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Ibrahim Badi [1]
Mohamed Ballem
Ali Shetwan

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SITE SELECTION OF DESALINATION PLANT IN LIBYA BY USING COMBINATIVE DISTANCE-BASED ASSESSMENT (CODAS) METHOD

Abstract: *Libya is one of the arid regions of the world, and it is facing a serious water supply shortage due to the increase in both population and water consumption in various sectors. Ground water is the main source of water in Libya, but it is limited and over exploited. Desalination of sea water is one of the possibilities for Libyan government to meet the problem of water shortage. Selecting the best location of desalination plant is important and a complex process because it is related to a variety of criteria. The aim of this paper is to select the best location of desalination plant in the northwestern coast of Libya. The selection of the best location was done by two main steps. The first step based on the criterion of minimizing water transportation cost, and the second step considered the influence of the external criteria on the location selection. The results of the case study show that the best location is the capital city (Tripoli) with respect to the assessment of COmbinative Distance-based ASsessment (CODAS) method. The sensitivity analysis was conducted to evaluate the robustness of the selected locations and it reveals that the CODAS method is stable and efficient to deal with multi-criteria decision-making problems. This study provides a suitable and useful tool for the decision makers concerning the optimum location of desalination facilities.*

Keywords: *Desalination, Location, Selection, Multi-criteria, Libya*

1. Introduction

Water is one of the most important substances on Earth and it is the corner stone to life development and prosperity. It covers two thirds of Earth's surface. Ninety seven percent of the water on Earth is salt water and only three percent is fresh water. Approximately one third of this fresh water is available for human consumption and it is found mainly as groundwater. The remaining two thirds are locked up in the frozen polar ice-caps and glaciers. The available amount of fresh water should be enough to satisfy the needs of all water consumers in the world. However, this is not the case, because of the variations in the availability of water resources from region to region in the world. The Middle East and North Africa are the most scarce regions of water in the world, and they are expected to face a worsening crisis in terms of its access to water in the coming decades (Serageldin, 1995).

[1] Corresponding author: Ibrahim Badi
Email: i.badi@eng.misuratau.edu.ly

Libya sited in North Africa and it is bordered by the southern coast of the Mediterranean Sea in the north, Egypt in the east, Algeria and Tunisia in the west, Chad and Niger in the south, and Sudan in the southeast. The total area of the country is about 1.76 million km², 95 % of it is desert. The climatic conditions are influenced by the Mediterranean Sea to the north and the desert to the south, resulting in an abrupt transition from one kind of weather to another; Temperatures vary between over 40°C in summer to below zero in winter. Annual rainfall is extremely low, with about 93 % of the land surface receiving less than 100 mm/year. The average annual rainfall for the whole country is only 26 mm. Rain usually occurs during the winter season, but varies greatly from place to place and from year to year. The highest rain falls are recorded in the northern Tripoli region (Jabal Nafusah and Jefarah plains) and in the northern Benghazi region (Al-Jabal al-Akhdar), making them the only areas of the country exceeding the minimum value of 250–300 mm considered necessary to sustain rainfed agriculture (Abdudayem and Scott, 2014; FAO, 2016).

Water resources are the sources of water that are potentially useful. They are important because of their various uses in agricultural, industrial, household, recreational and environmental activities. In fact, water is needed for life to exist. Water resources in Libya come from four sources: groundwater (providing almost 95% of the country's needs), surface water (including rainwater and dams), desalinated sea water, and wastewater recycling. The major sources of groundwater in Libya come from five water basins: Al-Sarir, Murzek, Al-Hamada, Al-Jabal al-Akhdar, and Al-Jefarah plain. Groundwater in the country can be divided into renewable resources, mostly found in shallow aquifers, and the non-renewable resources (fossil water) encountered in deep aquifers.

The second water resource in Libya is the surface water, and as mentioned above the annual rainfall is extremely low especially towards the southern regions and almost no rain falling in Kufra, Murzek and Sarir. The country has constructed a few dams, currently 19 dams designed for storage capacity of about 390 million m³; however their average annual storage capacity is only about 61 million m³. Furthermore, 20 dams are planned for construction representing an additional of about 137 million m³ of storage and 45 million m³ of additional average annual storage. Libya does not share any surface water with other neighboring countries, but most of its groundwater is shared (Abdudayem and Scott, 2014; FAO, 2016).

