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Use of an analytical hierarchy process for the selection of adequate desalination technologies for Spain and the Gulf Cooperation Council

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ABSTRACT

Various countries worldwide are known to face water scarcity problems. Seawater desalination is one of the solutions used to solve water scarcity issues in Spain and the Gulf Cooperation Council (GCC) states. These countries use three main water desalination technologies, namely, multi-effect distillation, multi-stage flash (MSF) and reverse osmosis (RO) desalination. Several factors must be considered to choose the most appropriate desalination technology for each country. In this paper, the analytical hierarchy process was employed to select adequate desalination technologies for Spain and the GCC countries by considering results obtained from a survey of experts in the field. This study found that the most suitable technologies for Spain and the GCC countries are RO and MSF, respectively.

Keywords: Analytical hierarchy process; Multi-effect distillation; Reverse osmosis; Multi-stage flash; Desalination

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1. Introduction

Desalination technologies have been widely utilized in countries with freshwater resources below their critical levels. These countries include Spain and the six Gulf Cooperation Council (GCC) countries, namely Saudi Arabia, United Arab Emirates, Bahrain, Kuwait, Oman and Qatar. The use of desalination technologies generates additional fresh water to cover continuously increasing water needs. In fact, desalination of seawater is the major alternative source of water to cope up with severe water deficiency. Notably, the GCC countries account for 45% of the total global desalination capacity [1]. A recently published report [2] indicated that 44% of the daily desalinated water was produced in the Middle East and North Africa (MENA) region. In the GCC region, the United Arab Emirates (UAE), Qatar, Saudi Arabia and Kuwait are among the 10 largest desalinated water users worldwide. It is expected that by 2020, the seawater desalination capacity of the GCC region will increase by 40% to meet the quickly rising requirements for clean and fresh water [3].

Notably, seawater desalination plants have supplied fresh water to the GCC countries since the early 1950s. The other prominent area of water desalination is Spain, which is the largest producer of desalinated water in Europe. The first Spanish plants were built in the 1960s, mainly in the Canary Islands (Atlantic Ocean), where desalination was the only reasonable alternative to supply water to the local population. Therefore, these two regions have emerged as the most significant producers of desalinated water in the world.

Two classes of desalination technologies are considered, namely:

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- Distillation, including multi-stage flash (MSF) and multi-effect desalination (MED) and
- Membrane separation reverse osmosis (RO) and electrodialysis (ED) [4].

It is well known that all proposed desalination technologies have their respective advantages, drawbacks and deficiencies. Therefore, the prevailing conditions of the location, region or country, including the environmental, economic and socio-cultural characters, must be considered when selecting a technology. Gude [5] reported some recent advances in desalination technology in his recent book, which discusses various issues like minimizing energy costs, reduction of waste and control of environmental footprint. Pinto and Marques [6] tried to standardize the structure and principal determinants of the cost of production of desalinated water, and provided relevant insights into the key factors that determine the success of a desalination project. The accurate choice of the most appropriate technology from those described previously is critical before the design and implementation of any desalination plant. Decision-making techniques with multiple criteria should be applied to systematically define all related issues, advantages and drawbacks [7–9]. Research studies in the field revealed that the use of integrating methods to find a convincing solution is beneficial [10]. Among such methods, the analytical hierarchy process (AHP) is used to handle decision making with various objectives and criteria. In practice, this method allows several environmental, socio-cultural, and economic conditions to be considered to choose the optimal water desalination alternative [11,12]. The AHP has been efficiently applied in the energy sector to select optimal sources of renewable energy in order to develop electricity production systems, as in Malaysia [13]; to find sustainable energy development strategies, as in Thailand [14]; or to select the most appropriate package of solar home systems, as in Bangladesh [15]. Hajeeh and Al-Othman [16] used AHP to select the best desalination technology for GCC countries, concluding that RO should be the most suitable method. However, Başaran et al. [17] re-analyzed the paper [16] and claimed that re-scaling some inconsistent matrices and revising few calculations were necessary resulting in different conclusions.

The present research study considers the shortcomings of the previous work [16] and applies the AHP method to decide the most appropriate water desalination technology among those currently used in the GCC countries as well as in Spain, which was not considered before. Various criteria and conditions were considered in the study that corroborate to the real conditions and standards prevalent in the different countries. The possible set of technologies (MSF, MED and RO) were selected on the basis that they are more commonly used than other worldwide technologies and contribute more than 90% of desalinated water production [18]. It must be pointed out that ED, contributing with as little as 3% share of the desalination capacity [18], is not considered in this study as it is rarely used in practice. The AHP method was chosen because it allows quantitative as well as qualitative criteria to be included in the decision-making process and can perform through a flexible hierarchy based on the problem at hand.

