

## CASE STUDY

# Application of Delphi method in site selection of desalination plants

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**ABSTRACT:** Given the reduced freshwater supplies across the world, seawater desalination is one of the appropriate methods available for producing freshwater. Selecting an optimal location is crucial in the installation of these plants owing to the environmental problems they cause. The present study was conducted to identify optimal locations for installing desalination Plants in the coastal areas of southern Iran (Hormozgan Province) with application of Delphi method. To implement this technique and identify, screen and prioritize effective criteria and sub-criteria, ten experts were surveyed through questionnaires and eight criteria and 18 sub-criteria were identified. All these sub-criteria were evaluated and classified in ArcGIS into five classes as input layers. The maps were then integrated based on the modulation importance coefficient and the identified priorities using a linear Delphi model and the final map was reclassified into five categories. Environmentally sensitive areas and seawater quality were respectively the criterion and sub-criterion that received the highest importance. After combining the layers and obtaining the final map, 63 locations were identified for installing desalination plants in the coastal areas on the Persian Gulf and Oman Sea in Hormozgan Province. At the end, 27 locations were high important and had optimal environmental conditions for establishing desalination plants. Of the 27 locations, six were located in the coastal area of the Oman Sea, one in the coastal area of the Strait of Hormuz and 20 others in the coastal area of the Persian Gulf.

**KEYWORDS:** Delphi method; Desalination; Oman Sea; Persian Gulf ; Site selection

## INTRODUCTION

Global water shortage is a major challenge with which different countries struggle (Ong *et al.*, 2016). Continuing population growth and economic growth are continually putting pressure on world demand for water (Goh *et al.*, 2016). Installing desalination plants to desalinate seawater is an appropriate solution to the shortage of freshwater. Desalination involves several processes to remove the excess salt and other chemicals dissolved in saltwater (Alshahri, 2016). Although desalination plants have numerous socioeconomic and environmental benefits, they

produce high-temperature brine, which may reduce the quality of coastal waters and endanger the marine environment (Lattemann and Höpner, 2008; Karbassi and Pazoki, 2015). The brine generated causes increases temperature and salinity and causes oxygen depletion (Cooley *et al.*, 2013) and habitat degradation as well as decline in the population of phytoplankton and invertebrates and fish communities (Roberts *et al.*, 2010) in marine ecosystems (Mezher *et al.*, 2011). Properly site selection for desalination plants is crucial in planning the establishment of these facilities (Sanver and May, 2010), and numerous factors including environmental, economic and management criteria should be considered in order to minimize the ecological and environmental risks associated with

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the site selection. Different site selection methods are used across the world, including TOPSIS method (Yal and Akgün, 2014), analytical hierarchy process (AHP) (Chaudhary et al., 2016), fuzzy (Alavipour et al., 2016; Kharat et al., 2016) and fuzzy-AHP (Wang et al., 2014). Additionally, environment specialists use the Delphi method, which is based on the intuitive opinions of a group of experts who comment on a specific subject to reach a consensus (Lang, 1995). The Delphi method, is thus based on the literature review, experts' opinions (Cho and Lee, 2013) and mathematical equations and is used for site selection (Andon Petrosian et al., 2013). The processes of identifying proper locations for installing desalination plants facilities are complicated and include environmental, economic and management criteria and the use of a geographical information system (GIS) (Kallali et al., 2007). GIS is amongst the different useful tools for site selection purposes (Uyan, 2013). Middle East region is well known as an area with water scarcity (Kim et al., 2015). Iran, a middle eastern country with arid and semi-arid climate (Yavari et al., 2015) and an average annual precipitation of 250 mm is therefore considered a low rainfall region of the world (Molavi Arabshahi et al., 2016). The coastal areas of southern Iran in Hormozgan Province are faced with a shortage of freshwater owing to their dry climate with an annual average precipitation of less than 170 mm (Asadpour, 2015), population growth and growth in various industries. Hormozgan Province is regarded as an important marine area of the world owing to its proximity to the Persian Gulf and Oman Sea as well as having communities of mangrove forests (Mafi-Gholami

et al., 2015a), coral reefs (Koupaei et al., 2015), sea grass (Erfteimeijer and Shuail, 2012), seaweed (Mohammadi et al., 2013) and also a variety of marine mammals (Braulik et al., 2010), fish (Daliri et al., 2012) and Sea Turtle (Pilcher et al., 2014). Few studies have been conducted on the site selection for desalination plants in these areas, in western Hormozgan Province (Basereh et al., 2014) and Qeshm Island (Kor et al., 2012). A review of studies conducted across the world indicated a lack of defined frameworks for developing and prioritizing the effective factors (contains criteria and sub-criteria) to identify suitable locations of desalination plants. The identification of important criteria and sub-criteria, prioritization of the sub-criteria and the detection of optimal locations for installing while minimizing their destructive environmental impacts appear necessary. The aim of this study was to identify optimal locations for installing desalination plants based on different criteria with application of Delphi method. The study has been carried out in Hormozgan Province during 2015- 2016.

## MATERIALS AND METHODS

### Study area

Hormozgan Province is situated in the north of the Persian Gulf and Oman Sea with a 1950.61 km coastline. This province covers an area of 71193.476 km<sup>2</sup> and is located in southern Iran. This study examined the coastal area of 1950 km length and 10 km width (with a width of 5 km on land and 5 km at sea) in order to determine the appropriate location for installing desalination plants. Fig. 1 illustrates the geographical location of the Hormozgan Province as the study area.