In the 1960s, Libya turned to desalination as an additional source of water, and became one of the largest users of both thermal and membrane desalination technologies in the Mediterranean region. According to the statistics of General Company of Water Desalination (GCWD), the total production of desalinated water in 1999 was 47,851,500 m^3 (about 131,100 m^3/day), and in 2009 was 51,432,675 m^3 (about 140,911 m^3/day). By comparing these figures it is clear that this sector has not seen a noticeable improvement or development over the decade between (1999–2009). However, desalination water from the Mediterranean Sea seems to be the first priority for Libya in the future due to unlimited seawater sources. Thus a number of desalination plants are planned or already under construction. Upon the completion of these projects, it is estimated that the production capacity of desalinated water in Libya will reach 86.5 million m³/year in 2025 (CEDARE, 2014; Abdudayem and Scott, 2014; Abufayed and El-Ghuel, 2001).

Wastewater treatment plants have been implemented at varying levels of interest from the 1970s to the early 1990s for the purposes of agriculture and environmental protection. In 2010 Libya has 79 wastewater treatment plants for a total capacity of 74 million m³, all of which were designed to produce effluents suitable for irrigation. However, out of the 504 million m³ municipal wastewater produced in 2012, only 40 million m³ were treated and directly used in irrigation

(FAO, 2016).

According to the 2015 census, population of Libya was about 6.3 million, and about 85% of the country populations live within the coastal cities where the climate is moderate. Also, Libya is one of the 26 countries in the developing world whose population could conceivably double in the next 25 years (Abdudayem and Scott, 2014; Elabbar and Elmabrouk, 2005; FAO, 2016; UNDP, 2016). As a result of the continuous population growth and water needs for the domestic, industrial and agricultural sectors, the amount of water drawn has increased sharply over time, and no doubt will increase in the future (Wheida and Verhoeven, 2007). The rates of surface water and renewable water per capita in Libya are the lowest in the Middle East and the North African Region (Abdudayem and Scott, 2014). Therefore, Libya is facing a serious water supply shortage due to an imbalance between limited water resources and its demands, and also because of disparate population distribution resulting in tremendous shortage in water supply in more populated area (Hasan, 2014; Wheida and Verhoeven, 2004).

In order to overcome the water deficit, the Libyan government has focused on unconventional water resources such as seawater desalination, and integrating them into a general water management policy. As reported by Elhajaji et al. (2014) that the cost of cubic meter produced by the Great Man-Made River Project is estimated to 0.83$, and the cost of desalinated water by thermal desalination plants is about 0.47$/$m^3$; thus seeing this as the best option for providing water, due to unlimited seawater sources. However, installation of suitable desalination plants in the right site will certainly play an important role in sustaining the economic development of the country and covering the municipal and industrial water requirements. Therefore, site selection of desalination plant is vital and can be one of the most important decisions in planning a desalination project.
This paper summarizes a method that can be used for selecting an optimal location for desalination facilities as they are expected to become a vital source of water supply in Libya. The paper suggests the best location for desalination plant by using two main steps approach: the first step is to calculate the water flow at every point. Secondly, multi criteria decision making (MCDM) methodology is used to select the best location. The paper is organized as follows. Section 2 presents a literature review on MCDM and CODAS Methods. Section 3 presents the methodology of the research, where case selection, region of interest, data collection, desalination plant location selection and applying of CODAS methods are addressed. In section 4, the results of the case study are presented and discussed. Finally, Section 5 presents concluding remarks that emerged from the analysis of the case study and scope for future research.

2. Literature review

2.1. Multi-criteria decision-making (MCDM) methods

Desalination can play an important role in the near future to bridge the gap between the available conventional water resources and the total water demand for the different uses (Afify, 2010). Desalination plant site selection is a field that is quite suitable for the use of MCDA. Desalination plants assessment for water production on different criteria (Afgan et al., 1999). In the past decades many Multi-criteria decision-making (MCDM) methods and techniques have been proposed by researchers. Such methods and techniques are helpful in identifying the best choice. Analytical Hierarchy Process AHP is a common multi-criteria decision making method. It is developed by Saaty (Saaty, 1979, 1990) to provide a flexible and easily understood way of analyzing complex problems. The problem is converted into hierarchy or levels, and then make a pairwise comparison to give weight for each factor and consistency ratio. AHP method has been used more than any other MCDM methods

