$$

in which q_j = initial weight of each criterion; and q_{j-1} = initial weight of a comparison criterion.

(5) *Fifth step* determining the relative weight of each criterion

The relative weight of each criterion is calculated with Eq. (3).

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

in which w_j = relative weight of each criterion; and n = number of criteria.

3.2 The ARAS multi-criteria decision-making method

The basis of ARAS multi-criteria decision-making method was presented by Zavadskas and Turskis, (2010). It states that it is possible to understand complex world phenomena by using relative comparisons. The results of ARAS ranking method are achieved according to the degree of utility of each alternative. The steps of this method are described below.

(1) *First step* forming the decision-making matrix

The decision-making matrix is formed according to the performance of each alternative relative to each criteria.

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

in which x_{ij} = the decision-making matrix's elements, A_i = alternatives set, and C_j = criteria set.

(2) *Second step* determining optimal value of each criterion.

The optimal value of each criterion is calculated considering cost or benefit criteria. The optimal value of each criterion is calculated with Eqs. (5) and (6) for benefit and cost criteria, respectively.

$$x_{oj} = \frac{\max}{i} x_{ij} \tag{5}$$

$$x_{oj} = \frac{\min}{i} x_{ij}^{*} \tag{6}$$

in which x_{oj} = optimal value of criterion j, $\frac{\max}{i} x_{ij}$ = maximum value of benefit criteria, and $\frac{\min}{i} x_{ij}^{*}$ = minimum value of cost criteria stored in column j.

(3) *Third step* calculating the normalized decision-making matrix

The decision-making matrix's elements are normalized by using linear normalization methodology with Eq. (7) for benefit and cost criteria, respectively.

$$r_{ij} = \begin{cases} \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}; \; j \in \Omega_{\max} \\ \frac{\frac{1}{x_{ij}^{*}}}{\sum_{i=0}^{m} \frac{1}{x_{ij}^{*}}}; \; j \in \Omega_{\min} \end{cases} \tag{7}$$

in which r_{ij} = normalized decision-making matrix' s elements, $\Omega_{\max}$ = benefit criteria set, and $\Omega_{\min}$ = cost criteria set.

(4) *Fourth step* calculating the weighted normalized decision-making matrix

In this step, the weighted normalized decision-making matrix is calculated with Eq. (8).

$$v_{ij} = w_j r_{ij} \tag{8}$$

in which v_{ij} = the weighted normalized decision-making matrix's elements.

(5) *Fifth step* calculating the overall performance rating of each alternative

The optimality of each alternative is calculated with Eq. (9).

$$S_i = \sum_{j=1}^{n} v_{ij};\ i = 1, 2, \cdots, m \tag{9}$$

in which S_i = the overall performance rating of each alternative.

(6) *Sixth step* calculating degree of utility for each alternative

The degree of utility of each alternative is calculated with Eq. (10).

$$Q_i = \frac{S_i}{S_0} \tag{10}$$

in which Q_i = degree of utility for each alternative, which ranges between zero and one, and S_0 = overall performance index of the optimal alternative. The alternative that has the largest value of Q_i is selected as the best alternative.

3.3 The normalization procedure based on distances from the decision-maker's preferences

All multi-criteria decision-making methods rely on various criteria expressed in different scales for measuring the performance of alternatives. Various normalization methods such as geometric, eigenvector, vectoral, rumina, and others are used for normalizing the criteria and thus making possible the comparison on a uniform scale. Stanujkic et al., (2013) evaluated the methods that were suggested by Weitendorf, (1976) and Juttler, (1966), and reported new method that allows decision-makers to state their preferences about the preferred performance rating accurately. Stanujkic and Zavadskas, (2015) reported a simplified equation for normalizing the criteria based on distances from the decision-maker's preferences, which is given by Eq. (11).

$$\begin{aligned} r_{ij} &= \frac{x_{ij}-x_{oj}}{x_j^+-x_j^-} \\ x_j^+ &= \begin{cases} \max\limits_i x_{ij};\ j \in \Omega_{\max} \\ \min\limits_i x_{ij};\ j \in \Omega_{\min} \end{cases} \\ x_j^- &= \begin{cases} \max\limits_i x_{ij};\ j \in \Omega_{\min} \\ \min\limits_i x_{ij};\ j \in \Omega_{\max} \end{cases} \end{aligned} \tag{11}$$

in which x_j^+ = maximum value of performance rating of criterion j, x_j^- = minimum value of performance rating of criterion j.

The value of r_{ij} can be positive, zero, or negative which are interpreted as follows:

If the value of r_{ij} is positive the rating of x_{ij} is higher than the preferred rating.
If the value of r_{ij} is zero the rating of x_{ij} is equal to the preferred rating.
If the value of r_{ij} is negative the rating of x_{ij} is lower than the preferred rating.

The weighted normalized decision-making matrix calculated with this method has zero, positive or negative elements.

3.4 Framework of the integrated ARCAS method

The ARCAS group-hybrid method was introduced by Stanujkic et al., (2017). It integrates two methods with different approaches to achieve a unified framework in the form of group decision-making, and uses a new approach for normalizing the decision-making matrix's elements. Group decision-making deals with complexities such as conflict resolution between the members of a group, reaching consensus, aggregation of personal preferences and applying it to group ratings. The framework of ARCAS method consists of several phases, whose steps are as follows:

(A) Identification of the problem and forming the set of alternatives
The decision problem is thoroughly assessed and the set of possible alternatives and the group of experts are formed.
(B) Determining set of criteria and sub-criteria, and evaluating them
The set of evaluation criteria is determined and their weights are calculated as explained below.
(C) The set of criteria and sub-criteria is determined by a group of experts, and each expert defines the desired level of rating for each criterion independently, according to Table 1.
(D) The relevance and the ranking of the criteria are determined according to with Eq. (12):

$$o_j = \frac{\sum_{k=1}^{K} q_j^k}{K} \tag{12}$$

in which o_j = the relative relevance of criterion j, q_j^k = rating of criterion j according to opinion of expert k, and K = number of experts.
Each expert calculates the final weight of each criteria and sub-criteria applying the SWARA method according to his opinions.
(E) Evaluation of alternatives

Table 1 Ratings for evaluating criteria

Rating	Meaning
1	Very low
2	Low
3	Medium low
4	Medium
5	Medium high
6	High
7	Very high