2. Desalination technologies

2.1. Multi-stage flash desalination

As shown in Fig. 1 [19], MSF desalination comprises a heating vessel called a brine heater and involves a number of stages, during which hot seawater is converted to steam and subsequently undergoes condensation to pure water. First, preheated salty water is heated in the brine heater until the temperature reaches 90°C–115°C. The working fluid enters the chamber of the ejector with a high velocity, which creates the necessary low pressure, thus driving the process fluid to enter the chamber. Then, the hot water at a high pressure enters the first stage, in which the pressure is maintained slightly under the saturation vapour pressure of water. The lower pressure causes the water to simultaneously boil and flash into steam.

Each stage contains a condenser, in which the steam condenses to pure water on the exterior surface of tube bundles, and a tray collector that collects the distilled water, which is eventually pumped to a freshwater storage tank. The latent heat of the condensation of the steam is used to preheat the feed brine circulating through the condenser. Mist eliminators or separators are employed to separate the pure steam from the high-salinity mist. The process is repeated several times as the water enters a series of stages. The pressure in each stage is lower than that in the previous one. The remaining brine is collected after the final stage. Part of the brine is recycled to the brine heater, while the other part is discharged into the sea. Each stage produces approximately 1% of the final recovery, and the average MSF recovery is around 19%–28% [20–21].

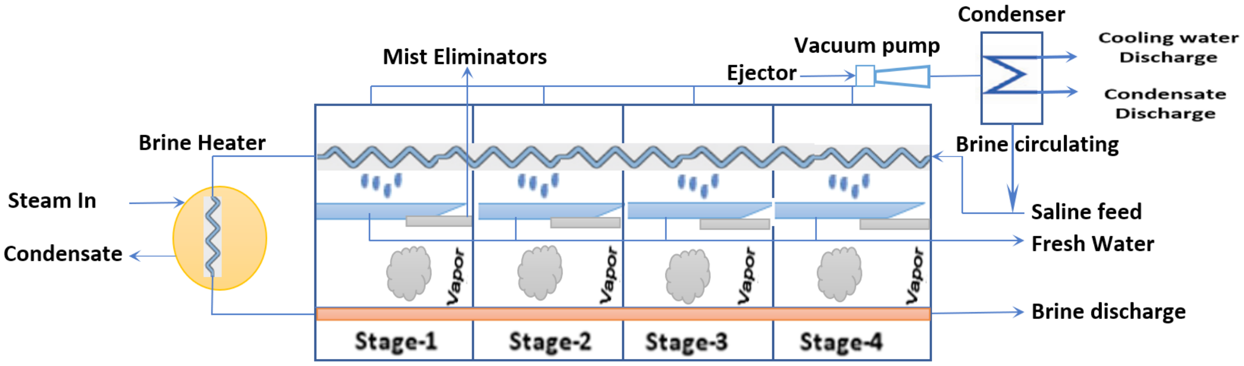

Fig. 1. Schematic diagram of a typical multi-stage flash (MSF) process.

2.2. Multi-effect distillation

MED comprises spraying saline water onto heat exchangers for evaporation and steam production; the subsequent condensation produces pure water. In the first stage, cold seawater is sprayed through multiple nozzles. The first chamber contains a steam-operated heat exchanger that heats the water droplets falling from the nozzles until they transform into steam. Subsequently, the steam rises and moves to the second stage through the heat exchanger inlet, as shown in Fig. 2 [19]. The steam from the first effect heats the water sprayed in the second stage, which turns into steam that heats the water droplets in the third stage; this process is repeated in all the subsequent stages. The pressure in each stage is lower than that of the previous stage to help the water boil without introducing additional heat. The steam that condenses in the heat exchangers is collected and sent to pure water tanks, and the remaining brine is rejected into the sea. MEDs typically operate at 62°C–75°C [20].

2.3. Reverse osmosis

The RO concept is based on reversing the osmotic process that naturally occurs when a saline solution is separated from another solution with a lower salt concentration by a water-selective membrane. During osmosis, water passes to the solution with a higher concentration of salts due to the difference in the water chemical potential until the osmotic equilibrium is reached. Fig. 3 shows a schematic diagram of a typical RO process, in which water from the more saline solution (seawater) is forced, under a high hydrostatic pressure exceeding the osmotic pressure, to pass through a water-selective semipermeable membrane to the side containing the solution with a lower salt concentration. Thus, water is transferred to the permeate side, leaving salt and impurities in the feed concentrate. This type of membrane permits or blocks solutes depending on its size and charge. RO can reject suspended and dissolved salts and various water contaminants. However, suspended solids can accumulate on the membrane surface, causing fouling. Therefore, a pre-treatment stage is generally required in all RO plants to remove suspended solids before water enters the plant. In addition, similar to thermal desalination, RO plant may require a post-treatment stage, such as a mineralization stage, depending on the water end-use [20].