(Aljamel et al., 2017; CHAI et al., 2013). AHP has been applied for water policies, and selecting desalination technology (Mohsen and Al-Jayyousi, 1999). However, the methodology of AHP is based on weighting the relative importance of criteria, while dependencies among criteria are neglected. In terms of mathematics and philosophy, AHP is capable of providing an easy and understandable method to practitioners. However, the drawback of the method is still insufficient to explain uncertain conditions particularly in pair-wise comparison stage. Most of human judgments could not be represented as exact numbers because some of the evaluation criteria are subjective and qualitative in nature. Therefore, it is very difficult for the decision-maker to express the preferences using exact numerical values and to provide exact pair-wise comparison judgments. To tackle these problems, AHP has been integrated with other methods, including ANN (Kuo et al., 2002), Fuzzy set theory (Jain et al., 2016; Gold and Awasthi, 2015; Stević et al., 2016; Božanić et al., 2015; Vasiljević et al., 2016; Tadic et al., 2013), Grey Relational Analysis (Liang et al., 2013; Bali et al., 2013), a combination of different methods (Zakeri and Keramati, 2015; Pamučar et al., 2016; Stević et al., 2016), and hybrid IR-AHPMABAC (Pamučar et al., 2018). It seems, however, that the growth of AHP applications may derive more from a simplification perspective rather than from a robust theoretical mathematical perspective.

2.2. Combinative Distance-based Assessment (CODAS) method

This method developed method by Ghorabaee et al., (2016) in 2016; and has a number of features that have not been considered in the other multi-criteria decision making method. The CODAS method has been compared with some of the existing MCDM methods, and was efficient to deal with MCDM problems. Ghorabaee et al. (2017) also used an integrated model by combining the fuzzy logic theory and the CODAS method to select the best suppliers. In their work, a fuzzy extension of the CODAS method was developed to deal with multi-criteria decision-making problems in an uncertain environment. They used the linguistic variables and trapezoidal fuzzy numbers to extend the CODAS method and propose a multi-criteria group decision-making approach. A numerical example of a shoe company was utilized to show the applicability of their method in multi-criteria market segment evaluation and selection. The results indicate that the fuzzy CODAS method was consistent with the results of the other method in the literature. Panchal et al. (Panchal et al., 2017) applied an integrated MCDM framework based on analytical hierarchy process (AHP) and a fuzzy CODAS approach for solving the maintenance decision problem in a process industry. In order to overcome the vagueness in human judgment, they have incorporated fuzzy set theory within the proposed framework. The sensitivity results confirmed the stability of their frame work. Also Badi et al. (2017) used CODAS method to select the best supplier, and sensitivity analysis conducted and they confirmed the stability of the method (Badi et al., 2018). In CODAS method, the desirability of alternatives is determined by using two measures. The main and primary measure are related to the Euclidean distance of alternatives from the negative-ideal. Using this type of distance requires an -norm indifference space for criteria. The secondary measure is the Taxicab distance, which is related to the -norm indifference space. Obviously, the alternative which has greater distances from the negative-ideal solution is more desirable. In this method, if two alternatives are incomparable according to the Euclidean distance, then the Taxicab distance is used as a secondary measure. Although the -norm indifference space is preferred in the CODAS, two types of indifference space could be considered in its process.

3. Research method

3.1. Case selection

As the cost of desalination continues to decrease with improved technologies, there are needs for optimally locating desalinization facilities over regional scales. In this study, the CODAS method based on the various data collected will be used to obtain optimum site selection of desalination plant. Macros in MS Excel were used to compute the developed model. The steps which are used in the method can be described as a decision support system that is used to support management and planning levels of business and organizations in decision-making. The decision support system is developed in this paper focuses on two important steps that summarize the methodology of the optimization. These two steps are solving the objective function to minimize the water transportation cost and identify candidate locations then applying multi-criteria analysis on all those locations in order to obtain best alternative location(s).

3.2. Region of interest

There are no permanent rivers in Libya, thus the country has planned, designed and implemented the world's largest and most expensive groundwater pumping and conveyance project called the Great Manmade River Project (GMRP) to transfer freshwater from its southern parts to the northern parts, as shown in Figure 1 (Abdudayem and Scott, 2014; Wheida and Verhoeven, 2007).

