A Fusion of Multi-Criteria Decision-Making for Select Recharge Structure

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Abstract

Groundwater recharge is essential in establishing reliable groundwater supplies in a region. Groundwater is a vital natural water resource, but its quantity and quality may vary significantly from one area to another. Growing urbanization and population increase have put a significant demand on groundwater supplies. Using Multi-Criteria Decision-Making (MCDM), several studies have identified good areas for recharging groundwater supplies. To help choose between several types of artificial recharge (AR) structures, we have developed an MCDM approach for this research. We used an MCDM fusion methodology to combine various AR criteria with the alternatives. This study collected eight criteria and eight alternatives. We used the average method to compute the weights of the criteria. Then, we used the COCOSO method as an MCDM fusion method to rank the alternatives. The results show that hydrological conditions are the best criteria, and stakeholder engagement is the lowest weight. The sensitivity analysis is performed to show the stability of the results in this study.

Keywords: Multi-Criteria Decision Making; Data Fusion; Recharge Structure; COCOSO Method.

1. Introduction

Water is the most vital element of the planet for our existence and environment, and it plays the primary role in supporting life on Earth. This is true at all phases of life, including survival, where it is essential for alleviating poverty, hunger, and sickness and for economic usage in our everyday lives. Water plays a crucial part, and no other substance can take its place. Every community has the provision of potable water as its principal goal. Surface water is increasingly limited, and groundwater is now recognized as a critical source to supply water needs for many sectors, including agriculture (89%), residential (9%), and industry (2%). About 61% of the water used for irrigation comes from the ground, while the remaining 24% comes from canals. Groundwater supplies half of all water used in cities and more than eighty-five per cent of all water used in homes in rural areas[1], [2].

Over the last decade, water pressure has been building due to population and industrial expansion, excessive water usage, inadequate irrigation, and pollution. The poisoning or pollution of water supplies is also a crucial factor. The

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need for water is rising quickly. Water pressure has been an issue in many places around the globe. Groundwater is essential for meeting residential, commercial, and agricultural needs[3]–[5].

The growing water demand is realized, and artificial recharge (AR) is essential to boost groundwater quality and quantity. Surface runoff is protected, saltwater intrusion is avoided, overdraft is decreased, and groundwater quantity and quality are increased because of AR. It slows down the stream and reduces its destructive power. It collects and retains excess precipitation, especially during drought, for later use. It also decreases peak flooding and damages and preserves the soil[6]–[8].

Evaluating AR structure and selecting the best is a multi-criteria decision-making (MCDM) problem.

When making a choice, consider several different criteria or considerations[9]–[11]. This is known as MCDM fusion. MCDM fusion approaches combine multiple and frequently competing criteria to provide better informed and complete decision-making[12], [13].

In MCDM fusion, results from several criteria evaluations are averaged into a single score based on the weights assigned to each criterion. Each criterion's weight and the degree of preference or pleasure associated with varying performance levels are considered throughout the fusion process[14]–[16].

The decision maker, the decision problem, and the accessible data all play a role in determining which MCDM fusion technique to choose. The goal is to integrate several criteria into a single decision-making structure, allowing for a more thorough and systematic assessment of available options[17], [18].

Engineering, economics, ecology, and public policy are just a few fields that may benefit from MCDM fusion approaches[19]–[22]. MCDM fusion approaches improve decision-making by providing a structured and rigorous framework for evaluating alternatives and choosing the most suitable option based on the decision-makers preferences and priorities by incorporating multiple criteria and considering their interdependencies[23], [24].

The main contributions of this study are

We proposed an MCDM fusion methodology to evaluate AR structure and select the best alternative.

We collected eight criteria and eight alternatives to select the best criterion and best alternative.

We proposed a COCOSO MCDM fusion method to analyse the AR structure and select the best alternative.

2. MCDM Fusion

In this section, we introduce the MCDM method as a fusion method with the criteria and alternatives. The process of combine and fusion of criteria and factors in decision making operations to assess the alternatives. So we used the MCDM fusion method to combined the various criteria in the decision making. Figure 1 shows the proposed model[25]–[27].