3. Evaluation methodology

3.1. Analytic hierarchy process method

The AHP is a useful and efficient decision aiding method for the formulation and analysis of decisions

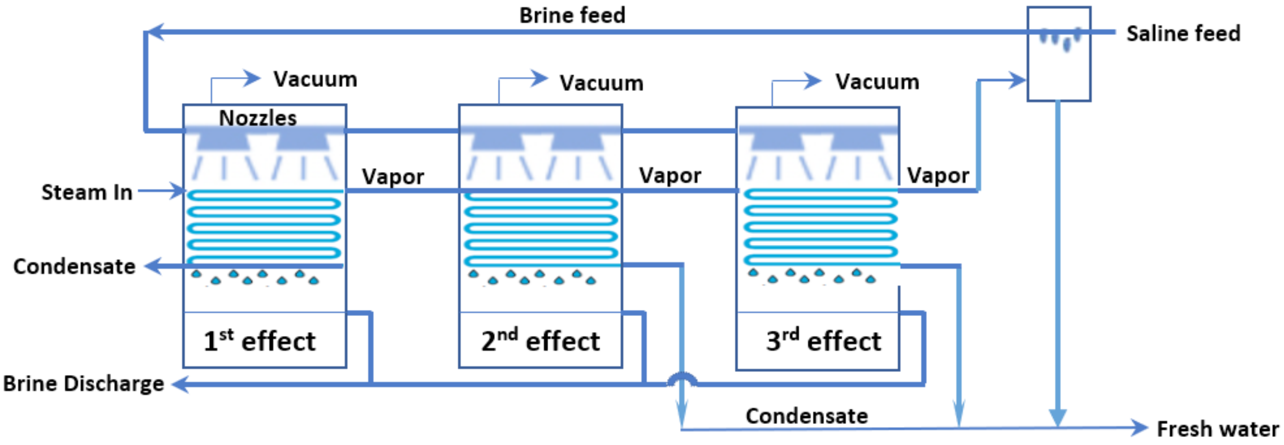

Fig. 2. Schematic diagram of a typical multi-effect distillation (MED) process.

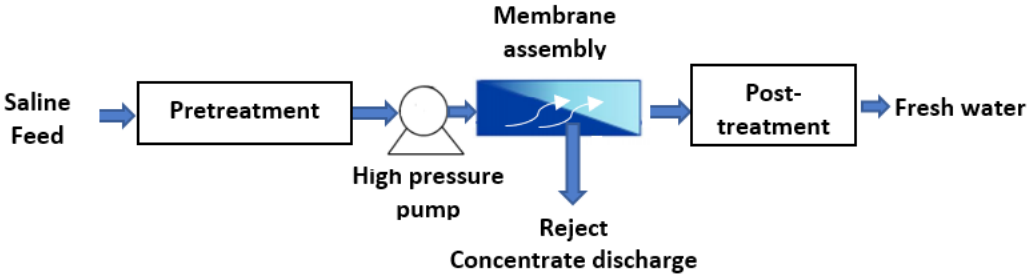

Fig. 3. Diagram showing the main components of a typical RO plant (osmotic pressure).

[22,23]. Saaty [24], who introduced the AHP method, pointed out that the AHP is "a general theory of measurement" [24]. It prioritizes and quantifies all possible alternatives by their evaluation and comparison among each other [25]. In addition, AHP systematically includes, categorizes and orders all potential factors that can affect a specific process and offers a structured and straightforward solution for decision making [26]. Numerous studies have applied this method in multiple fields, including the field of desalination [27–32]. For example, Hajeeh and Al-Othman [16] used AHP to identify the most suitable desalination technology for the GCC countries. Similarly, Mohsen and Al-Jayyousi [33] proposed an AHP model to assess several desalination technologies to enhance the water supply in Jordan.