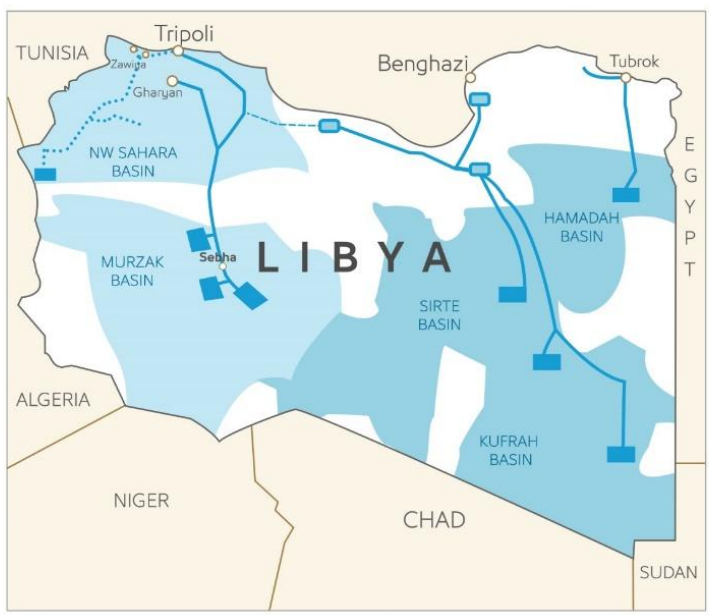

Figure 1. The water basins and GMRP on the map of Libya (Adapted from Abdudayem and Scott, 2014; FAO, 2016)

The region of interest in this paper is the northwestern part of Libya. It lies on the southern coast of the Mediterranean Sea starts from Ras-Eljdair in the west to Misurata in the east as shown in Figure 2. The region is important because it is an agricultural and populated area. As mentioned earlier, most of the population live in or around the coastal cities, for instance about a third of Libya's population lives in the capital city Tripoli.

Furthermore a large number of industries, such as chemical, petrochemical, steel, textile and power generation industries, are located in this region. The demand on water in this area compared with other regions in the country is relatively high and increasing with time as a result of the high growth rate of the population, and the increase in industrial, and agricultural activities. In this region, there are three operated desalination plants. Nevertheless their existing capacity is relatively insignificant compared to the total demand. Thus there is an urgent need for build up more desalination plants to meet these increasing water demands.

Figure 2. Cities in the North West coast of Libya

3.3. Data Collection

A comprehensive data about water demand is collected from each city and each potential site by reviewing previous studies and researches published by National Water Authority of Libya (Abdudayem and Scott, 2014; Alhrari et al., 2014). Likewise, the data include, geographical, environmental information, the distance between the cities, and electric power generation facilities. A questionnaire was distributed to a group of relevant experts in desalination plants and for each criterion was allocated with weight from 1 to 10. The criterion which was assigned with 10 is considered as a perfect condition for a particular location. As shown in Figure 2, the northwest coast of Libya contains mainly eleven cities starting from Ras-Eljidair at far west (on the border of Tunisia) and ending at Misurata (on the middle coast of Libya). Table 1 shows the progressive distance for each city starting from Ras-Eljdair, whereas Figure 3 shows the water demand for each city.

Table 1. Progressive distance and population for each city

City	Distance from Ras-Eljdair (km)	Population
Ras-Eljdair	0	19,000
Zoltun	20	70,000
Zwara	40	75,893
Subrata	90	80,000
Surman	100	36,707
Zawia	120	234,000
Tripoli	160	2,220,000
Qarabouli	220	78,000
Khomus	280	88,317
Zliten	320	200,000
Misurata	360	281,000