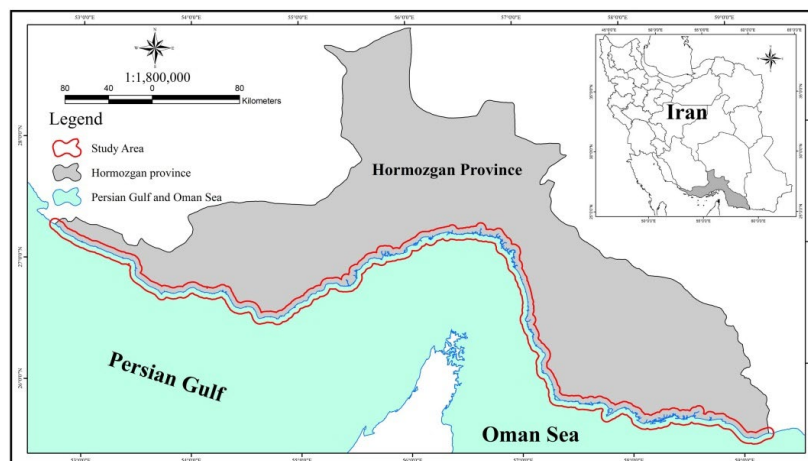


Fig. 1: The geographical location of the Hormozgan province as the study area

Methods

The selection of ideal locations for installing desalination plants is carried out in four steps in this study. The first step is to identify and screen the effective factors containing criteria and sub-criteria. In a second step is to prepare input layers and identify compulsory and preferred sub-criteria. The third step is to prioritize the preferred sub-criteria using the Delphi method. The fourth step is to integrate the layers to identify proper sites. Fig. 2 presents the different steps of site selection for desalination plants based on the Delphi method.

Identifying and screening effective factors containing criteria and sub-criteria

Identifying appropriate effective factors containing criteria and sub-criteria associated with the research subject is the first step in any management study (Hasanzadeh *et al.*, 2012). Table 1 presents the effective factors identified through the review of 10 different studies on the site selection for desalination plants.

In this method, effective factors were selected from different references reviewed and each factor was defined as a sub-criterion (Mousavi *et al.*, 2015).

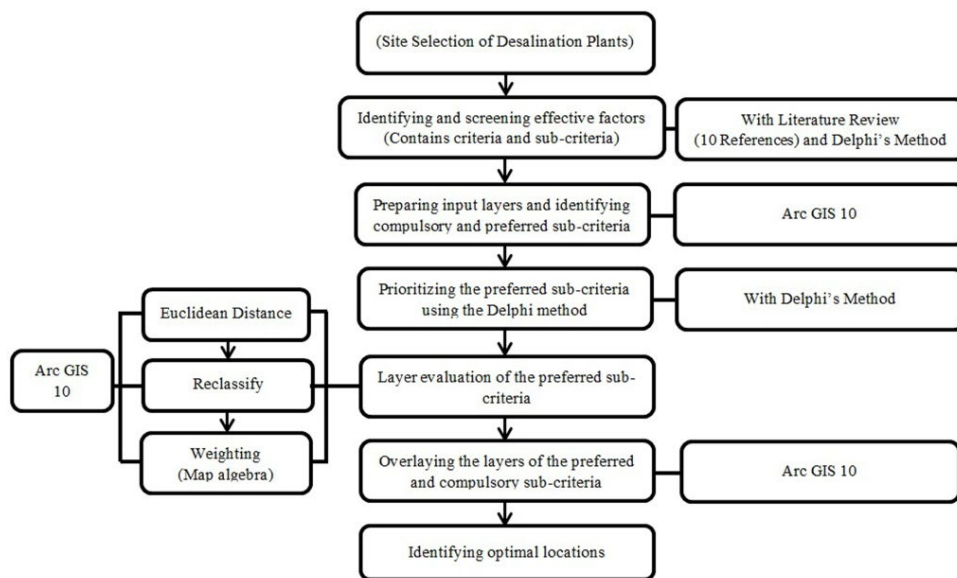


Fig. 2: Flowchart of different steps of site selection for desalination plants

Table 1: Identifying effective factors in different studies

Sub-criteria	Reference
5), 6), 7), 14), 17), 18), 20), 21)	Kor <i>et al.</i> , 2012
2), 11), 14), 28), 30), 31)	Basereh <i>et al.</i> , 2014
1), 2), 5), 14), 18), 21), 33)	Sanver and May, 2010
14), 17), 21), 22), 33)	Waddell, 2005
1), 2), 3), 4), 5), 9), 13), 15), 16), 21), 22), 23), 24), 25), 26), 29), 33)	Melbourne Water, 2007
1), 2), 5), 6), 12), 15), 20), 21), 33)	Life Res Sea Project, 2008
1), 2), 14), 17), 19), 20), 21), 23), 33)	Tsiourtis, 2008
14), 17), 32)	Victorian Desalination Project, 2011
1), 2), 20), 24)	Borrowman, <i>et al.</i> , 2013
5), 6), 7), 8), 10), 19), 27), 29)	Kallali, <i>et al.</i> , 2007

1) Environmentally sensitive land areas, 2) Environmentally sensitive coastal and marine areas, 3) Life species, 4) Wetland, 5) Slope, 6) Geology, 7) Soil texture, 8) Soil salinity, 9) Flood area, 10) Groundwater level, 11) Quality and quantity of fresh water, 12) Source water temperature (land), 13) Flushing times, 14) Sea water quality, 15) Bathymetry, 16) Sea area, 17) Water supply network, 18) Place of use, 19) City and village area, 20) Road network, 21) Electrical network, 22) Access to the beach, 23) Infrastructure, 24) Land use, 25) Aquaculture area, 26) Boating facilities, 27) Water transfer costs, 28) Creating jobs, 29) Cultural heritage, 30) Emigration. 31) Epidemic diseases. 32) Ability to meet future capacity requirements. 33) Waste water discharge.

Instead of direct interpretations, the descriptions in these references were taken in some cases and the sub-criteria identified were ultimately classified as a subset of the several main criteria. Separate indicators were defined in order to provide a better description for each sub-criterion if necessary. A total of 10 experts completed the expert opinion survey (Delphi survey) to screen and determine the percentage and degree of importance of the criteria and sub-criteria (Hasanzadeh *et al.*, 2013). These questionnaires enable experts to express their opinion about the importance of the criteria and in a next step sub-criteria on a five-level scale (Mafi-Gholami *et al.*, 2015b). An important rule of the Delphi studies is to select experts based on experience and knowledge (Davidson, 2013). Experienced professionals in the field of coastal zone management, environment and location of desalination plants were therefore selected. In order to sum up the votes of experts, the weighted values of the criteria and sub-criteria were calculated. These weights ranged between 0 and 10. Each Degrees of importance represent a range of weights for the criteria and sub-criteria, which is presented on a Likert scale in figure 2 (unimportant: value 1 at a range of 0-2, low important: value 3 at a range of 2-4, important: value 5 at a range of 4-6, highly important: value 7 at a range of 6-8 and very highly important: value 9 at a range of 8-10) (Mousavi *et al.*, 2015; Mafi-Gholami *et al.*, 2015b). The number of times each degree of importance was selected represented the value that degree of importance obtained.