The steps involved in the AHP method are schematically shown in Fig. 4, and may be summarized as follows [34]:

Step 1: The problem is broken into a hierarchy of the following components:

- Goals: the objective to be achieved.
- Criteria: the elements based on which the alternatives are evaluated.
- Alternatives: the possible set of actions, a good choice from which will depend on the extent to which the goal is achieved by fulfilling the different criteria.

where each of these components are identified with respect to the problem at hand. Sometimes an additional "sub-criteria" component is used below "criteria", particularly in complex problems [35], which, however, does not pertain to the present case.

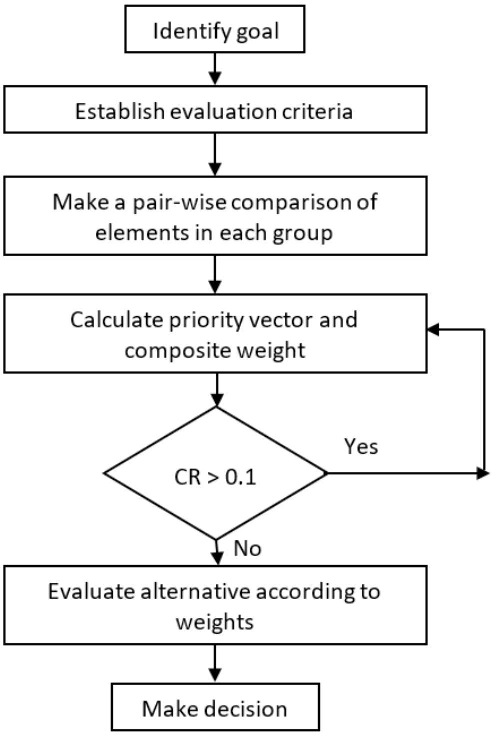

Fig. 4. Methodological approach of the AHP.

Step 2: Data are collected from experts or stakeholders from the qualitative pairwise comparison based on the hierarchy described in Step 1. Experts can score the comparison with the categories listed as follows:

- Equal
- Marginally strong
- Strong
- Very strong
- Extremely strong

Step 3: "Pairwise comparison matrices" are created from the various criteria and alternatives. Matrices are developed based on n (n – 1) judgements, where n stands for the number of elements in each level. For every pairwise comparison, reciprocals are assigned to the conjugate pair. Thus, if criterion i is judged to be twice as important as criterion k, then criterion k is considered to be half as important as i. More formally, the matrix A is formed based on the following rules [34]:

$$a_{ik} = \begin{cases} 1/a_{ki} & \text{where } a_{ki} \neq 0 \\ 1 & \text{if } i=k \end{cases}, \quad \text{for all } i,k = 1,2,\ldots,n \tag{1}$$

The diagonal elements of matrix A are unity, with the connotation that any criterion is exactly as important as itself. In particular, the n×n pairwise comparison matrix can be described as [34]:

$$A = \begin{pmatrix} 1 & a_{12} & \vdots & a_{1n} \\ 1/a_{12} & 1 & \vdots & a_{2n} \\ \cdots & \cdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{pmatrix} \tag{2}$$

Step 4: The overall priority or weight of the ith element (w_i) can be found from the normalized principal eigenvector W by solving the following standard linear algebra equation [34]:

$$AW = \lambda_{\max} W \tag{3}$$

where $\lambda_{\max}$ is the largest eigenvalue of A, and W is normalized in the sense that the sum of all its components is equal to 1. The n components of W give the weights of the n different criteria considered.

Step 5: The pairwise comparisons are said to be consistent if transitivity is preserved across all elements of A [34]:

$$a_{ik} = a_{ij}\, a_{jk} \qquad \text{for all } i,j,k \tag{4}$$

However, it is possible to accommodate certain amount of inconsistency in the ratings. The threshold is given by the constraint that consistency ratio (CR) should be less than or equal to 0.1 [34]. The consistency ratio is defined as:

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \tag{5}$$

where the consistency index (CI) is computed as [34]:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1} \tag{6}$$

and the random index (RI) is the average value of CI for the random matrices using the Saaty scale [12] given in Table 1.

Step 6: The final step of the AHP method consists of aggregating the local preferences $\mathrm{LP}_k(a_i)$ of each alternative a_i based on the weights w_k of the kth criteria C_k. This gives the composite weights $\mathrm{CW}(a_i)$ of each alternative a_i as [34]:

$$\mathrm{CW}(a_i) = \sum_k w_k \mathrm{LP}_k(a_i) \tag{7}$$

where w_k is the component of the eigenvector obtained in Eq. (3).

3.2. Cost factors of desalination technologies

The costs of the water produced by desalination have been significantly reduced over the last two decades. This is the result of the decrease in the prices of equipment and power consumption and advances in system design and operating experiences. The costs of desalination are more competitive than those of the operation and maintenance of long-distance water transport systems [36].