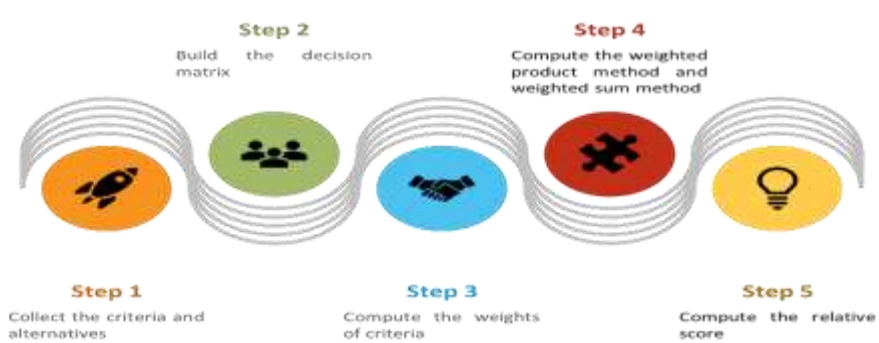

Figure 1: The steps of the MCDM fusion.

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The CoCoSo procedure was created by Yazdani et al. in 2019. As will be seen below, this approach is based on a combination of the exponentially weighted product method and the weighted sum method[28], [29].

Step 1. Build the decision matrix

The decision matrix is built by experts and decision maker with their opinions. The experts used the scale from 1 to 9 to evaluate the criteria and alternatives.

Step 2. Compute the weighted product method and weighted sum method.

We compute the weighted product method and weighted sum method based on the decision matrix between criteria and alternatives.

$$WP_i = \sum_{j=1}^{n}\left(x_{ij}w_j\right) \quad (1)$$

$$WS_i = \sum_{j=1}^{n}\left(x_{ij}\right)^{w_j} \quad (2)$$

Where w_j refers to the weights of criteria. The weights of criteria are computed by the average method by using the scale from 1 to 9. The x_{ij} refers to the normalization value in the normalization decision matrix. The decision matrix needed to be normalized in decision matrix by the positive and negative criteria as:

$$x_{ij} = \frac{a_{ij}-\min_i a_{ij}}{\max_i a_{ij}-\min_i a_{ij}} \quad (3)$$

$$x_{ij} = \frac{\max_i a_{ij}-a_{ij}}{\max_i a_{ij}-\min_i a_{ij}} \quad (4)$$

Where a_{ij} refers to the value in decision matrix and $i = 1,2, \dots m; j = 1,2, \dots n$

Step 3. Compute the relative score

$$\exists_i = \frac{1}{3}\left(\exists_{ia} + \exists_{ib} + \exists_{ic}\right) + \left(\exists_{ia} \cdot \exists_{iv} \cdot \exists_{ic}\right)^{\frac{1}{3}} \quad (5)$$

The relative score can be computed through three equations as:

$$\exists_{ia} = \frac{WS_i+WP_i}{\sum_{i=1}^{m}(WS_i+WP_i)} \quad (6)$$

$$\exists_{ib} = \frac{WS_i}{\min_i WS_i} + \frac{WP_i}{\min_i WP_i} \quad (7)$$

$$\exists_{ic} = \frac{\lambda WS_i+(1-\lambda)WP_i}{\lambda \max_i WS_i+(1-\lambda)\max_i WP_i} \quad (8)$$

The alternatives are ranked with the highest value in the relative score.

3. Results

In this section, we introduce the results of the MCDM fusion with the criteria and alternatives related to the recharge selection. We used in this paper eight criteria and eight alternatives to be select best one in this paper. The criteria are selected are detailed as:

1) Water Resource: The parameters for artificial recharge structures are heavily influenced by the aims and goals of water resource management.
2) Recharge Capacity: The efficiency with which an artificial recharge structure manages and distributes water is referred to as its "recharge capacity."
3) Infrastructure: When choosing and planning artificial recharge structures, it's necessary to take into account the proximity to existing resources.