For the screening the criteria and sub-criteria with application of Delphi method, the following six mathematical formulas comprising 1) maximum attainable value, 2) Moderated weight coefficient, 3) Moderated weight, 4) Weighted value, 5) percentage of importance, 6) degree of importance were used. In order to determine the percentage of importance (P), the maximum attainable value (A) was first obtained by multiplying the maximum expected value (N=10 in this study, equivalent to the number of all the respondents) by the maximum moderated weight (W=10) (Eq. 1). The Moderated weight coefficient was then calculated by dividing the maximum Moderated weight (10) by the sum of weights of value criteria (Eq. 2). The Moderated weight ( $y_i$ ) was calculated using the Moderated weight coefficient (Eq. 3). The weighted value ( $z_i$ ) was calculated using this Moderated weight and the value of criteria ( $n_i$ ) (Eq. 4). In the last step, the percentage of importance of each criterion was calculated by dividing

the sum of weighted value of criteria (by the maximum attainable value of the criterion (A) (Eq. 5). The weighted average of importance of each criterion was then obtained and considered the degree of importance of the criteria (D) by dividing the sum of the product of value in weights (degrees of importance) (by the total value (the total number of respondents, which equals 10 in this study) (Eq. 6) (Hasanzadeh *et al.*, 2013; Mafi-Gholami *et al.*, 2015b). It is worth mentioning that the main condition for selecting the main criteria and sub-criteria is to have at least half of the numerical value of each vertical and horizontal vector (Hasanzadeh *et al.*, 2012). A criterion is eliminated from the screening and locating process only if all its sub-criteria are eliminated from the importance chart of sub-criteria.

Criteria= C

Primary weight =  $x_i$

Number of experts voted a important level value = n

Total number of experts = N

Maximum moderated weight = W

1) Maximum attainable value (A) =  $N \times W$

2) Moderated weight coefficient =  $\frac{W}{\sum x_i}$

3) Moderated weight ( $y_i$ ) =  $\frac{W}{\sum x_i} \times x_i$

4) Weighted value ( $z_i$ ) =  $y_i \times n$

5) Percentage of Importance (PC) =  $\frac{\sum z_i}{A} \times 100$

6) Degree of Importance (DC) =  $\frac{\sum (x_i \times n)}{N}$

#### *Preparing input layers and identifying compulsory and preferred sub-criteria*

The GIS was used in Arc-GIS 10 for mapping. All the sub-criteria should be entered into Arc-GIS as input layers for site selection. Based on environmental protection laws, any manipulation is prohibited in areas such as the national park or habitat of threatened or endangered biodiversity, which should be considered in site selection for desalination plants. No activities are possible in terms of environmental conditions or the risks involved in the area, such as is the case in flood areas. The sub-criteria with these conditions were therefore classified as compulsory sub-criteria and were excluded from the prioritization process. The Other sub-criteria lacking these conditions were classified as preferred sub-criteria and entered the prioritization stage. The layer of compulsory sub-criteria was ultimately overlaid on the final locating

layer based on the preferred sub-criteria in Arc-GIS and in accordance with their boundaries.

*Prioritizing the preferred sub-criteria using the Delphi method*

After screening the criteria and in a next step screening the sub-criteria, the normalized importance coefficients of the criteria and sub-criteria were used to prioritize and calculate the modulation importance coefficient of the sub-criteria. The Importance coefficients (IC) of the criteria by multiplying the degree of importance (DC) by percentage of importance of the criteria (% PC) (Eq. 7). The normalized importance coefficients (NI) of the criteria were calculated by dividing the importance coefficient of each criterion by the sum of importance coefficients of the criterion (Eq. 8). The importance coefficients of the sub-criteria (IS) were calculated by multiplying the degree of importance (DS) by percentage of importance of the sub-criteria (%PS) (Eq. 9). The normalized importance coefficient of each sub-criterion (NI) was also obtained by dividing the importance coefficient of the sub-criterion by the sum of importance coefficients of the sub-criteria (Eq. 10). In order to calculate the normalized importance coefficient of the sub-criteria based on the criterion ( $C_iBS_j$ ), the importance coefficient of each sub-criterion ( $IS_j$ ) was divided by the sum of importance coefficients of the sub-criteria associated with the same criterion (Eq. 11). To prioritize the sub-criteria and determine the modulation importance coefficient (MI), the normalized importance coefficient of each sub-criterion based on the criterion ( $C_iBS_j$ ) was multiplied by the normalized importance coefficient (NI) associated with the same criterion (Eq. 12) (Andon Petrosian *et al.*, 2013).

$$7) IC_i = DC_i \times (\%P) C_i$$

$$8) NIC_i = IC_i / \sum_1^n IC_i$$

$$9) IS_j = DS_j \times (\%P) S_j$$

$$10) NIS_j = IS_j / \sum_1^n IS_j$$

$$11) C_iBS_j = IS_j / \sum_{s1ci}^{sn} IS_j$$

$$12) MIS_j = C_iBS_j \times NI_i$$

*The process of layer integration and location*

After developing the preferred layers in Arc-GIS, a distance map of each layer of the preferred sub-criteria was developed using Euclidean distance toolbar. The

layers created were evaluated using the Reclassify toolbar in Arc-GIS and were classified into five classes (Unimportant: value 1, Less important: value 3, Middle important: value 5, Important: value 7 and High important: value 9). A letter code was defined for each sub-criterion for integrating the maps (Andon Petrosian *et al.*, 2013). The layers were ultimately integrated using the linear model of the Delphi method and the Raster calculator toolbar in Arc-GIS based on the modulation importance coefficient of each sub-criterion and the priorities, and the site selection layer was obtained in accordance with the preferred sub-criteria. In order to identify high important locations, the layer obtained was reevaluated and reclassified in five classes. After overlaying the layer of compulsory sub-criteria on the evaluated layer of the preferred sub-criteria, the final layer of site selection for desalination plants was obtained. The locations with the highest spatial values were identified as high important locations and the most optimal places for installing desalination plants.