Zhou and Tol [37] reviewed the main criteria affecting the unit costs of a variety of desalination processes. In the present study, based on the recommendations by Hajeeh and Al-Othman [16], the following criteria are considered:

- Product water quality (C_1): the purity of the water obtained from the desalination plant expressed as the total dissolved solids content. Given that each technology has its limits of producing water with different qualities, this criterion influences the appropriate method to be adopted.
- Water recovery (C_2): The ratio of the amount of fresh water produced to the input feed flow rate. By affecting the energy requirement, this factor has a substantial effect on the cost of production.
- Energy consumption rate (C_3): the amount of energy required to produce unit volume of fresh water. This depends on the characteristics of the considered technology and the energy consumption of the desalination plant.
- Equipment efficiency and type of energy utilization (C_4): the efficiency of the technology used in terms of utilization rate of the input energy. This factor affects the cost of the produced water and it is naturally different for each technology, giving it an important part to play in making the right choice.
- Available technology (C_5): the ease of availability of the technology in the given conditions expressed as a qualitative variable. When a technology is not readily available, choosing it will be a blunder, making this an important criterion to be considered in proper decision making for commercial purposes.
- Plant capacity (C_6): production capacity of fresh water for a single production unit. Larger plants generally have lower production costs but they are costly to install and difficult to maintain.
- Total cost (C_7): Total production cost of unit volume of fresh water, which includes capital expenditure, recurring costs such as raw materials and labor, plus overheads. The choice of appropriate technology in any commercial plant is largely governed by the total cost.

Table 1
Random consistency indices for the different important levels [12]

Definition	Importance scale (n)	Random index (RI)
Equal importance	1	0.00
Intermediate values	2	0.00
Moderate importance	3	0.58
Intermediate values	4	0.90
Strong importance	5	1.12
Intermediate values	6	1.24
Very strong importance	7	1.32
Intermediate values	8	1.41
Extreme importance	9	1.45

The primary decision-making driver in the selection of a desalination technology for any region is the quality of the desalinated water. The quality determines the price per unit volume of the desalinated water, which is dependent on the initial cost of the plant and the plant maintenance cost and energy consumption.

3.3. Expert evaluation of criteria

Two groups of experts, each with more than 20 years of experience in the field of water desalination (e.g., academics and researchers from universities, researcher centres and companies in Spain and GCC) participated in this research study. In total, there were 12 experts from GCC and 16 experts from Spain. The AHP strategy began with a decomposition process followed by an integration process. The first level was to set the target purpose, which was determining the most appropriate technology for Spain and GCC countries. The next level was set to the criteria, and the last level was set to the alternatives required to achieve the target purpose. As mentioned earlier, the present study considers three alternatives, which are the most widely used technologies for water desalination in the GCC region and Spain:

- Multi-stage flash (a_1);
- Multi-effect distillation MED (a_2) and
- Reverse osmosis RO (a_3)

Fig. 5 shows the abovementioned AHP elements for the three levels.

The experts replied to the questionnaire based on the gradation scale for the quantitative comparisons of alternatives also graded as random index (RI) shown in Table 1.

Based on the opinion received from experts about the relative importance of the different criteria, two pairwise comparison matrices were constructed for Spain and the GCC countries. The matrices are presented in Tables 2 and 3.