(F) Each expert forms a decision-making matrix whose elements depend on the performance of each alternative relative to each criterion and sub-criterion. The meanings of ratings are listed in Table 2.
(G) The decision-making matrix's elements are normalized with Eq. (11). The weighted normalized decision-making matrix is calculated according to the steps of the ARAS method.
(H) Each expert determines the overall performance rating for each alternative. The ARCAS method applies the Si, whose value ranges between 1 and −1, for ranking the alternatives. Each expert forms a ranking of alternatives based on his/her opinion to achieve a final ranking. Evidently, the number of rankings is equal to the number of experts.
(I) Negotiation and selecting the best alternative
An alternative takes the first place according to the opinions of all experts is selected as the best alternative. However, different ranking orders may be obtained for each set of alternatives due disagreement between experts. When disagreement arises the experts can resolve it through negotiation to achieve a final decision. Negotiation may involve one or more of the following:
(J) Changing the initial preferred rating of criteria or change the weights of the criteria;
(K) Changing the ranking of alternatives according to additional parameters;
(L) Changing the ranking of alternatives by modifying the preferred rating of the experts and considering the modified ratings to rank the alternatives in the decision-making procedure.

4 Case study

The study area is an arid region (central region) in Iran, where there is pressing need to augment the water supply. The study area's arid climate, population growth and industrial expansion have caused water shortages. In addition, declining water quality has exacerbated the water shortage. Relying on unconventional water resources appears promising in augmenting the water supply in the study area.

This research involved five experts. One of them has expertise in the field of economics and the others are experts in the fields of environment and water resources management.

Table 2 Ratings for evaluating alternatives

Rating	Meaning
1	Very poor
2	Poor
3	Medium poor
4	Fair
5	Medium good
6	Good
7	Very good

5 Results

This section describes the results obtained with the ARCAS method.

5.1 ARAS method

5.1.1 Forming the group of experts and identifying the alternatives

A group of five experts was formed and six treated wastewater reuse alternatives (i.e., reuse in industries, artificial recharge of aquifers, irrigation of agricultural sector, recreational sector, landscape irrigation, and supplying environmental demands) were determined.

5.1.1.1 Determining the criteria, sub-criteria, and their preferred ratings The existence of priorities and different goals in consumer groups in a water/wastewater supply system requires various criteria for optimal treated wastewater allocation to reduce water stress. This work identified four main criteria: economical, technological, environmental, and socio-cultural, each with its own sub-criteria. See Fig. 2 for details about the criteria and sub-criteria.

The sub-criteria allow evaluating the system with respect to the criteria accurately. The sub-criteria of operation and maintenance costs, energy consumption costs for wastewater transmission, and investment costs are cost sub-criteria; the other sub-criteria are benefits.

The referred ratings of criteria and sub-criteria by five experts (E_1, E_2, E_3, E_4, and E_5) are listed in Tables 3 and 4.

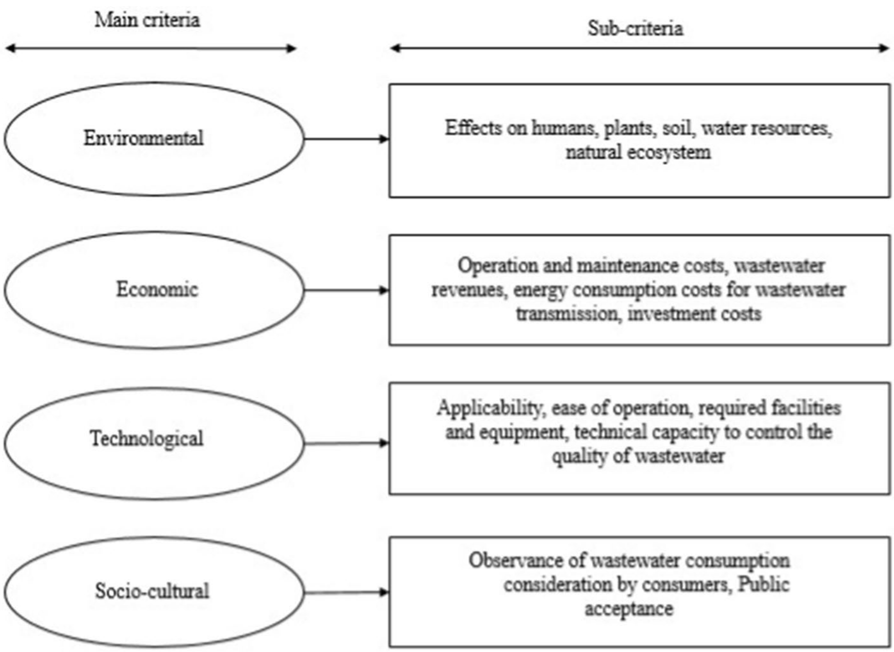

Fig. 2 The criteria and sub-criteria

Table 3 Preferred ratings of the criteria according to the experts' opinions

Preferred ratings				
Experts group	C_1	C_2	C_3	C_4
E_1	7	6	7	5
E_2	4	4	5	4
E_3	6	5	5	6
E_4	6	4	5	6
E_5	6	5	5	5

C_1 = Environmental criteria, C_2 = Economic criteria, C_3 = Technological criteria, and C_4 = Socio-cultural criteria

Table 4 Preferred ratings of the sub-criteria according to the experts' opinions

Preferred rating															
Experts group	$C_{1\text{-}1}$	$C_{1\text{-}2}$	$C_{1\text{-}3}$	$C_{1\text{-}4}$	$C_{1\text{-}5}$	$C_{2\text{-}1}$	$C_{2\text{-}2}$	$C_{2\text{-}3}$	$C_{2\text{-}4}$	$C_{3\text{-}1}$	$C_{3\text{-}2}$	$C_{3\text{-}3}$	$C_{3\text{-}4}$	$C_{4\text{-}1}$	$C_{4\text{-}2}$
E_1	7	7	6	5	7	6	7	7	5	7	6	7	5	6	7
E_2	6	4	6	4	5	7	6	6	7	5	5	7	6	5	6
E_3	6	5	4	4	5	4	5	6	4	6	5	5	4	5	4
E_4	6	5	5	6	5	5	6	7	7	7	7	7	5	6	7
E_5	7	5	7	6	5	6	6	7	7	6	5	6	5	6	5