**RESULTS AND DISCUSSION**

*Screening the effective factors (Contains criteria and sub-criteria)*

By investigating 10 different researches, 33 sub-criteria as 9 main criteria were found and classified for site selection desalination plants. The degree and percentage of importance of each criteria and sub-criteria were calculated by analyzing the experts' responses using the Delphi method and were presented as diagrams of percentage and degree of importance. Of the total nine main criteria and 33 sub-criteria identified, five main criteria and 18 sub-criteria received more than half of the numerical value of each vertical vector and horizontal vector in the importance diagrams of the criteria and sub-criteria. The sub-criteria of slope from the criterion of land Features, the sub-criterion of flood area from the criterion land water resources' features and the sub-criterion of cultural heritage from the criterion of social significance were accepted in the diagram of the importance of the sub-criteria. Land features, land water resources' features and social significance were accepted owing to the acceptance of their sub-criteria; that is, a total of eight criteria were accepted. The criteria and sub-criteria that did not receive the required percentage and degree of importance were eliminated. According to experts' comments and comparison of degrees of

importance of the criteria, environmentally sensitive areas received the highest percentage and degree of importance with a 55% and 8.8 degree of importance, while social significance received the lowest percentage of importance (21.63%). The other criteria ranked respectively as follows: Sea features (percentage of importance: 51.25), economic criteria (percentage of importance: 39.96), management criteria (percentage of importance 33.3), access criteria (percentage of importance: 28.882), land water resources' features (percentage of importance: 27.45) and land Features (percentage of importance: 24.96). A total of 18 top sub-criteria that obtained the required score for locating desalination plants were: 1) Environmentally sensitive land areas, 2) Environmentally sensitive Coastal and marine areas, 3) Life species, 4) Wetland, 5) Slope, 6) Flood area, 7) Sea water quality, 8) Bathymetry, 9) Sea area, 10) Place of use, 11) City and village area, 12) Road network, 13) Electrical network, 14) Access to the beach, 15) Infrastructure, 16) Aquaculture area, 17) Cultural heritage and 18) Waste water discharge. Fig. 3 shows the diagram of the importance of the criteria and Fig. 4 shows the diagram of the importance of the sub-criteria.

*Mapping the sub-criteria and identifying the definite sub-criteria*

The map pertaining to each of the sub-criterion was developed in Arc-GIS by preparing the input layers and indices of the sub-criteria identified. Of 18 sub-criteria identified, four were identified as compulsory based on environmental regulations and restrictions. Given the indicators of environmentally sensitive land areas and environmentally sensitive coastal-marine areas, these two were identified as common sub-criteria. After identifying and separating the compulsory sub-criteria as the compulsory layer, 15 preferred sub-criteria were classified in a subset of 7 criteria, including:

- 1) Environmentally sensitive land areas: protected area, wildlife refuge, hunting prohibited area, biosphere reserves, forest reserve
- 2) Environmentally sensitive coastal and marine areas: protected area, wildlife refuge, hunting prohibited area, biosphere reserves, firth -estuary- river
- 3) Wetland
- 4) Sea water quality: temperature, salinity
- 5) Slope
- 6) Bathymetry

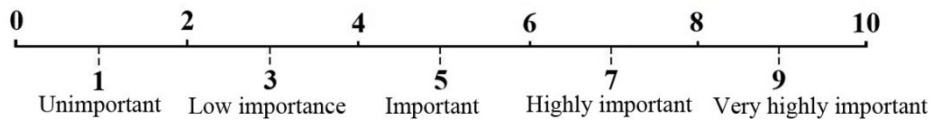


Fig. 3: Likert range for determination of the important level of criteria (Mafi-Gholami et al., 2015b)

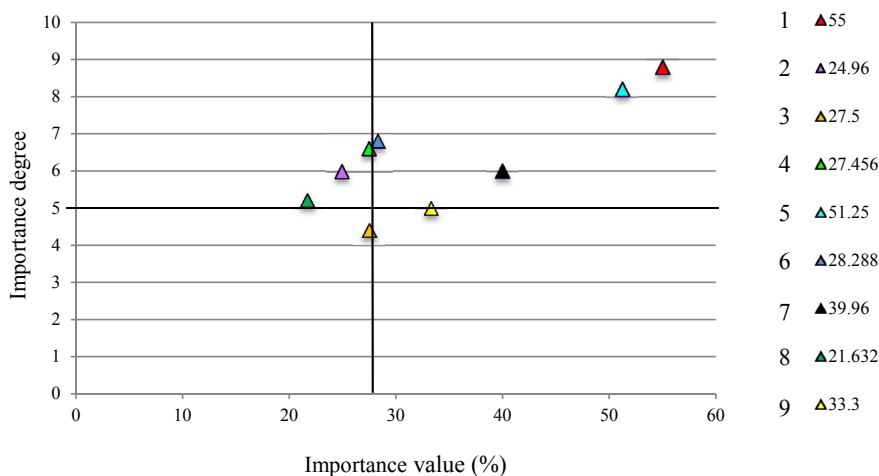


Fig. 4: Importance diagram of the criteria of site selection for desalination plants  
 1) Environmentally sensitive area 2) Land features 3) Soil features 4) Features of land water resources  
 5) Sea features 6) Access 7) Economic 8) Social significance 9) Management.

- 7) Place of use
- 8) City and village area
- 9) Road Network
- 10) Electrical Network
- 11) Access to the beach
- 12) Infrastructure
- 13) Aquaculture areas
- 14) Cultural Heritage
- 15) Waste water Discharge.

It is worth noting that flood area were the only compulsory sub-criterion of the criterion of land water

resources' features selected and was thus excluded from the prioritization process. Table 2 presents all the compulsory sub-criteria, and Fig. 5 shows their geographical positions.