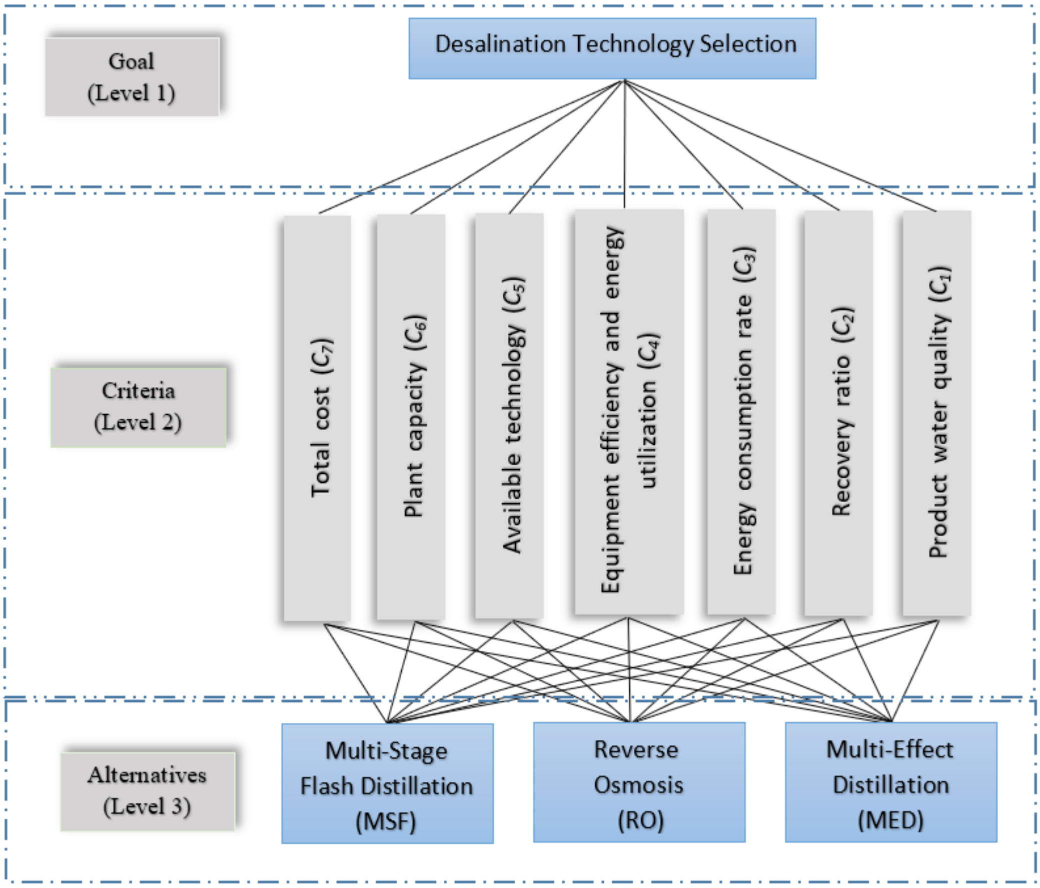

Fig. 5. Three-level hierarchal representation of the problem with seven criteria and three alternatives.

Table 2
Fractional importance of the compared criteria for Spain

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	w_k×100
C_1	1	1/5	1/6	1/3	1/2	1	1/9	3.2%
C_2	5	1	1	4	7	6	1/4	18.7%
C_3	6	1	1	5	6	5	1/4	19.0%
C_4	3	1/4	1/5	1	5	6	1/6	10.3%
C_5	2	1/7	1/6	1/5	1	1/2	1/9	3.4%
C_6	1	1/6	1/5	1/6	2	1	1/6	4.0%
C_7	9	4	4	6	9	6	1	41.4%

Table 3
Fractional importance of the compared criteria for the GCC countries

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	w_k×100
C_1	1	2	1	1/2	1/3	3	1/3	9.5%
C_2	1/2	1	1/7	1/2	1/3	1	1/9	4.0%
C_3	1	7	1	1/3	2	5	1/4	15.0%
C_4	2	2	3	1	2	2	1/5	15.0%
C_5	3	3	1/2	1/2	1	2	1/6	11.0%
C_6	1/3	1	1/5	1/2	1/2	1	1/5	5.0%
C_7	3	9	4	5	6	5	1	40.6%

These entries, in turn, represent preferences of the different criteria in relation to each other. For example, in the case of Spain, the product water quality (criterion C_1) was assessed vis-à-vis other criteria by experts, and their relative fractional importance values are presented in Table 2. Compared with water recovery (C_2), product water quality (C_1) was five times less preferred. In contrast, compared with the range of energy consumption (C_3), C_1 was six times less preferred. Similarly, the data in Table 3 for the GCC countries indicates that product water quality (C_1) was two times more preferred than water recovery (C_2) and equally preferred as range of energy consumption (C_3).

Briefly, the ratings of the intersection of each row with each column provide the degree of preference in comparison with each other. If the number in the rating is larger than 1, the criterion in that row is preferred over the criterion in the column by the given specific amount. Alternatively, if the number is less than 1, the criterion in the column is preferred over the criterion in the row by the denominator number.

According to Saaty [12], the best way to evaluate the preference intensity between two elements is by using a nine-point scale, as shown in Table 1. Then, the suitable RI value may be selected from Table 1, which translates the grades to scale of 0 to 1, which makes further calculations easier. The RI values listed in Table 1 are used for both consistent and non-consistent matrices. When CR is less than 0.1, the consistency of the ratings is considered to be adequate [34].

Otherwise, the pairwise comparison matrix is considered invalid (Fig. 4), which may be successively modified to fulfill the said criteria. The estimation of alternative local priorities can be carried out by utilizing a similar process for every criterion.