$C_{1\text{-}1}$ = Effect on humans, $C_{1\text{-}2}$ = effect on plants, $C_{1\text{-}3}$ = effect on soil, $C_{1\text{-}4}$ = effect on water resources, $C_{1\text{-}5}$ = effect on natural ecosystem, $C_{2\text{-}1}$ = investment costs, $C_{2\text{-}2}$ = operation and maintenance costs, $C_{2\text{-}3}$ = energy consumption costs for wastewater transmission, $C_{2\text{-}4}$ = wastewater revenues, $C_{3\text{-}1}$ = applicability, $C_{3\text{-}2}$ = required facilities and equipment, $C_{3\text{-}3}$ = technical ability to adapt the quality of produced wastewater, $C_{3\text{-}4}$ = ease of operation, $C_{4\text{-}1}$ = public acceptance, $C_{4\text{-}2}$ = observance of wastewater consumption consideration by consumers

Table 5 Relative relevance of the criteria

	C_1	C_3	C_4	C_2
Relative relevance	5.8	5.4	5.2	4.8

Table 6 Relative relevance of the sub-criteria

	$C_{1\text{-}1}$	$C_{1\text{-}3}$	$C_{1\text{-}5}$	$C_{1\text{-}2}$	$C_{1\text{-}4}$	$C_{3\text{-}3}$	$C_{3\text{-}1}$	$C_{3\text{-}2}$	$C_{3\text{-}4}$	$C_{4\text{-}2}$	$C_{4\text{-}1}$	$C_{2\text{-}3}$	$C_{2\text{-}2}$	$C_{2\text{-}4}$	$C_{2\text{-}1}$
Relative relevance	6.4	5.6	5.4	5.2	5	6.4	6.2	5.6	5	5.8	5.6	6.6	6	6	5.6

5.1.2 Calculating the relative relevance

The relative relevance of criteria and sub-criteria were calculated with Eq. (12). The relative relevance of criteria and sub-criteria are listed in Tables 5 and 6, respectively.

According to Table 5 and the calculated relative relevance the environmental criterion received the highest relative relevance (5.8) for optimal treated wastewater allocation, followed by the technological, socio-cultural, and economical criteria with relative relevance equal to 5.4, 5.2 and 4.8, respectively.

According to the results of Table 6 the socio-cultural sub-criterion with relative relevance equals to 6.4, technical ability to adopt the quality of produced wastewater sub-criterion with relative relevance equals to 6.4, acceptance of wastewater use by consumers sub-criterion with relative relevance equals to 5.8, and energy consumption costs for wastewater transmission sub-criterion with relative relevance equals to 6.6 were the most important sub-criteria with respect to the environmental, technological, socio-cultural and economic criteria, respectively.

5.2 SWARA weighting method

The criteria were sorted according to the ranking of the previous steps. The relative importance of criteria was determined and the weight of the criteria and sub-criteria were calculated according to the SWARA weighting method. The results of main criteria's weighting and the results of environmental sub-criterion weighting for the first expert are listed in Tables 7 and 8, respectively, as an example.

The weights of the technological, socio-cultural and economical sub-criteria were determined by the first expert. The results are listed in Table 9.

The weights of the main criteria and sub-criteria determined by the first expert with the SWARA method were multiplied by the weights of the corresponding sub-criteria to obtain the final weights of sub-criteria. The results are listed in Table 10.

Table 7 Weights of the criteria (first expert)

Criteria	s_j	k_j	w_j	q_j
C_1		1	1	0.461
	0.652			
C_3		1.652	0.605	0.279
	0.840			
C_4		1.840	0.329	0.152
	0.398			
C_2		1.398	0.235	0.108
				Sum of the weights = 1

S_j = comparative importance of the average values relative to the previous criterion. For example, the comparative importance of the average value of the environmental criterion (C_1) relative to the technological criterion (C_3) equals 0.652,and that of C_3 relative to C_4 = 0.840

s_j = comparative importance of the average values relative to the previous criterion. For example, the comparative importance of the average value of the environmental criterion (C_1) relative to the technological criterion (C_3) equals 0.652,and that of C_3 relative to C4 = 0.840

Table 8 Weights of the environmental sub-criteria (first expert)

Sub-criteria	s_j	k_j	w_j	q_j
C1-1		1	1	0.456
	0.950			
C1-3		1.950	0.513	0.234
	0.400			
C1-5		1.400	0.366	0.167
	0.800			
C1-2		1.800	0.204	0.093
	0.880			
C1-4		1.880	0.108	0.049
				Sum of the weights = 1

Table 9 Weights of the sub-criteria (first expert)

Technological		Socio-cultural		Economic	
C_{3-3}	0.513	C_{4-2}	0.600	C_{2-3}	0.427
C_{3-1}	0.258			C_{2-2}	0.254
C_{3-2}	0.145	C_{4-1}	0.400	C_{2-4}	0.186
C_{3-4}	0.085			C_{2-1}	0.133
Sum of the weights = 1		Sum of the weights = 1		Sum of the weights = 1	

Table 10 Final weights of the environmental, technological, socio-cultural and economic sub-criteria (first expert)

Weights of criteria	Sub-criteria	Weights of sub-criteria	Final weights of sub-criteria
0.461	C_{1-1}	0.456	0.210
	C_{1-3}	0.234	0.108
	C_{1-5}	0.167	0.077
	C_{1-2}	0.093	0.043
	C_{1-4}	0.049	0.023
0.279	C_{3-3}	0.513	0.143
	C_{3-1}	0.258	0.072
	C_{3-2}	0.145	0.040
	C_{3-4}	0.085	0.024
0.152	C_{4-2}	0.600	0.091
	C_{4-1}	0.400	0.061
0.108	C_{2-3}	0.427	0.046
	C_{2-2}	0.254	0.028
	C_{2-4}	0.186	0.020
	C_{2-1}	0.133	0.014

Table 11 Weights of the main criteria for the second to fifth expert

Weights of criteria				
Criteria	E_2	E_3	E_4	E_5
C_1	0.480	0.374	0.395	0.458
C_3	0.242	0.331	0.264	0.283
C_4	0.173	0.181	0.188	0.169
C_2	0.105	0.114	0.153	0.089

