Desalination 444 (2018) 26–34

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

A multi-criteria decision support system to rank sustainable desalination plant location criteria

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ARTICLE INFO

Keywords:
Desalination plant
Decision support system
Plant location criteria
Analytical hierarchal process
Sustainability criteria
Multi-criteria decision making

ABSTRACT

Due to globally increased demand of drinkable and usable water, countries are focusing more in building desalination plants. Desalination plant location selection is a strategic decision and decision makers need to deal with multiple criteria that are sometimes conflicting in nature. In addition to technical and operational aspects, sustainability (social, environmental, economical) aspect needs to be considered in desalination plant location decision. The purpose of this paper is to develop a multi-criteria decision support system (DSS) to rank desalination plant location criteria in United Arab Emirates (UAE) by considering social, environmental, economical, technical and operational aspects. Result shows that technical (21.9%) and economical (20.9%) are top two main aspects of desalination plant location criteria. Similarly, waste water discharge (22.2%), life species (13.3%), real cost of water and government subsidy (18%), quality and quantity of fresh water (12.4%), and water supply network (9%) are the top ranked sub-criteria of environmental, social, economic, technical, and operational aspects respectively.

1. Introduction

Even though our planet is covered about 70% by water, but unfortunately, only 3% of it is usable for drinking and other domestic purposes. In addition to that, population growth, industrialization, and agriculture reducing the usable amount of water significantly. Due to this fact it is essential for countries to find different ways of producing drinking and usable water. Globally, over 90 million m^3 of water is desalinated a day from approximately 18,500 desalination plants [1]. United Arab Emirates (UAE) is one of the top five countries who have highest desalination capacities [1]. According to the United Arab Emirates (UAE) ministry of climate change and environment, 96% of domestic consumption of water used for drinking and other domestic use comes from around 70 desalination plants located in the UAE. To cope with ever-rising water consumption, lack of rainfall, and rivers, desalinating and using sea water is one of the solutions of the problem.

One of the oldest forms of water treatment that is still popular across the globe is desalination. It is a process "*that removes the excess salt and dissolved solids from brackish water or seawater to obtain fresh water*" [2]. It is estimated that about 70% of the world's desalination plants are located in the Middle East because they do not have any rivers, lack of rainfall, and groundwater is running out. Desalination plant location selection is a strategic decision and requires huge capital to build and operate. It has several socioeconomic benefits. It is estimated that around $300 million to $2.9 billion (depending on the location) is required to build any desalination plant. Moreover, its required significant amount of energy once the plant is operational. In addition to that, decision makers need to consider different criteria that are sometimes conflicting in nature. Therefore, we consider desalination plant location selection decision as a multi-criteria decision making (MCDM) problem.

Due to the absence of rivers, fewer amounts of rain, and hot weather condition makes desalination the only feasible solution to supply usable and drinking water in the country. UAE is located in the arid zone of Arabian Peninsula which has high rate of evaporation. UAE is consists of seven emirates; Abu Dhabi (AUH), Dubai (DXB), Sharjah (SHJ), Ajman (AJM), Fujairah (FUJ), and Umm Al Quwain (UAQ). The capital of the UAE is AUH. Total population of UAE is > 9.5 million in which only 10% are UAE nationals and the remainder is made up of expatriates. The total installed production capacity in AUH is about 4,127,850 m^3/day in which about 40% of the water used in AUH has been desalinated, and almost all drinking water is desalinated [1]. Similarly DXB installed desalination production capacity is around 2.14 million m^3/day; SHJ 500,000 m^3/day, and in northern emirates is 296,776 m^3/day [1].

Desalination plant location is critical to the success of the project.

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https://doi.org/10.1016/j.desal.2018.07.007
Received 24 May 2018; Received in revised form 3 July 2018; Accepted 3 July 2018

There are several reasons related to operational, economical, environmental and technical for its success such as (i) it must be near to power source as desalination plant require power supply and (ii) It must be near sew water as to decrease the cost of sew water intake pipeline (operational), (iii) the output of the desalination plant must close to customers to reduce cost of transmission and distribution (economical), and (iv) the desalination project must not affect any biological sanctuary or have negative impact on environmental surrounding.

There are several challenges (technically, operationally, economically etc.) usually decision makers faced in desalination plant location selection in UAE such as (i) limited costal area due to urbanization, (ii) Cost of desalination plant land as it is sea front and surround by high rise building, which makes expansion of existing desalination plant difficult and expensive, (iii) dumping of excess Treated Sewage Effluent in the sea near by the intake of desalination plant, (iv) some power plants are located in land and far away from the sea to meet increase of power peak demand during summer so retrofitting desalination plant in it later on is a big challenge, (v) as environmental standards are updated and implemented annually, new limits are needed to be met as far as discharge of brine to sea and this is another challenge, (vi) by 2050 all of desalination plant will be mostly RO so replacement of MSF and MED by RO is a challenge as well, and (vii) All power supply is directed to be of renewable energy sources to make desalination more sustainable.