4. Results and discussion

This research included three main desalination technologies, namely, RO, MED and MSF, which were investigated based on the experts' opinions. These technologies were deployed to structure the required decision hierarchy. The pairwise comparisons were evaluated with the hierarchy elements depicted in Fig. 5 from the upper to the lower levels. This evaluation was followed by a calculation of both the ratings and weights of the criteria for each type of technology, as shown in Tables 2–4. The final results of the distributed questionnaires are summarized in Table 5.

The most dominant criterion in the selection of desalination technology is the total cost (C_7). The percentage weights (w_k) of this criterion are found to be 41.4% for Spain, and 40.6% for the GCC countries (Fig. 6). This is quite logical, because such technologies generally involve very high costs. The second most dominant criterion is the rate of energy consumption per unit water product (C_3), with percentage weights 19% for Spain and 15% for the GCC countries. The next most dominant criterion is the equipment efficiency and energy utilization (C_4), with percentage weights of 10.3% for Spain and 15% for the GCC countries. This criterion is then followed by the water recovery (C_2), with percentage weights 18.7% for Spain and 4% for the GCC countries.

The fifth most important criterion is the available technology (C_5), representing percentage weight values of 3.4% for Spain and 11% for the GCC countries. The product water quality (C_1) is the next greatest criterion, with percentage weights of 3.2% for Spain and 9.5% for the GCC countries. The last criterion is the plant capacity (C_6), which has percentage weights of 5% and 4% for the GCC countries and Spain, respectively. Table 4 lists the constructed matrices related to the pairwise comparisons of various technologies using the

Table 4
Pairwise comparison of the different technologies with respect to the various criteria for Spain and the GCC countries

	Spain				GCC countries			
	MSF	MED	RO	w_k×100	MSF	MED	RO	w_k×100
Product water quality (C_1)								
MSF (a_1)	1	1	7	46.7%	1	9	9	82.0%
MED (a_2)	1	1	7	46.7%	1/9	1	1	9.0%
RO (a_3)	1/7	1/7	1	6.6%	1/9	1	1	9.0%
Recovery ratio as a function of the feed (C_2)								
MSF (a_1)	1	1/2	1/9	7.4%	1	9	1/7	26.5%
MED (a_2)	2	1	1/9	11.7%	1/9	1	1/6	6.8%
RO (a_3)	9	9	1	80.8%	7	6	1	66.7%
Energy consumption rate per unit water product (C_3)								
MSF (a_1)	1	1/2	1/9	7.4%	1	1/9	1/9	5.2%
MED (a_2)	2	1	1/9	11.7%	9	1	1/7	23.7%
RO (a_3)	9	9	1	80.8%	9	7	1	71.0%
Equipment efficiency and type of energy utilization (C_4)								
MSF (a_1)	1	1	1/9	9.1%	1	9	1	47.4%
MED (a_2)	1	1	1/9	9.1%	1/9	1	1/9	5.2%
RO (a_3)	9	9	1	81.8%	1	9	1	47.4%
Available technology (C_5)								
MSF (a_1)	1	9	1	47.3%	1	7	1	45.0%
MED (a_2)	1/9	1	1/9	5.3%	1/7	1	1/9	6.0%
RO (a_3)	1	9	1	47.4%	1	9	1	49.0%
Plant capacity (C_6)								
MSF (a_1)	1	9	1	47.3%	1	9	1	47.3%
MED (a_2)	1/9	1	1/9	5.3%	1/9	1	1/9	5.3%
RO (a_3)	1	9	1	47.4%	1	9	1	47.4%
Total cost (C_7)								
MSF (a_1)	1	1/9	1/7	6.0%	1	9	2	58.0%
MED (a_2)	9	1	1	49.0%	1/9	1	1/9	5.0%
RO (a_3)	7	1	1	45.0%	1/2	9	1	37.0%

Table 5
Composite weights (CW) of the different desalination technologies in Spain and the GCC countries

Criterion	Spain				GCC countries			
	w_k	MSF	MED	RO	w_k	MSF	MED	RO
C_1	0.032	0.467	0.467	0.067	0.095	0.818	0.091	0.091
C_2	0.187	0.074	0.118	0.808	0.041	0.265	0.068	0.667
C_3	0.190	0.074	0.118	0.808	0.150	0.052	0.237	0.711
C_4	0.103	0.091	0.091	0.818	0.150	0.474	0.053	0.474
C_5	0.034	0.474	0.053	0.474	0.11	0.451	0.059	0.49
C_6	0.041	0.474	0.053	0.474	0.048	0.474	0.053	0.474
C_7	0.414	0.059	0.49	0.451	0.406	0.579	0.052	0.368
CW×100	–	11.0%	32%	57%	–	47%	21%	32%