Table 12 Final weights of the sub-criteria for the second to fifth expert

Final weights of sub-criteria				
Sub-criteria	E_2	E_3	E_4	E_5
$C_{1\text{-}1}$	0.224	0.167	0.191	0.192
$C_{1\text{-}3}$	0.121	0.098	0.100	0.114
$C_{1\text{-}5}$	0.071	0.052	0.056	0.073
$C_{1\text{-}2}$	0.042	0.034	0.031	0.046
$C_{1\text{-}4}$	0.023	0.023	0.018	0.033
$C_{3\text{-}3}$	0.101	0.137	0.109	0.111
$C_{3\text{-}1}$	0.064	0.075	0.069	0.075
$C_{3\text{-}2}$	0.046	0.062	0.048	0.055
$C_{3\text{-}4}$	0.031	0.057	0.038	0.042
$C_{4\text{-}2}$	0.114	0.100	0.119	0.099
$C_{4\text{-}1}$	0.059	0.081	0.069	0.070
$C_{2\text{-}3}$	0.048	0.053	0.062	0.041
$C_{2\text{-}2}$	0.030	0.028	0.046	0.026
$C_{2\text{-}4}$	0.017	0.021	0.027	0.014
$C_{2\text{-}1}$	0.010	0.011	0.018	0.008
Sum of the weights	1	1	1	1

The same process was repeated by four other experts, whose criteria weights and final sub-criteria weights are listed in Tables 11 and 12, respectively.

5.3 ARCAS method

5.3.1 Evaluating alternatives

The preferred rating was first determined by each expert and the decision-making matrix was formed. The decision-making matrices for the first and second experts as examples are listed in Tables 13 and 14, respectively, for exemplary purpose. This procedure was performed by the three other experts and their decision-making matrices were formed.

Table 13 Decision-making matrix (first expert)

Sub-criteria	C_{1-1}	C_{1-3}	C_{1-5}	C_{1-2}	C_{1-4}	C_{3-3}	C_{3-1}	C_{3-2}	C_{3-4}	C_{4-2}	C_{4-1}	C_{2-3}	C_{2-2}	C_{2-4}	C_{2-1}
q^T	0.210	0.108	0.077	0.043	0.023	0.143	0.072	0.040	0.024	0.091	0.061	0.046	0.028	0.020	0.014
PR	7	6	7	7	5	7	7	6	5	7	6	7	7	5	6
A_1	6	7	4	7	7	6	5	6	7	7	4	7	7	6	6
A_2	6	5	5	6	7	7	4	5	6	6	5	3	5	6	4
A_3	7	5	5	5	5	7	6	5	4	6	5	4	5	7	5
A_4	5	6	7	6	6	3	4	4	5	2	2	6	6	7	2
A_5	6	4	3	7	5	7	6	5	6	5	6	4	7	6	7
A_6	5	4	2	6	5	5	2	4	6	1	2	3	4	3	3

A_1 = industrial sector, A_2 = artificial recharge, A_3 = agricultural irrigation, A_4 = landscape irrigation, A_5 = environmental and A_6 = recreational

Table 14 Decision-making matrix (second expert)

	Sub-criteria														
	$C_{1\text{-}1}$	$C_{1\text{-}3}$	$C_{1\text{-}5}$	$C_{1\text{-}2}$	$C_{1\text{-}4}$	$C_{3\text{-}3}$	$C_{3\text{-}1}$	$C_{3\text{-}2}$	$C_{3\text{-}4}$	$C_{4\text{-}2}$	$C_{4\text{-}1}$	$C_{2\text{-}3}$	$C_{2\text{-}2}$	$C_{2\text{-}4}$	$C_{2\text{-}1}$
q^T	0.224	0.121	0.071	0.042	0.023	0.101	0.064	0.046	0.031	0.114	0.059	0.048	0.030	0.017	0.010
PR	6	6	5	4	4	7	5	5	6	6	5	6	6	7	7
A_1	6	3	5	2	5	5	4	4	4	5	3	4	7	7	6
A_2	7	4	5	6	7	5	5	6	3	5	3	4	5	5	6
A_3	7	6	7	6	6	5	4	5	4	7	4	3	4	5	5
A_4	5	5	4	7	5	4	3	4	3	4	1	2	5	4	4
A_5	6	6	6	5	6	7	5	3	6	5	4	5	3	4	5
A_6	2	3	1	2	2	2	2	2	1	2	1	2	2	3	3

5.3.2 Normalization of the decision-making matrices and calculating the weighted normalized decision-making matrices

The experts' decision-making matrices were normalized. The obtained results from normalization of the decision-making matrix's elements by the first and second experts, used as exemplary, are listed in Table 15.

The weighted normalized decision-making matrix was calculated by multiplying the weight of each sub-criterion by the normalized decision-making matrix's elements that are relevant to that sub-criterion. The calculated results from weighting the normalized decision-making matrix's elements for the first and second experts as examples are listed in Table 16.

5.3.3 Determining the overall performance rating

The overall performance rating of each alternative was determined and the alternatives were ranked. The overall performance ratings and rankings of alternatives by all experts are listed in Table 17. Table 17 shows different ranking orders of alternatives by the experts. For instance, according to the opinion of the first expert the agricultural irrigation alternative with comparative performance S_i equal to −0.120 was selected as the best alternative, and industrial, artificial recharge, environmental, landscape irrigation and recreational alternatives are ranked from second to sixth, respectively. Considering the S_i value for each ranking treated wastewater allocation to the agricultural irrigation sector was ranked first by the first, second, and fourth experts and has the largest number of appearances in the first rank. Yet, the opinions of the third and fifth experts ranked artificial recharge as the best alternative.

5.3.4 Negotiation and selection of the best alternative

The opinions of the third and fifth experts differed from the preferred rating of the other experts. The performance of the alternatives was revised by the third and fifth experts to bring the opinions of these experts closer to the preferred rating by the other experts. The decision-making matrices in the second iteration by the third and fifth experts are listed in Table 18.

In addition, the third and fifth experts reviewed the preferred rating of criteria to achieve consensus with other experts in selecting the agricultural irrigation as the best alternative and bring their opinions closer to the preferred rating of the decision-making space. The weights of the environmental sub-criteria were re-calculated and are listed in Table 19.

The final weights of the environmental sub-criteria by the third and fifth experts are listed in Table 20. The changes performed in the second iteration led to revised overall performance ratings. The results of the alternatives' ranking are listed in Table 21. It is seen in Table 21 the S_i values for the agricultural irrigation alternative were the largest. Therefore the agricultural irrigation was selected as the best alternative.

6 Conclusion

Reuse of treated wastewater as an unconventional water supply resource expands the water supply for high-consumption sectors and thus reduces the stress on scarce water resources. Optimal allocation of unconventional resources faces many challenges due to diverging objectives of stakeholders. The group multi-criteria decision-making method is useful for solving multi-dimensional problems.