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4) Environmental Impacts: The possible negative environmental implications of artificial recharge structures should be carefully considered throughout their construction.
5) Water Quality: One of the most important considerations is the purity of the water supply used for recharging. There shouldn't be any chance of contamination provided the water quality is suitable for the intended aquifer.
6) Stakeholder Engagement: Stakeholder engagement is essential for understanding the viewpoints of local people, water consumers, and relevant authorities, as well as addressing any concerns or possible conflicts that may arise from artificial recharge initiatives.
7) Cost: Artificial recharge structures must be cost-effective to construct and maintain.
8) Hydrogeological conditions: Artificial recharge structures' viability is heavily dependent on the hydrogeological parameters of the target aquifer, such as permeability, porosity, and hydraulic conductivity.

We used in this paper eight alternatives to be ranked and select best one. The description of the alternative as:

1) Recharge ponds: Recharge basins or ponds are dug or created depressions in the earth that accept and store surface water or treated wastewater.
2) Managed Aquifer Recharge: The term "Managed Aquifer Recharge" refers to an array of systems for regulated and improved groundwater recharging.
3) Infiltration Galleries: Aquifer infiltration galleries are subterranean constructions made of perforated pipes or chambers.
4) Spreading Ground: Large fields called spreading grounds are used to distribute or reroute surface water or treated effluent.
5) Percolation Tanks: Surface runoff or redirected water may be collected in percolation tanks.
6) Recharge Wells: In a recharge well, surface water or treated wastewater is injected directly into a non-confined aquifer.
7) Recharge Trenches: In order to collect and transport surface water or treated wastewater, recharge trenches are dug or built channels or trenches.
8) Injection Wells: Surface water or treated wastewater is injected directly into a confined or semi-confined aquifer using injection wells.

We introduce the results of the COCOSO fusion method based on the set of criteria and alternatives of recharge structure selection.

Step 1. We built the decision matrix between criteria and alternatives. We let the experts and decision makers evaluate the criteria and alternatives. The experts used the scale from 1 to 9 to evaluate the criteria and alternatives. We compute the weights of criteria by the average method as shown in Figure 2. The results of weights of criteria show the hydrological conditions has the height weight and stakeholder engagement has the lowest weights.

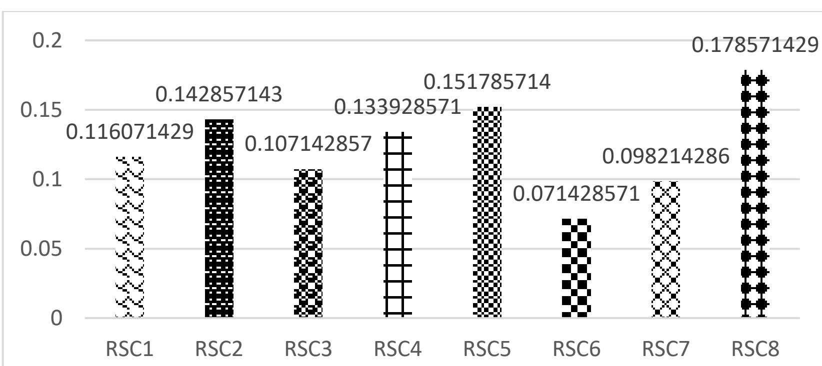

Figure 2: The weights of eight criteria of recharge structure.

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Step 2. Eqs. (1 and 2) are used to compute the weighted product method and weighted sum method based on the normalization values. The normalization decision matrix is built by using Eqs. (3 and 4) as shown in Table 1. Then the weighted product method and weighted sum method are computed as shown in Tables 2 and 3.

Table 1: The normalization decision matrix data fusion.

	RSC_1	**RSC_2**	**RSC_3**	**RSC_4**	**RSC_5**	**RSC_6**	**RSC_7**	**RSC_8**
RSA_1	0.42857	0.625	1	1	1	0.8	0.625	1
RSA_2	0	0	0	0	0.4	0	0.125	0.28571
RSA_3	0.57143	1	0	0	0.8	0.2	0.25	0.71429
RSA_4	0.14286	0.625	0	0	0	0	0.5	0.85714
RSA_5	0	0.5	0.33333	1	0.4	0.8	0.75	1
RSA_6	0.85714	0.375	0.66667	0	0.6	1	0.875	0.57143
RSA_7	1	0.625	0.83333	0.5	0.2	0.2	1	0.14286
RSA_8	1	1	1	1	0.8	0.8	0	0

Table 2: The sum weighted method matrix of data fusion.