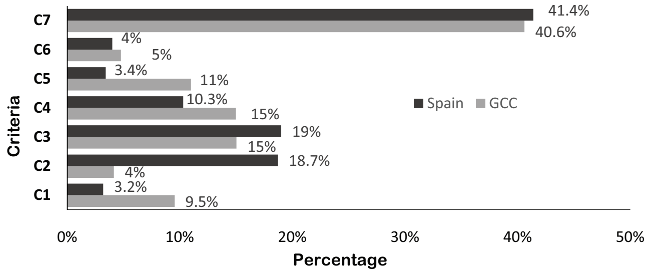

Fig. 6. Pairwise comparisons of different criteria and their percentage weights (w_k) in the GCC countries and Spain.

abovementioned criteria and their different assigned weights. Moreover, Table 6 summarizes the rankings of multiple technologies for each criterion with the specified composite weights. Based on the gathered data, criteria and different alternatives, the composite weights of various desalination technologies in both the GCC countries and Spain were calculated. The results of the processed data are presented in Tables 5 and 6.

Fig. 7 shows that the most suitable technology for Spain is RO (57%), followed by MED (32%) and MSF (11%). In contrast, for the GCC countries, the most preferred technology is MSF (47%), followed by RO (32%) and MED (21%).

In Spain, the main advantages of the RO technology are the satisfactory fulfillment of the requirements for high quality of the produced water, intermediate capital cost and operational flexibility [30]. RO has a meaningful impact in reducing the high water demands of domestic and industrial users. On the other hand, the MSF seawater desalination technology has certain advantages for the GCC countries. These advantages include the simplicity of MSF facilities and the high technological reliability and excellent water capacity of single MSF units [36]. However, MSF requires larger energy consumption than MED and RO technologies, which is readily available at a reasonable cost in the Gulf countries. In addition, an MSF plant can comfortably work with higher salinity levels of input water, which is another possible reason for the experts' opinion being tilted toward choosing this technology for the GCC countries.

With this finding, which summarily differs from the finding of Hajeeh and Al-Othman [16], it is expected that MSF will be viewed as a prospective alternative to RO in the Gulf countries, and elsewhere where fuel is cheap.

Table 6
Ranking of the different desalination technologies according to the various criteria in Spain and the GCC countries

Criterion	Spain			GCC countries		
	MSF	MED	RO	MSF	MED	RO
C_1	1	1	2	1	2	2
C_2	3	2	1	2	1	3
C_3	3	2	1	3	2	1
C_4	2	2	1	1	2	1
C_5	1	2	1	2	1	3
C_6	1	2	1	1	2	1
C_7	3	1	2	1	3	2

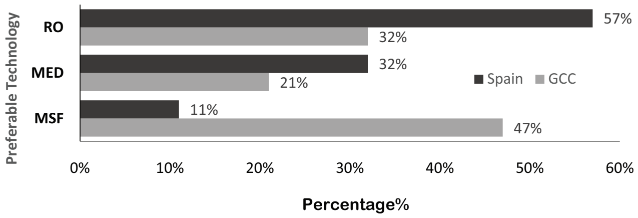

Fig. 7. Ranking of different desalination technologies based on the composite weights of the criteria for the GCC countries and Spain.

5. Conclusions

An efficient method to decide the most appropriate water desalination technologies for the GCC countries and Spain based on the AHP method is presented. These countries experience a lack of freshwater projects, due to the high cost and energy demands of desalination plants. Therefore, the GCC countries and Spain need more detailed investigations of the scenario in order to determine the most appropriate desalination technologies. According to the opinions of experts in both the GCC countries and Spain, the dominant criterion to select the most appropriate technology emerged to be the total cost of freshwater production, followed by the energy consumption of desalination plants. The results of this study revealed that the most suitable technology in the GCC countries is MSF, while RO is the most suitable desalination technology for Spain. The choice of MSF in the Gulf is possibly prompted by the high feed water salinity, cheap availability of fossil fuel, as well as important financial, industrial and ecological conditions. The factors affecting the choice of RO as the recommended desalination technology in Spain could possibly be the lower operating cost, lower footprint and demand for high quality water. It is envisaged that the present recommendations will help industries in these regions to consider the appropriate technologies for a better business and prospective future.

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