*Prioritization and modulation importance coefficients of the preferred sub-criteria*

After screening and identifying the criteria, the normalized importance coefficient was found to be the component that serves to measure the importance of the criteria. The criteria with a higher normalized

Table 2: The compulsory sub-criteria identified

Criteria	Sub-criteria	Indicators	Study area	Privacy (m.)
Environmentally sensitive area	Environmentally sensitive land areas	National park and national natural landmark	-	1000
		National park and National natural landmark	*	1000
	Environmentally sensitive coastal and marine areas	Coral reef	-	1000
		Sea grass	*	1000
		Seaweed	*	1000
		Mangrove forests	*	1000
		Bird	*	1000
		Marine mammals	*	1000
	Life species	Terrestrial mammals	*	1000
		Sea turtle nesting sites	*	1000
Sea features	Sea area	-	60	
Features of land water resources	Flood area	-	* 1000	

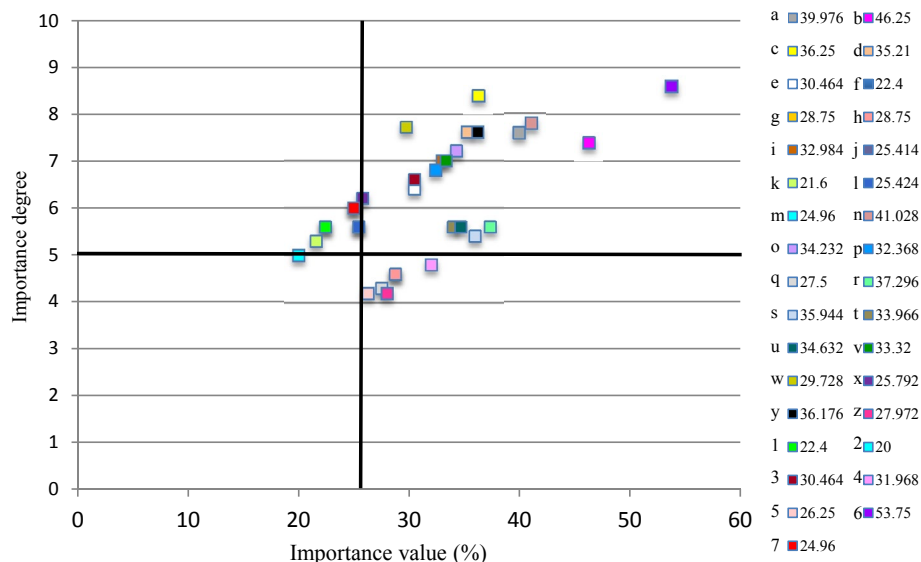


Fig. 5: Importance diagram of the sub-criteria of site selection for desalination plants

- a) Environmentally sensitive land areas, b) Environmentally sensitive coastal and marine areas, c) Life species, d) Wetland, e) Slope, f) Geology, g) Soil texture, h) Soil salinity, i) Flood area, j) Groundwater level, k) Quality and quantity of fresh water, l) Source water temperature (land), m) Flushing times, n) Sea water quality, o) Bathymetry, p) Sea area, q) Water supply network, r) Place of use, s) City and village area, t) Road network, u) Electrical network, v) Access to the beach, w) Infrastructure, x) Land use, y) Aquaculture area, z) Boating facilities, 1) Water transfer costs, 2) Creating jobs, 3) Cultural heritage, 4) Emigration, 5) Epidemic diseases, 6) Ability to meet future capacity requirements, 7) Waste water discharge

importance coefficient are more important than the other criteria. As shown in Table 5, the normalized importance coefficients of the criteria in descending order is 0.2742 (environmentally sensitive area), 0.2380 (sea features), 0.1358 (economic criterion), 0.1089 (access), 0.0848 (land features) and 0.0637 (social significance). The modulation importance coefficient is the most important component for demonstrating the priority and degree of importance of the sub-criteria in the linear model. Of the 15 preferred sub-criteria in the prioritization stage, the modulation importance coefficient of the sub-criteria of seawater quality was the highest (0.1349), followed by bathymetry (0.1035) and environmentally sensitive coastal and marine areas (0.1026), ranking second and third. As seen in Table 3, the sub-criterion of city and village area position, road network and electrical network received the lowest modulation importance coefficient and priorities. In the following items, calculation of the modulation importance coefficient for environmentally sensitive coastal and marine area was shown.

- 1) Importance coefficients of the criteria (environmentally sensitive area):  $55 \times 8.8=484$
- 2) Normalized importance coefficients of the criteria (environmentally sensitive area):  $484/1765.115=0.2742$
- 3) Importance coefficients of the sub-criteria

(environmentally sensitive Coastal & marine area):  $46.25 \times 7.4=342.25$

4) Normalized importance coefficients of the sub-criteria (environmentally sensitive Coastal & marine area):  $342.25/ 3848.748= 0.0889$

5) Normalized importance coefficient of the sub-criteria (environmentally sensitive Coastal & marine area) based on the criterion (environmentally sensitive area):  $342.25/ 913.662 = 0.374$

6) Modulation importance coefficient of the sub-criteria (environmentally sensitive Coastal & marine area):  $0.374 \times 0.2742= 0.1026$

*Identifying proper locations in the study area*

The present study used a linear model based on the priorities and modulation importance coefficients to develop the output map in Arc-GIS for site selection desalination plants. According to Table 3, each sub-criterion is involved in the linear model through a letter code. Environmentally sensitive land areas (EL), environmentally sensitive coastal and marine areas (EM), wetland (WL), sea water quality (WQ), slope (SP), bathymetry (BT), place of use (PU), city and village area (CV), road network (RN), electrical network (EN), access to the beach (AB), infrastructure (IS), aquaculture areas (AA), cultural heritage (CH) and waste water discharge (WD). The following, linear model was developed based on the Delphi

Table 3: Calculating normalized importance coefficients of criteria and modulation importance coefficient of sub-criteria