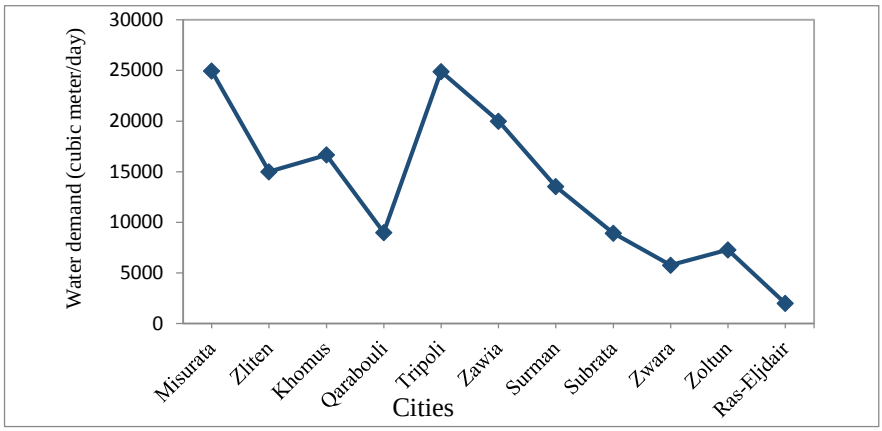

Figure 3. Water demand for cities in northwest coast of Libya

3.4. Desalination Plant Location Selection

Based on certain criteria, analytical methods can be utilized to find the best desalination plant location. The best location is selected amongst a variety of possible locations. Depending on the facility type, the new plant can be considered as either a point location or an area location. Six parameters can be categorized facility location problems: new facility characteristics, existing facility location, new and existing facility interactions, solution space characteristics, distance measure, and the objective. In this study, the facility is considered as appoint location and facility characteristic is capacity. Assuming that there are no desalination plants in the area of study, the existing facility location as well as new and existing facility interaction elements can be ignored. The solution space characteristics and distance measures are determined through the prevailing geographic data available.

In the first step, a list of possible locations depending on the criterion of minimizing water transportation cost is generated and estimated by using equation (1) (Alhrari et al., 2014).

$$\min \left\{ \sum_{i=1}^{n} Q_i \left[L_i(F, a_i) \right]^2 \right\} \quad (1)$$

Where:

Q: Water demand for city i [m^3/day]

F: Location of the desalination plant

a_i: Location of city i

L_i (F, a_i): The absolute shortest distance between the desalination plant and city i

For every point, equation (1) calculates the quantity of water transported from desalination plant to every city. The model will calculate the minimum value. Based on equation (1), the best location for desalination plant is shown in Figure 4. The curve represents the objective function at different locations of cities along the west coast of Libya. The minimum point of the curve is the best location. The distance that corresponds to the lowest point of the curve is far from east Ras-Eljdair about 170 km. Therefore, this point is the best location where the amount of transferred water is minimum. This selection is considered as the best location and denoted by S5, after that it will be added to the other possible locations in the second step. Also, the criterion of minimizing water transportation cost will be added to the other criteria, and it depends on QL^2values. The aim is to subject the significance of the selected locations to multi-criteria method in order to consider the influence of other external criteria on the location selection. The external criteria include ten different criteria: raw water proximity, raw water quality, product water distribution network, vicinity

power plants/electrical network, industrial network, product water selling price, energy cost, labor cost, local regulation and applicable standard, and manpower skills. These criteria have been prepared based on the questionnaire forms that have been filled in by the experts and managers who work in the university and desalination plants. It should be noted that six criteria are excluded because their values are equal in all locations. The six excluded criteria include: industrial network, product water selling price, energy cost, labor cost, local regulation and applicable standard, and manpower skills.

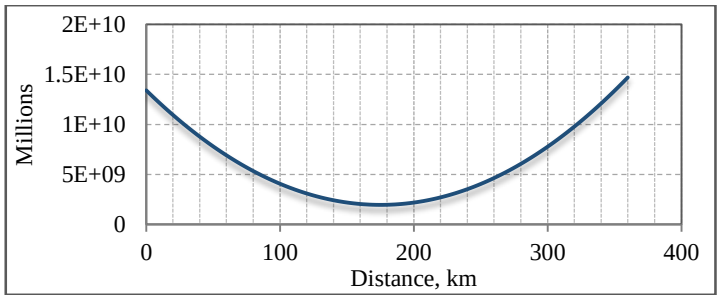

Figure 4. The best location for desalination plant based on equation (1)

3.5. CODAS Method

In this section, a Combinative Distance-based Assessment (CODAS) method is applied to deal with multi-criteria decision-making problems. Based on the assumption that alternatives and criteria are available, the steps of the proposed method can then be presented as follows:

Step 1. Developing the decision making matrix as follows:

$$X = [x_{ij}]_{n\times m} = \begin{bmatrix} x_{11}x_{12} & \dots & x_{1m} \\ x_{21}x_{22} & \dots & x_{2m} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ x_{n1}x_{n2} & \dots & x_{nm} \end{bmatrix}$$

where x_{ij} ($x_{ij} \geq 0$) denotes the performance value of ith alternative on jth criterion ($i \in \{1,2,\dots,n\}$ and $j \in \{1,2,\dots,m\}$).