Table 15 Normalized decision-making matrices (first and second experts)

Experts	Alternatives	Sub-criteria														
		$C_{1\text{-}1}$	$C_{1\text{-}3}$	$C_{1\text{-}5}$	$C_{1\text{-}2}$	$C_{1\text{-}4}$	$C_{3\text{-}3}$	$C_{3\text{-}1}$	$C_{3\text{-}2}$	$C_{3\text{-}4}$	$C_{4\text{-}2}$	$C_{4\text{-}1}$	$C_{2\text{-}3}$	$C_{2\text{-}2}$	$C_{2\text{-}4}$	$C_{2\text{-}1}$
1	A_1	−0.5	0.333	−0.6	0	1	−0.25	−0.5	0	0.667	0	−0.5	0	0	0.25	0
	A_2	−0.5	−0.333	−0.4	−0.5	1	0	−0.75	−0.5	0.333	−0.167	−0.25	1	0.667	0.25	0.4
	A_3	0	−0.333	−0.4	−1	0	0	−0.25	−0.5	−0.333	−0.167	−0.25	0.75	0.667	0.5	0.2
	A_4	−1	0	0	−0.5	0.5	−1	−0.75	−1	0	−0.833	−1	0.25	0.333	0.5	0.8
	A_5	−0.5	−0.667	−0.8	0	0	0	−0.25	−0.5	0.333	−0.333	0	0.75	0	0.25	−0.2
	A_6	−1	−0.667	−1	−0.5	0	−0.5	−1.25	−1	0.333	−1	−1	1	1	−0.5	0.6
2	A_1	0	−1	0	−0.4	0.2	−0.4	−0.333	−0.25	−0.4	−0.2	−0.667	0.667	−0.2	0	0.333
	A_2	0.2	−0.667	0	0.4	0.6	−0.4	0	0.25	−0.6	−0.2	−0.667	0.667	0.2	−0.5	0.333
	A_3	0.2	0	0.333	0.4	0.4	−0.4	−0.333	0	−0.4	0.2	−0.333	1	0.4	−0.5	0.667
	A_4	−0.2	−0.333	−0.167	0.6	0.2	−0.6	−0.667	−0.25	−0.6	−0.4	−1.333	1.333	0.2	−0.75	1
	A_5	0	0	0.167	0.2	0.4	0	0	−0.5	0	−0.2	−0.333	0.333	0.6	−0.75	0.667
	A_6	−0.8	−1	−0.667	−0.4	−0.4	−1	−1	−0.75	−1	−0.8	−1.333	1.333	0.8	−1	1.333

Table 16 Weighted normalized decision-making matrices (first and second experts)

Experts	Alternatives	Sub-criteria														
		C_{1-1}	C_{1-3}	C_{1-5}	C_{1-2}	C_{1-4}	C_{3-3}	C_{3-1}	C_{3-2}	C_{3-4}	C_{4-2}	C_{4-1}	C_{2-3}	C_{2-2}	C_{2-4}	C_{2-1}
1	A_1	−0.105	0.036	−0.046	0	0.023	−0.036	−0.036	0	0.016	0	−0.030	0	0	0.005	0
	A_2	−0.105	−0.036	−0.031	−0.021	0.023	0	−0.054	−0.020	0.008	−0.015	−0.015	0.046	0.018	0.005	0.006
	A_3	0	−0.036	−0.031	−0.043	0	0	−0.018	−0.020	−0.008	−0.015	−0.015	0.035	0.018	0.010	0.003
	A_4	−0.210	0	0	−0.021	0.011	−0.143	−0.054	−0.040	0	−0.076	−0.061	0.012	0.009	0.010	0.011
	A5	−0.105	−0.072	−0.062	0	0	0	−0.018	−0.020	0.008	−0.030	0	0.035	0	0.005	−0.003
	A_6	−0.210	−0.072	−0.077	−0.021	0	−0.071	−0.090	−0.040	0.008	−0.091	−0.061	0.046	0.028	−0.010	0.009
2	A_1	0	−0.121	0	−0.017	0.004	−0.041	−0.021	−0.011	−0.012	−0.023	−0.039	0.032	−0.006	0	0.003
	A_2	0.045	−0.081	0	0.017	0.014	−0.041	0	0.011	−0.018	−0.023	−0.039	0.032	0.006	−0.009	0.003
	A_3	0.045	0	0.024	0.017	0.009	−0.041	−0.021	0	−0.012	0.023	−0.019	0.048	0.012	−0.009	0.006
	A_4	−0.045	−0.040	−0.012	0.025	0.004	−0.061	−0.043	−0.011	−0.018	−0.046	−0.078	0.064	0.006	−0.013	0.010
	A_5	0	0	0.012	0.008	0.009	0	0	−0.023	0	−0.023	−0.019	0.016	0.018	−0.013	0.006
	A_6	−0.179	−0.121	−0.047	−0.017	−0.009	−0.101	−0.064	−0.034	−0.031	−0.091	−0.078	0.064	0.024	−0.017	0.013

Table 17 Overall performance ratings and rankings of alternatives

Alternatives	Experts									
	E_1		E_2		E_3		E_4		E_5	
	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank
A_1	−0.174	2	−0.251	4	0.159	3	−0.013	2	−0.029	3
A_2	−0.192	3	−0.082	3	**0.169**	**1**	−0.092	3	**0.071**	**1**
A_3	**−0.120**	**1**	**0.081**	**1**	0.164	2	**0.023**	**1**	0.019	2
A_4	−0.552	5	−0.258	5	−0.186	5	−0.367	5	−0.558	5
A_5	−0.262	4	−0.009	2	0.050	4	−0.108	4	−0.041	4
A_6	−0.654	6	−0.690	6	−0.476	6	−0.614	6	−0.620	6

Bolded items indicate first rank

The ARCAS group-hybrid method was herein applied to make rank optimal treated wastewater allocation. The ARCAS method integrates the SWARA weighting method and the ARAS multi-criteria decision-making method with a new normalization procedure based on distances from the decision-maker's preferences.