Criteria	Normalized importance coefficients of criteria	Sub-criteria	Importance coefficients of the sub-criteria	Normalized importance coefficients of the sub-criteria	Normalized importance coefficient of the sub-criteria	modulation importance coefficient of the sub-criteria	Priority of the sub-criteria	Code
Environmentally sensitive area	0.2742	Environmentally sensitive land areas	303.817	0.0789	0.0332	0.0911	5	EL
		Environmentally sensitive coastal and marine areas	342.25	0.0889	0.0374	0.1026	3	EM
Land features	0.0848	Wetland	267.595	0.0695	0.2928	0.0802	7	WL
		Slope	194.969	0.0506	1	0.084	6	SP
Sea features	0.2380	Sea water quality	320.0184	0.0831	0.5649	0.1344	1	WQ
		Bathymetry	246.4704	0.0640	0.4350	0.1035	2	BT
Access	0.1089	place of use	208.8576	0.0542	0.2075	0.0225	12	PU
		City and village area	194.0976	0.0504	0.1928	0.021	13	CV
		Road network	190.2096	0.0494	0.1889	0.0205	14	RN
		Electrical network	180.0864	0.0467	0.1789	0.0194	15	EN
		Access to the beach	233.23	0.0605	0.2317	0.0252	11	AB
Economic	0.1358	Infrastructure	228.8976	0.0594	0.4543	0.0616	10	IS
		Aquaculture areas	274.9376	0.0714	0.5456	0.0741	8	AA
Social significance	0.0637	Cultural heritage	201.0624	0.0522	1	0.0637	9	CH
Management	0.0943	Waste water discharge	462.25	0.1201	1	0.0943	4	WD



method to integrate the maps for identifying proper locations for desalination plants.

$$\begin{aligned} \text{Site selection for desalination plants} = & (WQ*0.1344) \\ & + (BT*0.1035) + (EM*0.1026) + (WD*0.0943) \\ & + (EL*0.0911) + (SP*0.084) + (WL*0.0802) \\ & + (AA*0.0741) + (CH*0.0637) + (IS*0.0616) \\ & + (AB*0.0252) + (PU*0.0225) + (CV*0.021) + \\ & (RN*0.0205) + (EN*0.0194) \end{aligned}$$

The distance maps of environmentally sensitive land areas, environmentally sensitive coastal and marine areas, are respectively shown in Figs. 7 and 8. According to Table 4, nine sub-criteria show an increasing trend; that is, their location value increases with their numerical value. In other words, the locations with a higher numerical value are more appropriate; for example, the greater is a location's distance from environmentally sensitive coastal-marine areas, the better is that location. In contrast,

six sub-criteria showed a declining trend; that is, the lower is the numerical value of an identified location or the closer it is to the range of these sub-criteria, the more appropriate is that location.

The final map was obtained for site selection desalination plants in Hormozgan Province was developed by combining the layers evaluated based on the linear model and considering the priorities and modulation importance coefficients of the sub-criteria and ultimately by overlaying the layer of compulsory sub-criteria on the final layer of the preferred sub-criteria. Based on the final map obtained, 63 locations were found to be appropriate for installing desalination plants on the coast of the Persian Gulf and Oman Sea in Hormozgan Province. By reclassifying and reevaluating the final map, 27 high important locations were found to have the highest priority, spatial value and score for installing water desalination facilities. As shown in Figs. 9, a total of 28 highly important locations were obtained and all the other locations

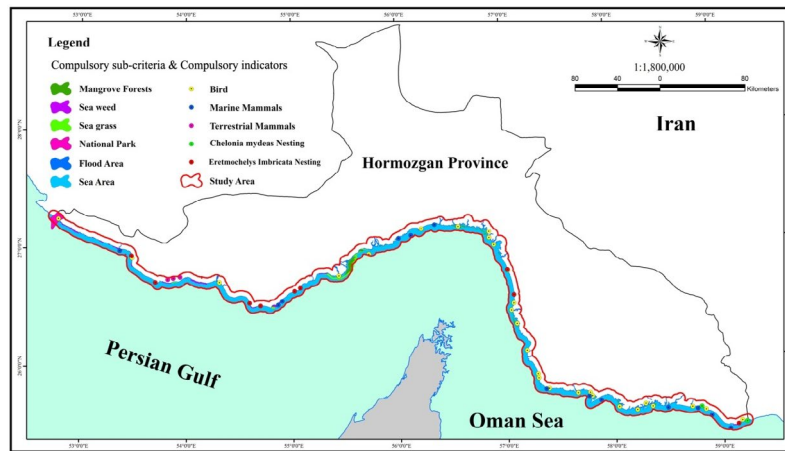


Fig. 6: Map of the compulsory sub-criteria and indicators in study area

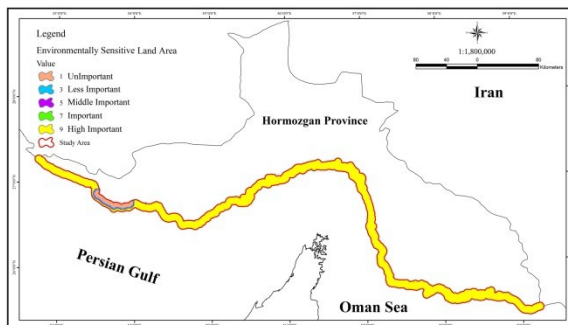


Fig. 7: Evaluated map of distance to environmentally sensitive land areas

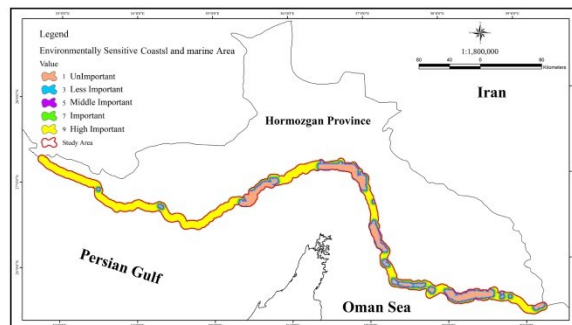


Fig. 8: Evaluated map of distance to environmentally sensitive coastal and marine areas