	RSC_1	**RSC_2**	**RSC_3**	**RSC_4**	**RSC_5**	**RSC_6**	**RSC_7**	**RSC_8**
RSA_1	0.04974	0.08929	0.10714	0.13393	0.15179	0.05714	0.06138	0.17857
RSA_2	0	0	0	0	0.06071	0	0.01228	0.05102
RSA_3	0.06633	0.14286	0	0	0.12143	0.01429	0.02455	0.12755
RSA_4	0.01658	0.08929	0	0	0	0	0.04911	0.15306
RSA_5	0	0.07143	0.03571	0.13393	0.06071	0.05714	0.07366	0.17857
RSA_6	0.09949	0.05357	0.07143	0	0.09107	0.07143	0.08594	0.10204
RSA_7	0.11607	0.08929	0.08929	0.06696	0.03036	0.01429	0.09821	0.02551
RSA_8	0.11607	0.14286	0.10714	0.13393	0.12143	0.05714	0	0

Table 3. The product weighted method matrix of data fusion.

	RSC_1	**RSC_2**	**RSC_3**	**RSC_4**	**RSC_5**	**RSC_6**	**RSC_7**	**RSC_8**
RSA_1	0.90633	0.93506	1	1	1	0.98419	0.95489	1
RSA_2	0	0	0	0	0.87016	0	0.81527	0.79955
RSA_3	0.93711	1	0	0	0.9667	0.8914	0.87271	0.94169
RSA_4	0.79783	0.93506	0	0	0	0	0.93419	0.97285
RSA_5	0	0.90572	0.88896	1	0.87016	0.98419	0.97214	1
RSA_6	0.98227	0.86926	0.95749	0	0.92539	1	0.98697	0.9049
RSA_7	1	0.93506	0.98066	0.91135	0.78326	0.8914	1	0.70646
RSA_8	1	1	1	1	0.9667	0.98419	0	0

Step 3. Then compute the relative score by using Eqs. (5,6,7, and 8) as shown in Figure 3.

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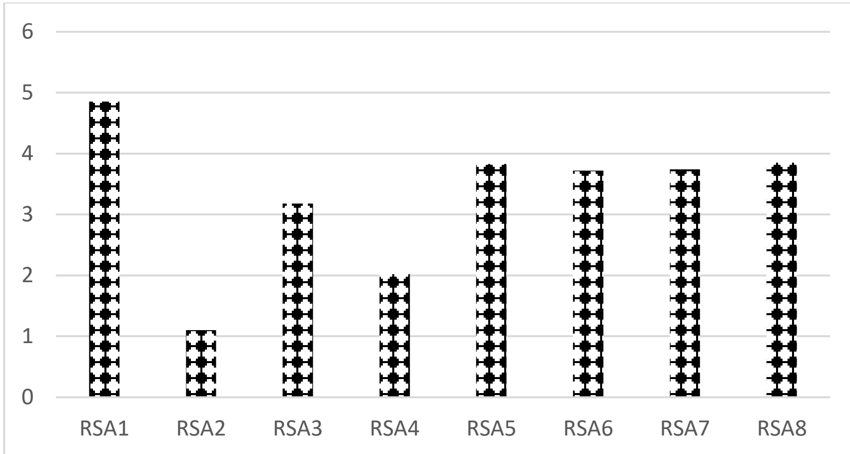

Figure 3: The relative score values.

The COCOSO fusion method show the alternative 1 is the best alternative and alternative 2 is the worst alternative.

We performed the sensitivity analysis to show the stable of the results. We change the parameters of λ between 0 and 1 then rank the alternative under different values to show the stable of the results and strength of the proposed model. Figure 4 shows the rank of alternatives under different values of λ. We show the alternative 1 is the best and alternative 2 is the worst. We show the proposed model is suitable and the results are stable.