The ARCAS group-hybrid method' application herein presented considered the opinions of experts to identify six treated wastewater allocation alternatives that are the use of treated wastewater for landscape irrigation, agricultural irrigation, industrial use, artificial recharge of aquifers, recreation and environmental supply. Four main criteria of environmental, technological, economic, and socio-cultural nature, 15 sub-criteria and their preferred ratings were determined. Criteria and sub-criteria were ranked according to the relative relevance and weighting with the SWARA method.

The six treated wastewater allocation alternatives were evaluated by each expert individually, and their ratings were specified based on the alternatives' overall performance rating S_i. The ARCAS hybrid method is a group decision-making method that involves negotiation to resolve disagreement in alternatives raking by reviewing their relative performances. The final results established that based on the experts' opinions the agricultural irrigation alternative was determined as the best treated wastewater allocation alternative among the consumer sectors for reducing water scarcity in the study area.

7 Discussion

The key feature of the ARCAS method is the participation of experts who set the criteria with which to obtain the ranking of the alternatives. Subsequently the experts negotiate and exchange ideas to reach a consensus. This approach allows experts to defend their preferences in selecting the best alternative. Therefore, the ARCAS method, on the one hand, incorporates each expert's point of view in his/her field of expertise, and, on the other hand, a ranking of the alternatives is obtained through the exchange of opinions between the experts. Other decision-making methods obtain the decision-making matrix based on the integration of opinions of several experts without considering the position of each expert on each alternative available.

The ARCAS method involved negotiation among the experts that led to a change of the S_i values of the second and fifth experts after the second iteration. The S_i values for

Table 18 Decision-making matrices in the second iteration (third and fifth experts)

Experts	Alternatives	Sub-criteria														
		C_{1-1}	C_{1-3}	C_{1-5}	C_{1-2}	C_{1-4}	C_{3-3}	C_{3-1}	C_{3-2}	C_{3-4}	C_{4-2}	C_{4-1}	C_{2-3}	C_{2-2}	C_{2-4}	C_{2-1}
3	Preferred rating	6	4	5	5	4	5	6	5	4	4	5	6	5	4	4
	A_1	7	3	7	3	6	7	7	5	5	4	7	5	6	6	7
	A_2	7	5	5	4	7	5	5	4	5	6	6	4	5	5	6
	A_3	7	7	7	5	7	6	5	5	4	4	6	5	5	4	5
	A_4	5	4	5	4	4	2	3	6	3	3	4	6	2	4	4
	A_5	6	4	5	6	4	5	3	4	6	4	6	3	6	7	5
	A_6	3	3	2	1	3	2	1	3	2	2	3	3	4	1	3
5	Preferred rating	7	7	5	5	6	6	6	5	5	5	6	7	6	7	6
	A_1	5	6	4	5	5	7	6	7	5	5	4	5	5	7	5
	A_2	6	7	7	7	7	6	5	5	4	6	5	4	4	5	5
	A_3	7	7	6	7	7	7	7	5	4	6	5	5	7	7	6
	A_4	3	2	3	3	2	3	3	4	3	3	3	4	4	3	3
	A_5	6	5	5	4	7	7	6	5	3	6	6	6	6	7	6
	A_6	1	2	2	2	2	4	2	4	5	3	2	5	3	3	2

Table 19 Weights of environmental sub-criteria in second iteration (third and fifth experts)

Experts	Environmental sub-criteria	s_j	k_j	w_j	q_j
3	C_{1-1}		1	1	0.433
		0.690			
	C_{1-3}		1.690	0.592	0.256
		0.800			
	C_{1-5}		1.800	0.329	0.142
		0.450			
	C_{1-2}		1.450	0.227	0.098
		0.410			
	C_{1-4}		1.410	0.161	0.070
					Sum of the weights = 1
5	C_{1-1}		1	1	0.404
		0.600			
	C_{1-3}		1.600	0.625	0.253
		0.590			
	C_{1-5}		1.590	0.393	0.159
		0.500			
	C_{1-2}		1.500	0.262	0.106
		0.350			
	C_{1-4}		1.350	0.194	0.078
					Sum of the weights = 1

the agricultural irrigation alternative by the first to fifth experts were equal to −0.120, 0.081, 0.203, 0.023 and 0.108, respectively, which were the largest values of Si among all the treated wastewater allocation alternatives. Therefore, allocating the treated wastewater to the agricultural sector for irrigation would reduce considerably the water stress in the study region. The ARCAS group-hybrid method produced an overall ranking of alternative with respect to the S_i S_i, which is displayed in Fig. 3. Figure 3 shows that industrial use, artificial recharge, environmental supply, landscape irrigation, and recreational alternatives are ranked second to sixth, respectively, behind agricultural irrigation. Group decision-making achieves consensual response through negotiation and

Table 20 Final weights of the environmental sub-criteria in the second iteration (third and fifth experts)

Experts	Environmental sub-criteria	Sub-criteria	Weights of sub-criteria	Final weights of sub-criteria
3	0.374	C_{1-1}	0.433	0.162
		C_{1-3}	0.256	0.096
		C_{1-5}	0.142	0.053
		C_{1-2}	0.098	0.036
		C_{1-4}	0.070	0.026
5	0.458	C_{1-1}	0.456	0.208
		C_{1-3}	0.234	0.107
		C_{1-5}	0.167	0.077
		C_{1-2}	0.093	0.043
		C_{1-4}	0.049	0.023

Table 21 Overall performance ratings and ranks of alternatives in the second iteration

Alternatives	Experts									
	E_1		E_2		E_3		E_4		E_5	
	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank
A_1	−0.174	2	−0.251	4	0.176	2	−0.013	2	−0.028	3
A_2	−0.192	3	−0.082	3	0.179	3	−0.092	3	0.073	2
A_3	**−0.120**	**1**	**0.081**	**1**	**0.203**	**1**	**0.023**	**1**	**0.108**	**1**
A_4	−0.552	5	−0.258	5	−0.196	5	−0.367	5	−0.560	5
A_5	−0.262	4	−0.009	2	0.053	4	−0.108	4	−0.041	4
A_6	−0.654	6	−0.690	6	−0.516	6	−0.614	6	−0.620	6