Therefore the objective of this paper is in three folds that are to (i) introduce the application of Analytical Hierarchal Process (AHP) to identify and prioritize desalination plant location selection criteria, (ii) briefly review the steps of AHP implementation, and demonstrate its application in desalination plant selection criteria, and (iii) check robustness of decision using sensitivity analysis. We believe that this study will encourage the application of multi-criteria decision making in area of desalination in general and desalination plant location in particular. Our contribution is summarized as follows:

i) This paper will highlight the importance of plant location process in the field of desalination and will propose approach to provide systematic way to select the best location in UAE.
ii) AHP based DSS will helps decision makers in finding the appropriate desalination plant location criteria.
iii) A sensitivity analysis will be performed to look at the response of criteria once the relative importance rating of every criterion was modified.

2. Multi-criteria decision making applications

MCDM methods and its integration with other methods have been successfully applied by many researchers and practitioners in several areas such as in information and communication technologies in analyzing ICT suppliers' offers in contracting processes [3], desalination process selection for most suitable desalination technology for the treatment of brackish groundwater [4], environmental impact assessment [5, 6], water resources management [7], solid waste management to rank fuel alternatives for the U.S waste collection industry with respect to a multi-level environmental and financial decision matrix and to identify, validate, and rank criteria that are essential for hospital waste management suppliers' selection [8, 9], climate change to assess the vulnerability to climate change and variability using various group MCDM methods and identified the sources of uncertainty in assessments [10], decision-support system for conceptual design of mechanisms for function-generation design tasks [11], facility location decision for process selection and evaluation for manufacturing systems for new facility and [12, 13], and energy [14].

AHP is the most widely used MCDM method and has been used in various applications [15]. There is a huge literature on the applications of AHP with over 1300 papers and one hundred scholarly dissertations [15, 16] which shows its importance. Application of AHP can be found in literature in many areas such as renewable energy [17, 18], water resources management [19, 20],desalination technologies [21, 22], seawater reverse osmosis plant [23], development of the seawater desalination project [24], hotel industry [25]. The main advantage of using AHP is its ability to capture decision makers' subjective and objective opinions [15, 26], wide applicability and ease of use [27], user friendly supporting software [28], allows group decision making [29], breakdown decision into hierarchy of goals, criteria, and alternatives [30–33].

Here it is important to mention for the readers about AHP. AHP was developed by Saaty in 1980 and since then it has been applied in many areas. Because of its simplicity and ease of use, managers and decision makers prefer to use AHP. It helps in breaking down the complex problem into hierarchal structure. It relies on the judgments of experts to rank alternatives using pairwise comparison and numerical judgments from an absolute scale of numbers called Saaty scale. AHP consists of the following steps and as mentioned in [34–36].

i) Define the problem by setting objectives and goal.
ii) Develop hierarchy by breaking the problem into different levels.
iii) Construction of pairwise comparison metrices.
iv) Perform pairwise comparison using Saaty's scale mentioned in Table 1.
v) Calculate consistency ratio to check expert's judgment consistency. As per Saaty (1980), it should be ≤ 0.1.

3. Methodology

In order to achieve objectives set in Section 1, and rank sustainable desalination plant location criteria, a two phased step-by-step methodology based on AHP has been proposed and mentioned in Fig. 1 below: AHP was selected to use as a MCDM technique because of several reasons which are as follows:

i) It is easy to implement
ii) AHP is able to capture both subjective and objective assessment of decision makers using pair-wise comparison.
iii) Biasness of decision makers' judgements can easily be calculated using consistency ratio.
iv) Robustness of the decision can easily be check by performing sensitivity analysis.

3.1. Phase 1: identification and validation

This phase of methodology consists of three steps. The main purpose of this phase is to identify and validate sustainable desalination plant location criteria and sub-criteria, and form experts group.

Step 1: *Identification of criteria and sub-criteria*
In this step, we have identified criteria from literature review and divided them in five different aspects in which three of them are related to sustainability and two of them are technical and operational aspects. List of main aspects and sub-criteria are mentioned in above Table 2.

Table 1
AHP Scale for pairwise comparison [32, 34].

Importance scale	Importance description
1	Equal importance of “i” and “j”
3	Weak importance of “i” and “j”
5	Strong importance of “i” and “j”
7	Demonstrated importance of “i” and “j”
9	Absolute importance of “i” and “j”

Note: 2, 4, 6, and 8 are intermediate values.
For detailed example and step by step approach about how AHP works, readers are referred to [34–36].