Step 2. Compute the normalized decision matrix. Linear normalization of performance values is used as given by equation (2).

$$n_{ij} = \begin{cases} \frac{x_{ij}}{max_i x_{ij}} & if\ j \in N_b \\ \frac{min_i x_{ij}}{x_{ij}} & if\ j \in N_c \end{cases} \quad (2)$$

Where N_b and N_c represents the sets of benefit and cost criteria, respectively.

Step 3. Compute the weighted normalized decision matrix. The weighted normalized performance values are calculated as given by equation (3).

$$r_{ij} = w_j n_{ij} \quad (3)$$

Where $w_j (0 < w_j < 1)$ denotes the weight of jth criterion, and $\sum_j^m = 1, w_j = 1$.

Step 4. Determine the negative-ideal solution (point) as given in equation (4).

$$ns = [ns_j]_{1\times m}$$
$$ns_j = min_i r_{ij} \quad (4)$$

Step 5. Calculate the Euclidean and Taxicab distances of alternatives from the negative-ideal solution as given in equations (5) and (6) respectively.

$$E_i = \sqrt{\sum_{j=1}^m (r_{ij} - ns_j)^2} \quad (5)$$

$$T_i = \sum_{j=1}^m |r_{ij} - ns_j| \quad (6)$$

Step 6. Construct the relative assessment matrix as given in equation (7).

$$R_a = [h_{ik}]_{n\times n} \quad (7)$$

$$h_{ik} = (E_i - E_k) + \big(\psi(E_i - E_k) \times (T_i - T_k)\big)$$

Where $k\in \{1, 2,\ldots, n\}$ and ψ denotes a threshold function to recognize the equality of the Euclidean.

$$\psi(x) = \begin{cases} 1 & if\ |x| \geq \tau \\ 0 & if\ |x| < \tau \end{cases}$$

In this function, τ is the threshold parameter that can be set by the decision-maker. It is suggested to set this parameter at a value between 0.01 and 0.05. If the difference between Euclidean distances of two alternatives is less thanτ, these two alternatives are also compared by the Taxicab distance. In this study, it is assumed that τ= 0.02 for the calculations.

Step 7. Calculate the assessment score of each alternative as given by equation (8).

$$H_i = \sum_{k=1}^{n} h_{ik} \quad (8)$$

Step 8. Rank the alternatives according to the decreasing values of assessment score (H). The alternative with the highest H is the best choice among the alternatives.

CODAS method is used to evaluate the alternatives. In addition to the best location (S5) that was found in the step 1, four locations are suggested include: Tripoli (S1), Azawia (S2), Qarabouli (S3) and Surman (S4).These locations are selected according to their QL^2 values. On the other side, five criteria are used: Raw water proximity, Raw water Quality, product water distribution network, vicinity power plants/electrical Network, and cost. Suppose that weighted normalized performance values (r_{ij}) have been calculated. These values are dimensionless and between 0 and 1. Figure 5 shows the position of all alternatives according to these values.

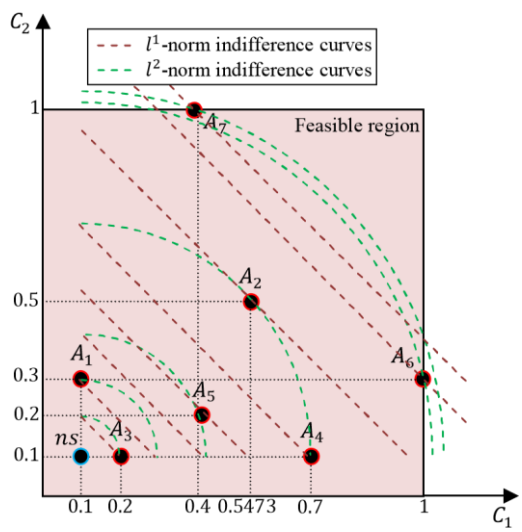

Figure 5. A simple graphical example with two criteria (Ghorabaee et al., 2016)

It can be seen from Figure 4, that A_2 has greater Taxicab distance from the negative-ideal point. This fact is clear according to the indifference curves, which is presented in the Figure. Therefore, we can say that $A_2$is more desirable than A_4, and the final ranking is$A_3 < A_1 < A_5 < A_4 < A_2 < A_6 < A_7$.