Bolded items indicate first rank

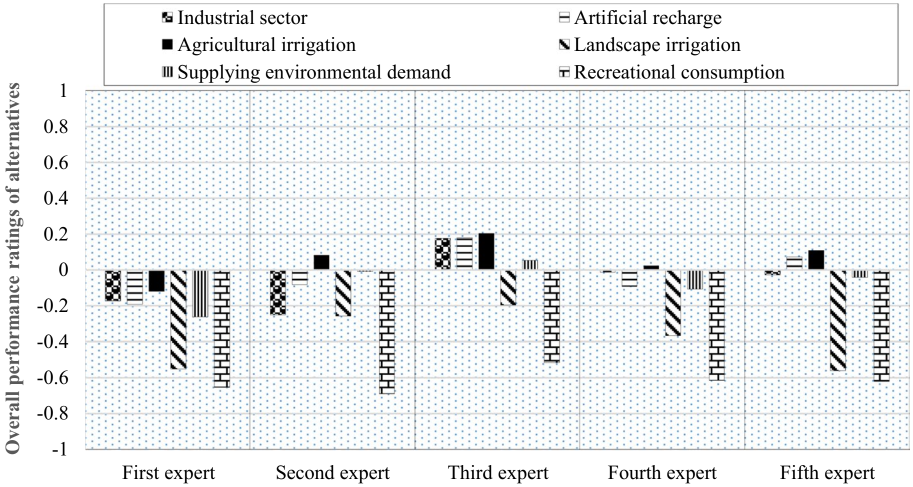

Fig. 3 Chart of the overall performance ratings of the alternatives

exchange of information and views that narrow down the ideal space shared by experts and stakeholders, thus leading to robust and reliable decision-making.

8 Limitations

The ARCAS MCDM method is based on the negotiation process. Several experts are involved in the decision-making, and each of them contributes a separate ranking of the alternatives. This complicates the reaching of a final consensus. Reaching a final ranking becomes cumbersome if there are numerous evaluation criteria.

9 Policy recommendations

This work's results provide an example of the successful application of MCDM to treated wastewater reuse planning. Considering the opinions of several experts who provide their rankings and negotiate for a consensus choice of the best alternative enhances to treated wastewater reuse.

Authors contributions KEA developed the theory and performed the computations. PG verified the analytical methods. PSA and PG encouraged KEA to investigate a specific aspect. PSA supervised the findings of this work, and PG and HL helped supervise the project. All authors discussed the results and contributed to the final manuscript. KEA wrote the manuscript with support from PSA, PG, and especially L. PSA and PG conceived the original idea.

Data availability Authors have no restrictions on sharing data.

References

Afshar, A., & Mariño, M. A. (1989). Optimization models for wastewater reuse in irrigation. *Journal of Irrigation and Drainage Engineering, 115*(2), 185–202.

Ashofteh, P. S., Rajaee, T., Golfam, P., & Chu, X. (2019). Applying climate adaptation strategies for improvement of management indexes of a river–reservoir irrigation system. *Irrigation and Drainage, 68*(3), 420–432. https://doi.org/10.1002/ird.2336

Azadi, F., Ashofteh, P.-S., Shokri, A., & Loáiciga, H. A. (2021). Simulation-optimization of reservoir water quality under climate change. *Journal of Water Resources Planning and Management*. https://doi.org/10.1061/%28ASCE%29WR.1943-5452.0001436

Baawain, M. S., Al-Mamun, A., Omidvarborna, H., Al-Sabti, A., & Choudri, B. S. (2020). Public perceptions of reusing treated wastewater for urban and industrial applications: Challenges and opportunities. *Environment, Development and Sustainability, 22*, 1859–1871. https://doi.org/10.1007/s10668-018-0266-0

Ebrahimzadeh Azbari, K., Ashofteh, P.-S., Golfam, P., & Singh, V. P. (2021). Optimal wastewater allocation with the development of an SECA multi-criteria decision-making method. *Journal of Cleaner Production, 321*, 129041. https://doi.org/10.1016/j.jclepro.2021.129041

El Moussaoui, T., Wahbi, S., Mandi, L., Masi, S., & Ouazzani, N. (2019). Reuse study of sustainable wastewater in agroforestry domain of Marrakesh city. *Journal of the Saudi Society of Agricultural Sciences, 18*(3), 288–293. https://doi.org/10.1016/j.jssas.2017.08.004

Fooladi Dehghani, B., & Khofhfetrat, A. (2020). AHP-GP approach by considering the Leopold matrix for sustainable water reuse allocation: Najafabad case study, Iran. *Periodica Polytechnica Civil Engineering, 64*(2), 485–499. https://doi.org/10.3311/PPci.14689

Gdoura, K., Anane, M., & Jellali, S. (2015). Geospatial and AHP-multicriteria analyses to locate and rank suitable sites for groundwater recharge with reclaimed water. *Resources, Conservation and Recycling, 104*, 19–30. https://doi.org/10.1016/j.resconrec.2015.09.003

Golfam, P., Ashofteh, P.-S., & Loáiciga, H. A. (2021). Integration of gray system theory (GST) with AHP decision making for wastewater-reuse decision making. *Journal of Hazardous, Toxic, and Radioactive Waste,*. https://doi.org/10.1061/%28ASCE%29HZ.2153-5515.0000619

Golfam, P., Ashofteh, P. S., Rajaee, T., & Chu, X. (2019). Prioritization of water allocation for adaptation to climate change using multi-criteria decision making (MCDM). *Water Resources Management, 33*(10), 3401–3416. https://doi.org/10.1007/s11269-019-02307-7

Hanjra, M. A., & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy, 35*(5), 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006

Iglesias, A., & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management, 155*, 113–124. https://doi.org/10.1016/j.agwat.2015.03.014

Jing, L., Chen, B., Zhang, B., & Li, P. (2013). A hybrid stochastic-interval analytic hierarchy process approach for prioritizing the strategies of reusing treated wastewater. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2013/87480

Juttler, H. (1966). "Untersuchungen zur Fragen der Operationsforschung und ihrer Anwendungsmoglichkeiten auf okonomische Problemstellungen unter besonderer Berucksichtigung der Spieltheorie [Investigations on the question of operational research and its application to economic problems with special consideration of the game theory], Doctoral dissertation. Fakultat der Humboldt-Universitat, Berlin

Kalbar, P. P., Karmakar, S., & Asolekar, S. R. (2012). Technology assessment for wastewater treatment using multiple- attribute decision-making. *Technology in Society, 34*(4), 295–302. https://doi.org/10.1016/j.techsoc.2012.10.001

Karanjeeka, D. D., & Regulwar, D. G. (2021). Evaluation of treated wastewater reuse alternatives using fuzzy-multi criteria decision making techniques. *Journal of Indian Association for Environmental Management, 41*(2), 15–20.