Table 4: Evaluation of the sub-criteria based on distance

Criteria	Sub-criteria		Rates for Delphi					Trend
Environmentally sensitive area	Environmentally sensitive land areas	meter	0-1000	1000-2000	2000-3000	3000-4000	4000<	Increasing
		score	1	3	5	7	9	
	Environmentally sensitive coastal and marine areas	meter	0-1000	1000-2000	2000-3000	3000-5000	5000<	Increasing
		score	1	3	5	7	9	
Land features	Wetland	meter	0-1000	1000-2000	2000-3000	3000-4000	4000<	Increasing
		score	1	3	5	7	9	
	Slope	%	0-15	15-20	20-30	30-45	45<	Declining
Sea features	Sea water quality: -Temp.	celsius	<27.7	27.7-28	28-28.3	28.3-28.6	28.6<	Declining
		score	9	7	5	3	1	
	-Salinity	ppt	<38.1	38.1-38.3	38.3-38.6	38.6-38.9	38.9<	Declining
		score	9	7	5	3	1	
Access	Bathymetry	meter	0-(-1)	(-1)-(-2)	(-2)-(-4)	(-4)-(-6)	-6<	Increasing
		score	1	3	5	7	9	
	Place of use	meter	0-15000	15000-30000	30000-60000	60000-90000	90000<	Declining
		score	9	7	5	3	1	
Economic	City and village area	meter	0-1000	1000-2000	2000-3000	3000-4000	4000<	Increasing
		score	1	3	5	7	9	
	Road network	meter	0-4000	4000-6000	6000-8000	8000-12000	12000<	Declining
		score	9	7	5	3	1	
Social significance	Electrical network	meter	0-5000	5000-20000	20000-30000	30000-60000	60000<	Declining
		score	9	7	5	3	1	
	Access to the beach	meter	0-500	500-1000	1000-1500	1500-2000	2000<	Declining
		score	9	7	5	3	1	
Management	Infrastructure	meter	0-500	500-1000	1000-1500	1500-2000	2000<	Increasing
		score	1	3	5	7	9	
Management	Aquaculture areas	meter	0-1000	1000-2000	2000-3000	3000-4000	4000<	Increasing
		score	1	3	5	7	9	
Management	Cultural heritage	meter	0-500	500-1000	1000-1500	1500-2000	2000<	Increasing
		score	1	3	5	7	9	
Management	Waste water discharge	meter	0-1000	1000-2000	2000-3000	3000-5000	5000<	Increasing
		score	1	3	5	7	9	

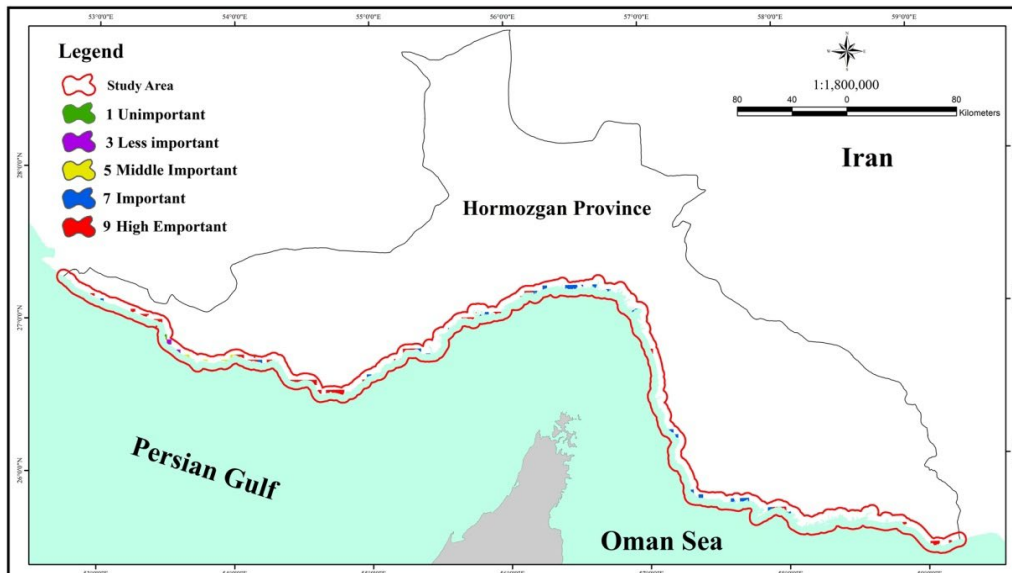


Fig. 9: Final map of site selection for desalination plants

were identified as middle important to unimportant locations. As shown in Fig. 10, of the 27 high important locations, six were located in the coastal area of the Oman Sea, one in the coastal area of the Strait of Hormuz and 20 others in the coastal area of the Persian Gulf. Table 5 contains the spatial details of these 27 locations with the best conditions in terms of the identified criteria for installing desalination plants in Hormozgan Province.

The present findings show that the method of site selection for desalination plants using GIS in Arc-GIS can serve as a useful tool for identifying a set of locations with detailed information (Melbourne Water GHD, 2007). Screening of the criteria, screening and prioritization of the sub-criteria through

various methods such as Delphi were also found to be important steps of site selection studies (Andon Petrosian et al., 2013; Basereh et al., 2014). Seawater quality and coastal environment were found to be the important criteria in site selection for desalination plants in a study on prioritization criteria based on the Delphi method (Basereh et al., 2014), which is consistent with the results of the present study. Studies have proposed proximity to place of use and seawater quality as the most important place criteria (Kor et al., 2012), which is consistent with the presents findings. The present study found that seawater quality, bathymetry, environmentally sensitive coastal and marine areas, waste water Discharge sites and environmentally sensitive land areas have a higher