4. Results and Discussion

Establishing the criteria is the first step in the process of sites assessment. In this paper, qualitative criteria are identified based on questionnaire forms. In order to facilitate the solution process for the site assessment problem, macros in MS Excel were used to compute the model. As mentioned above, in this assessment problem five different criteria are considered: raw water proximity, raw water quality, product water distribution network, vicinity power plants/electrical network and cost. All these criteria are defined as benefit criteria, except the cost and proximity are defined as cost criteria. However, integration in industrial network, product water, selling price, energy cost, labor cost, local regulation, applicable Standard and manpower skills are excluded because they are equal in all sites. The five suggested sites and the corresponding data are given in Table 2. These locations are selected according to their QL^2 values. The selected locations are: Tripoli (S1), Zawia (S2), Qarabouli (S3), Surman (S4) and suggested location (S5). S5 is the selected location that was previously identified in step 1.Every criterion has a given weight by experts, and the total weight of each criterion is 1.0. Also, each criterion for the suggested locations have been allocated with weights by the experts.

Table 2. Data of the case study

	Weights of criteria	0.19	0.26	0.24	0.17	0.14
Alternatives		Proximity	Quality	Network	Vicinity	Cost
S1		8	8	10	9	5
S2		8	9	9	9	8
S3		9	9	7	8	6
S4		8	8	7	8	9
S5		9	8	7	7	4

Based on Table 2, the decision matrix can be constructed. Then the normalized decision matrix is calculated as shown in Table 3. For each criterion, this can be done by dividing each weight of the suggested sites on the maximum weight of this criterion. Using weights of criteria that are given in Table 2, the weighted normalized performance values can be calculated and then the negative-ideal solution is determined. According to the obtained values, the Euclidean and Taxicab distances of alternatives from the negative-ideal solution are also computed. The negative-ideal solution, Euclidean and Taxicab distances are presented in Table 4.

Table 3. The normalized decision matrix

Alternatives	Criteria				
	Proximity	Quality	Network	Vicinity	Cost
S1	1.000	0.889	1.000	1.000	0.800
S2	1.000	1.000	0.900	1.000	0.500
S3	0.889	1.000	0.700	0.889	0.667
S4	1.000	0.889	0.700	0.889	0.444
S5	0.889	0.889	0.700	0.778	1.000

The relative assessment matrix and the assessment scores (H) of alternatives can be calculated by using Table 4 and Equation (6) as presented in Table 5. It should be noted that, the calculations are performed with τ= 0.02.

Table 4. The weighted normalized decision matrix and the negative-ideal solution

Alternatives	Criteria					Distances	
	Proximity	Quality	Network	Vicinity	Cost	Euclidean	Taxicab
S1	0.1900	0.2311	0.2400	0.1700	0.1120	0.0976	0.1807
S2	0.1900	0.2600	0.2160	0.1700	0.0700	0.0712	0.1436
S3	0.1689	0.2600	0.1680	0.1511	0.0933	0.0465	0.0789
S4	0.1900	0.2311	0.1680	0.1511	0.0622	0.0283	0.0400
S5	0.1689	0.2311	0.1680	0.1322	0.1400	0.0778	0.0778
Negative-ideal solution	0.1689	0.2311	0.1680	0.1322	0.0622		

Table 5. The relative assessment matrix and the assessment scores of alternatives

	S1	S2	S3	S4	S5	H
S1	0	0.0635	0.15296	0.20998	0.02	0.4463
S2	-0.0635	0	0.08942	0.14644	-0.007	0.1658
S3	-0.153	-0.089	0	0.01814	-0.03	-0.2544
S5	-0.21	-0.146	-0.0181	0	-0.087	-0.4618
S5	-0.0199	0.0066	0.0302	0.08723	0	0.1041

As can be seen from Table 5, the highest H is location S1 (Tripoli). Therefore, S1is the best location with respect to the assessment of the CODAS method. Compared to the results obtained by Alhrari et al. (2014), the best location was located at a place of 25 km from Ras-Eljdair close to the city of Zoltun. The difference in the results is due to the fact that the study of Alhrari et al. was limited on four cities, while the current study included twelve cites. In addition, a sensitivity analysis has been conducted to demonstrate the validity and stability of the CODAS method. Fourteen values of τ ranged between 0.01 and 1.00 are used to evaluate their effect on locations assessment ranking. Table 6 shows the values of τ and their effect on sites ranking. According to the results of the sensitivity analysis, it was found that the CODAS method is stable and efficient to deal with multi-criteria decision-making problems.