Keršulienė, V., Zavadskas, E. K., & Turskis, Z. (2010). Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA). *Journal of Business and Economics Management, 11*(2), 243–258. https://doi.org/10.3846/jbem.2010.12

Kim, Y., Chung, E. S., & Jun, S. M. (2015). Iterative framework for robust reclaimed wastewater allocation in a changing environment using multi-criteria decision-making. *Water Resources Management, 29*(2), 295–311. https://doi.org/10.1007/s11269-014-0891-9

Loáiciga, H. A. (2015). Managing municipal water supply and use in water-starved regions: Looking ahead. *Journal of Water Resources Planning and Management*. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000487

Motoshita, M., Itsubo, N., & Inaba, A. (2011). Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. *The International Journal of Life Cycle Assessment, 16*(1), 65–73. https://doi.org/10.1007/s11367-010-0236-8

Nasri, M., & Soleimani, A. (2011). "Using reuse water for irrigation green space of Naein city." International Journal of Environmental and Ecological Engineering. https://doi.org/10.5281/zenodo.1074567

Pahl-Wostl, C., Tàbara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., & Taillieu, T. (2008). The importance of social learning and culture for sustainable water management. *Ecological Economics, 64*(3), 484–495. https://doi.org/10.1016/j.ecolecon.2007.08.007

Papaiacovou, I. (2001). Case study- wastewater reuse in Limassol as an alternative water source. *Desalination, 138*(1–3), 55–59. https://doi.org/10.1016/S0011-9164(01)00244-2

Park, D. (2009). The economic impacts of water shortage during a drought in Korea: Using intraregional I-O analysis. *Advances in Water Resources and Hydraulic Engineering, Springer, Berlin, Heidelberg*. https://doi.org/10.1007/978-3-540-89465-0_59

Partyka, M. L., & Bond, R. F. (2022). Wastewater reuse for irrigation of produce: A review of research, regulations, and risks. *Science of the Total Environment, 828*, 154385. https://doi.org/10.1016/j.scitotenv.2022.154385

Paul, M., Negahban-Azar, M., Shirmohammadi, A., & Montas, H. (2020). Assessment of agricultural land suitability for irrigation with reclaimed water using geospatial multi-criteria decision analysis. *Agricultural Water Management, 231*, 105987. https://doi.org/10.1016/j.agwat.2019.105987

Pérez, J. J., Cabrerizo, F. J., Alonso, S., Dong, Y. C., Chiclana, F., & Herrera-Viedmab, E. (2018). On dynamic consensus processes in group decision making problems. *Information Sciences, 459*, 20–35. https://doi.org/10.1016/j.ins.2018.05.017

Pourmand, E., Mahjouri, N., Hosseini, M., & Nik-Hemmat, F. (2020). A multi-criteria group decision making methodology using interval type-2 fuzzy sets: Application to water resources management. *Water Resources Management, 34*, 4067–4092. https://doi.org/10.1007/s11269-020-02657-7

Rao, S. M., & Mamatha, P. (2004). Water quality in sustainable water management. *Current Science Association, 87*(7), 942–947.

Rimi Abubakar, I. (2016). Quality dimensions of public water services in Abuja, Nigeria. *Utilities Policy, 38*, 43–51. https://doi.org/10.1016/j.jup.2015.12.003

Savun-Hekimoğlu, B., Erbay, B., Hekimoğlu, M., & Burak, S. (2021). Evaluation of water supply alternatives for Istanbul using forecasting and multi-criteria decision making methods. *Journal of Cleaner Production, 287*, 125080. https://doi.org/10.1016/j.jclepro.2020.125080

Shrivastava, V., Ali, I., Marjub, M. M., Rene, E. R., & Florencia Soto, A. M. (2022). Wastewater in the food industry: Treatment technologies and reuse potential. *Chemosphere, 293*, 133553. https://doi.org/10.1016/j.chemosphere.2022.133553

Soltanjalili, M. J., Bozorg Haddad, O., & Mariño, M. A. (2013). Operating water distribution networks during water shortage conditions using hedging and intermittent water supply concepts. *Journal of Water Resources Planning and Management, 139*(6), 644–659. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000315

Stanujkic, D., Magdalinovic, N., & Jovanovic, R. (2013). A multi-attribute decision-making model based on distance from decision maker's preferences. *Informatica, 24*(1), 103–118.

Stanujkic, D., & Zavadskas, E. K. (2015). A modified weighted sum method based on the decision maker's preferred levels of performances. *Studies in Informatics and Control, 24*(4), 461–469. https://doi.org/10.24846/v24i4y201510

Stanujkic, D., Zavadskas, E. K., Karabasevic, D., Turskis, Z., & Kersuliene, V. (2017). New group decision-making ARCAS approach based on the integration of the SWARA and the ARAS methods adopted for negotiations. *Journal of Business Economics and Management, 18*(4), 599–618. https://doi.org/10.3846/16111699.2017.1327455

Tampo, L., Alfa-Sika Mande, S. L., Adekanmbi, A. O., Boguido, G., Akpataku, K. V., Ayah, M., Tchakala, I., Gnazou, M. D. T., Bawa, L. M., Djaneye-Boundjou, G., & Alhassan, E. H. (2022). Treated wastewater suitability for reuse in comparison to groundwater and surface water in a peri-urban area: Implications for water quality management. *Science of the Total Environment, 815*, 152780. https://doi.org/10.1016/j.scitotenv.2021.152780

Tsanis, I. K., Koutroulis, A. G., Daliakopoulos, I. N., & Jacob, D. (2011). Severe climate-induced water shortage and extremes in Crete. *Climatic Change, 106*(4), 667–677. https://doi.org/10.1007/s10584-011-0048-2

Weitendorf, D. (1976). "Beitrag zur Optimierung der räumlichen Struktur eines Gebäudes", Doctoral Dissertation, Weimar

Zavadskas, E. K., Govindan, K., Antucheviciene, J., & Turskis, Z. (2016). Hybrid multiple criteria decision-making methods: A review of applications for sustainability issues. *Economic Research-Ekonomska Istraživanja, 29*(1), 857–887. https://doi.org/10.1080/1331677X.2016.1237302

Zavadskas, E. K., & Turskis, Z. (2010). A new additive ratio assessment (ARAS) method in multi-criteria decision-making. *Technological and Economic Development of Economy, 16*(2), 159–172. https://doi.org/10.3846/tede.2010.10