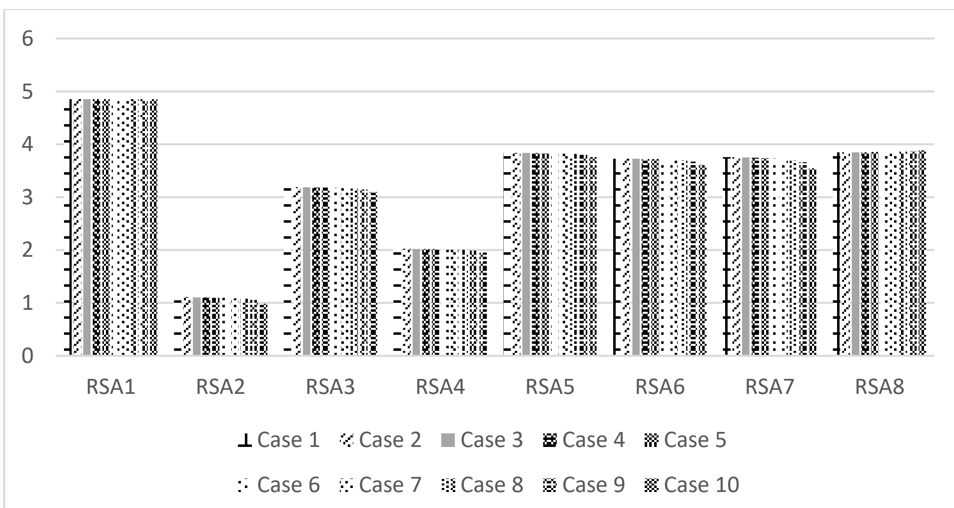

Figure 4: The relative score value under different values of λ parameter.

4. Conclusions

Selecting a suitable recharge structure is a vital step in undertaking artificial recharge projects and facilitating the replenishment of groundwater supplies. There are several variables to consider while deciding on a recharge structure, such as hydrogeological parameters, water quality, land availability, water availability, and project goals.

By carefully considering these criteria, water resource managers and engineers may make educated choices to guarantee recharge projects' efficacy, efficiency, and sustainability. It is crucial to match the unique characteristics of the project site with the most appropriate option, as each recharge structure alternative offers distinct benefits and considerations.

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Capturing and storing surface water or treated wastewater in recharge basins/ponds allows for natural infiltration and is a cost-effective option. Water may be introduced into enclosed or partially enclosed aquifers by injection wells in a direct and manageable manner. Capturing and infiltrating surface runoff or redirected water using percolation tanks and recharge trenches is an efficient way to replenish groundwater supplies. Water may be injected into non-confined aquifers in a targeted and concentrated manner using recharge wells. Infiltration galleries provide a managed and dispersed approach to recharging water supplies. Grounds allowed to stretch out offer extensive spaces to distribute and penetrate surface water.

In addition, the term "Managed Aquifer Recharge" (MAR) refers to a wide variety of approaches and frameworks that may be modified to meet the needs of individual projects. MAR maximises groundwater recharge and improves water resource management by integrating various recharge structures and operational practices.

When deciding on a recharge structure, it's essential to consider how well it will work with the local hydrogeology, how well the source water will mix with the aquifer, how well it will be distributed, and how much of an influence it will have on the environment. Factors such as cost-effectiveness, infrastructure availability, and stakeholder participation should also be considered.

A project's ability to successfully contribute to groundwater management and conservation hinges on the recharge structure chosen. Water managers can increase water availability, decrease water scarcity, and foster sustainable water resource management for the long-term benefit of communities and ecosystems by matching the characteristics of the project site with the most appropriate recharge structure alternative.

We proposed an MCDM fusion method to evaluate the AR structure and select the best alternative. We used eight criteria and eight alternatives. We collected the criteria and alternatives from previous studies. The COCOSO method is an MCDM fusion method used to rank the alternatives. The weights of the criteria are computed to show their importance. The results show that hydrological conditions are the best criterion, and stakeholder engagement is the worst criterion. Then, we applied the COCOSO method to show the rank of alternatives. The results show the recharge ponds are the best alternative, and the managed aquifer recharge is the worst alternative.

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