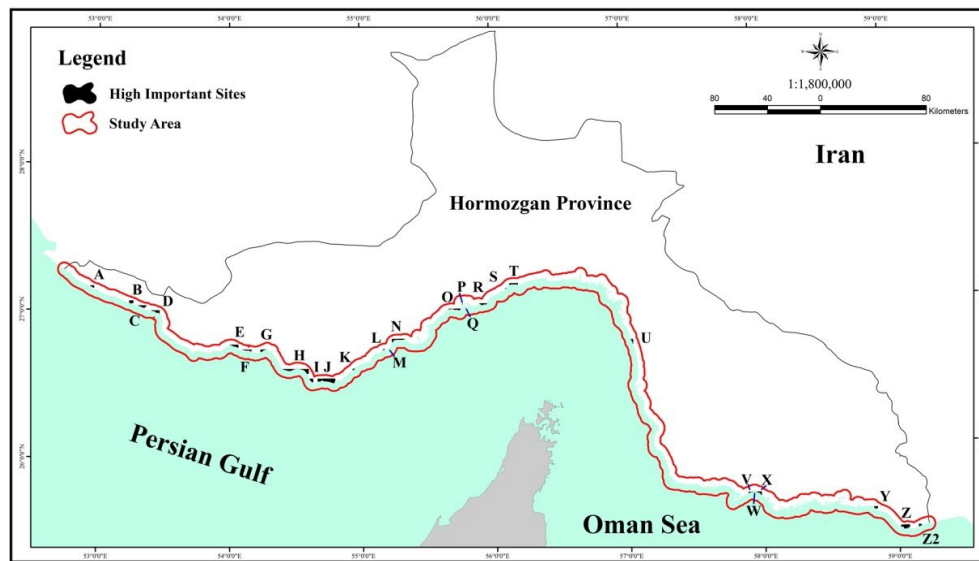


Fig. 10: Areas with a high important spatial value

Table 5: Spatial details, high important locations identified

Site	Location	E	N	Site	Location	E	N
A	Persian Gulf	52°57'41"	27° 9'16"	O	Persian Gulf	55°42'37"	26°59'4"
B	Persian Gulf	53°15'8"	27° 2'40"	P	Persian Gulf	55°42'37"	26°59'4"
C	Persian Gulf	53°19'59"	27° 1'25"	Q	Persian Gulf	55°46'4"	27° 1'45"
D	Persian Gulf	53°27'24"	26°59'4"	R	Persian Gulf	55°47'28"	27° 0'26"
E	Persian Gulf	54° 1'58"	26°45'30"	S	Persian Gulf	55°55'57"	27° 1'40"
F	Persian Gulf	54° 7'13"	26°43'34"	T	Persian Gulf	56° 5'59"	27° 7'47"
G	Persian Gulf	54°14'47"	26°43'29"	U	Strait of Hormuz	56° 9'18"	27° 9'22"
H	Persian Gulf	54°32'30"	26°35'51"	V	Oman Sea	57° 2'51"	26°45'18"
I	Persian Gulf	54°37'7"	26°31'18"	W	Oman Sea	57°54'5"	25°42'3"
J	Persian Gulf	54°43'44"	26°31'26"	X	Oman Sea	57°56'0"	25°42'10"
K	Persian Gulf	54°56'15"	26°35'41"	Y	Oman Sea	57°58'15"	25°41'53"
L	Persian Gulf	55°10'2"	26°43'33"	Z	Oman Sea	58°50'0"	25°33'46"
M	Persian Gulf	55°12'36"	26°43'52"	Z2	Oman Sea	59° 2'45"	25°25'26"
N	Persian Gulf	55°16'12"	26°47'40"	-	-	-	-

priority compared to other sub-criteria. The study of the 27 high important locations identified based on the evaluation table (Table 4) in relation to the sub-criterion of seawater quality showed that, given the declining trend of the water temperature indicator, 20 locations were located at a temperature range below 27.7 °C. Location A was found to have the lowest and location V the highest coastal water temperature compared to the other locations. Given the declining trend of salinity, 15 locations were found to have a seawater salinity range of less than 38.1 ppt. The Coastal waters of location Z2 had the lowest salinity while locations F and G had the highest salinity level compared to other locations identified. The Coastal waters of 20 locations were found to have a bathymetric range of above 6 meters owing to the increasing trend of bathymetry; of these 20 locations, O had the highest depth while P, Q and Z had the lowest depth compared to other locations. Given the increasing trend observed in the sub-criterion of environmentally sensitive coastal and marine areas, 23 locations were found to be located at a distance above 5000m from protected areas, 25 locations at greater than this distance from biosphere reserves and 10 locations from firth-estuaries-rivers; among these locations, location A had the greatest distance and location X the smallest distance to protected areas. Z2 and A were located at the greatest respective distance and O was at the smallest distance to the biosphere reserves. U and Z2 were found to have the smallest distance from firth-estuaries - rivers. A small area of U and Z2 was found to be located within firth-estuary-river. A total of 23 locations identified were located at a distance above 5000m from waste water discharge locations, which reflects the increasing trend observed in this sub-criterion. Z2 was also located at the greatest distance from wastewater discharge locations and S at the smallest distance. A total of 26 locations were found to be located at a distance above 4000m from environmentally sensitive land areas. According to the results that all the identified locations are located at the optimal distance from the compulsory areas, which are consistent with some studies (Victorian Government project, 2011). The optimal locations found in another study (Waddell, 2005), were outside protected areas, which is consistent with the obtained results from this study. In terms of seawater quality, the locations identified in the Persian Gulf basin were found to have lower temperature and higher salinity compared to the

locations in the Oman Sea basin. Most of the locations identified in the Persian Gulf and Oman Sea basins were found to have similar bathymetric conditions. In terms of the sub-criterion of environmentally sensitive coastal-marine areas, the locations identified in the Oman Sea basin were located at a closer distance to protected areas and firth-estuaries-rivers but at a greater distance from biosphere reserves and wastewater discharge locations.

## CONCLUSION

Examining of all the effective criteria and sub-criteria with application of Delphi method led to the identification of 63 proper locations for installing desalination plants on the southern coast of Iran in Hormozgan Province, in the vicinity of the northern Persian Gulf and Oman Sea. A total of 27 high important locations were optimal in terms of the study criteria and sub-criteria and involved the least environmental risks and impacts on the study area. Organizations associated with environmental protection and water resource management, such as the Department of Environment, Ministry of Power, research institutes in the area including Hormozgan Fisheries Organization and the Institute of Oceanography are recommended to more accurately investigate the identified locations and ultimately proceed with establish desalination plants.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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