Table 6. Ranking locations with different values of τ

	τ													
	0.01	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.15**	**0.30**	**0.50**	**1.00**
S1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
S3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
S4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
S5	3	3	3	3	2	2	2	2	2	2	2	2	2	2

Figure 6 shows the effect of changing the value of the threshold parameter(τ) graphically, as can be seen from the figure the first location (S1) is the best regardless of τvalue. Changing the τ parameter has minor effect on the ranking of alternatives that can undermine the validity of the results.

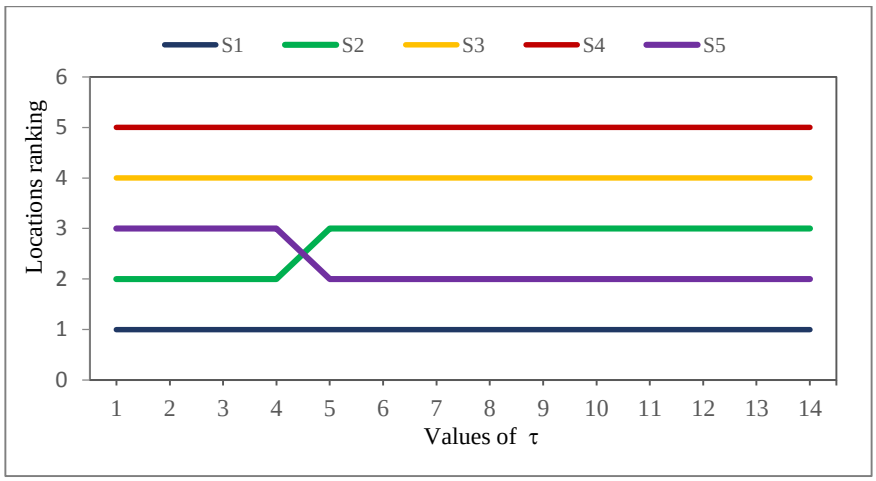

Figure 6. Locations ranking with different values of τ

As a result of Libyan population growth, more water will be needed to meet its needs. At present, limited water resources make water demand beyond the conventional water resources in Libya. Consequently, groundwater levels are decreasing making extraction difficult and costly. In the present time there is an urgent need for integrated water resources management with a particular focus on non-conventional water resources namely, sea water desalination and reuse of waste water. The choice of plant site is very vital to the design, financing of construction and operation of desalination plants. There are many criteria affecting the selection process of desalination site. The selected criterion used in this work are quite generic, thus with minor modification, they can be used in other cases. The systematic technique used is advantageous as any new site could easily be incorporated in the model.

5. Conclusion and scope for future research

This paper contributes to the knowledge by developing for the first time a methodology using CODAS method to select the best location of desalination plant in north west coast of Libya. The selection of the best location consists of two main steps. Firstly, by applying the objective function to minimize water transportation costs. Then, multi-criteria analysis is applied by using CODAS method to select the best location. The results of the case study showed that the best selection location for desalination plant is S1 (Tripoli city). Furthermore, sensitivity analysis is conducted to evaluate the robustness of the selected locations. A "What if Analysis" was performed to see if there were any changes among the selected locations. The results show no changes in the ranked results, as location S1 remained the best location. In conclusion, the study provides a suitable tool for the decision makers concerning the optimum location of desalination facilities. Furthermore, the good results from multi-criteria analysis are mainly depended upon accurate knowledge of the various parameters and their weights.

For future research the following possible area may be studied:

- Provide a sound basis for comparing the costs and benefits of desalination to other sources of water. An underlying problem in water management is the difficulty in assessing the true cost of water, including not only infrastructure, energy and other direct costs, but also environmental costs, impacts on other water users and other externalities. Developing better metrics for analyzing the true cost and sustainability of various water sources is critical to making better water management decisions, including choices about alternative water supply sources such as desalination.
- Due to lack of information about various effects of desalination plants on receiving waters and coastal ecosystems. Research is needed for ecosystem management to provide science-based information that can facilitate science-based permitting and developing regulatory guidelines.
- Conducting feasibility study to examine the possibility of using renewable energy to power the desalination plant as an option in the future.
- Using more than one desalination plant.

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Ibrahim Badi
Misurata University,
2429 Misurata
Libya
i.badi@eng.misuratau.edu.ly

Mohamed Ballem
Misurata University,
2429 Misurata
Libya
ballem77@yahoo.com

Ali Shetwan
Misurata University,
2429 Misurata
Libya
ali.shetwan@eng.misuratau.edu.ly