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Priority Determination of a Dual-Purpose Nuclear Power Plant Location in the Arabian Peninsula Using Fuzzy-Decision Analysis

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ABSTRACT. The fuzzy decision analysis technique is used for priority determination of the best location for a dual purpose nuclear power plant on the west coast of the Arabian Peninsula. From among several suggested locations, only four were chosen for further evaluation since they met specific minimal criteria and international standards. Two of the four sites are located on the northern part of the Red Sea Coast and the other two on the southern part. Twenty criteria were used in the analysis.

The analysis ranked the fourth site in first place followed by the third one.

Different approaches may be used for decision analysis. Keeney's multi-attribute utility function, Saaty's eigenvalue pairwise comparison technique and Fuzzy Decision analysis are some of the approaches used for this purpose. Keeney's approach is a normative one. This approach may be explained as follows: given m alternatives contributing to n attributes, the model assumed preference independence and utility independence (Keeney 1973). The utility function can be either additive, that is

$$Z_j = \sum_{i=1}^{n} K_i \, U_{ij}$$

if $\sum_{i=1}^{n} k_i = 1$

or multiplicative, *i.e.*

$$Z_j = \left[\prod_{i=1}^{n} (1 + kk_i\ U_{ij}) - 1\right]/k$$

otherwise.

where U_{ij} = utility of alternative j in relation to attribute i.
k_i = scale factor of attribute. i.

In this approach, the objective is to find maximum Z_j which translates to most preferable alternative (where k_i is a weight assigned to attribute i, U_{ij} is a weight assigned to alternative j with respect to attribute i).

The utility of the attributes k_i is evaluated through ordering the attributes according to their relative importance. Similarly the utility of alternative j with regard to attribute i, U_{ij} is evaluated. Using both, the utility function can be found. This approach has been used for different applications; Keeney (1973, 1979), Ellis, and Kenney (1972), Keeney and Nair (1977) and Kirkwood (1982). On the other hand Saay's approach is based on a pairwise comparison technique in this approach, given m alternatives and n attributes, a pairwise comparison between the attributes is done, and for each attribute, a matrix of pairwise comparisons between the alternatives with respect to the attribute is formed. The normalized eigenvector of the first matrix provides the relative weights $(\omega_1,\ldots,\omega_n)$ for each attribute, while the normalized eigenvector of the matrix related to attribute i provides the relative weights $(W_{i1},\ldots,W_{im})$ of the alternative with respect to that attribute. The weight of alternative j is then:

$$Z_j = \left[\sum_{i=1}^{n} w_i\ W_{ij}\right.$$

A scale of 1 to 9 and its reciprocals is used to perform the pairwise comparisons between each pair of attributes and between each pair of alternatives with regard to each attribute. This approach has been used for different purposes; Hussein, *et al.* (1987), Lugasi *et al.* (1985), Mehrez and Sinuany-Stern (1983), Saaty (1978, 1981, 1982) and Wind and Saaty (1980). The Fuzzy Decision technique (used in the present analysis) has been applied in different fields by Abdul-Fattah (1982), Abdul-Fattah and Abulfarag (1982), Abdul-Fattah and Sofrata (1986), Gaines (1976), Kenarangui, *et al.* (1979), Watson *et al.* (1979) and Zadeh (1972, 1976).

The purpose of this work is to provide a basis for priority determination of a location for a dual-purpose nuclear power plant on the west coast of the Arabian

Peninsula. Four locations along the Red Sea Coast (two at the north and two at the south were considered in this analysis) other regions were eliminated due to safety reasons or unavailability of cooling water; Hussein *et al.* (1987). Fuzzy-Decision technique was employed to determine the most preferred site among the four.

Initial Screening

The site selection process starts with the initial screening of the candidate sites to determine their suitability for further consideration. The most critical factors considered in the initial screening process in this work were; safety, environmental, social and economic factors. Only locations which satisfied the criteria established by these factors were considered for further evaluation and more strict criteria were applied to them. Subsequent evaluation of these locations using fuzzy decision analysis is the main concern of this paper.

An assumption is made (implicitly) when areas are included or excluded mainly because they fall just under or over a cut-off level on one criterion. Really, there is no sharp distinction, and utilizing this approach may eliminate some potential areas which may be fine on many criteria but just barely fail on one or two. However, such an approach provides some mean of rapidly focusing attention on candidate areas which have higher probabilities of containing acceptable potential locations.

According to the above argument, three regions were excluded in this study:

i) The central region was excluded due to its far distance from both the Arabian Gulf and the Red Sea where cooling water is a must, and construction of cooling water pipelines could be very expensive. Thus the exclusion here is based on economic aspects.

ii) The eastern region (around the Arabian Gulf coast) is excluded due to the existance of oil fields. Also this region is near the other Arabian Gulf countries, and this may raise some environmental and political problems especially if an accident takes place.

iii) The central part of the western region (along the Red Sea coast) is excluded because of its closeness to the holy places (Makkah and Madinah) since muslims from all-over the world visit these places regularly and especially in large numbers during both Pilgrimage and Omra seasons, *i.e.* the whole region of Miqat is excluded.

From this discussion it is concluded that only the northern and southern regions along the Red Sea coast were considered for further analysis. Within those two regions, four locations were identified as potential sites for building the proposed power plant. These were:

1) Duba, 120 km west of Tabuk (a moderately populated area with limited agriculture). A power plant at this site may also serve the central region, but requires the construction of long pipelines, transmission lines and construction lines, all may have to be extended through rough mountains. This may increase the cost/kwe.

2) Ummluj, which is about 200 km north west of Madinah, (a highly populated area, especially in the pilgrimage and Omra seasons). The power plant in this case would mainly serve Madinah and may serve Jeddah and Makkah as well as the central region of Saudi Arabia, especially Qasseem which is the most important agricultural area in the Kingdom. However, this would increase the cost/kwe due to the need for construction of long pipelines and transmission lines.

3) Al-Qunfudah, 130 km north of Abha and 150 km south of Al-Baha. Both are agricultural, moderately populated areas. A power plant at this location may serve besides Abha and Al-Baha, both regions of Jeddah and Makkah. However, this requires the construction of long water pipelines and transmission lines. This translates to an increase in the cost/kwe.

4) Al-Shuqaiq, 70 km north of Jezan and 60 km southwest of Abha, both are moderately populated agricultural areas. A power plant at this location may serve not only Abha and Jezan regions, but also other regions, especially Jeddah and Makkah (but with substantial increase in the cost/kwe due to the construction of long water pipelines, transmission lines, and construction lines).

A map showing the above locations with reference to major cities in the peninsula is given in Fig. 1.

Site Preference

Detailed descriptions of the potential sites are important in identifying the characteristics, based on which, one site is preferred to another. The information required in such case could include, the area, the location, the present use, the quality, quantity and location of the water supply, details of the natural factors

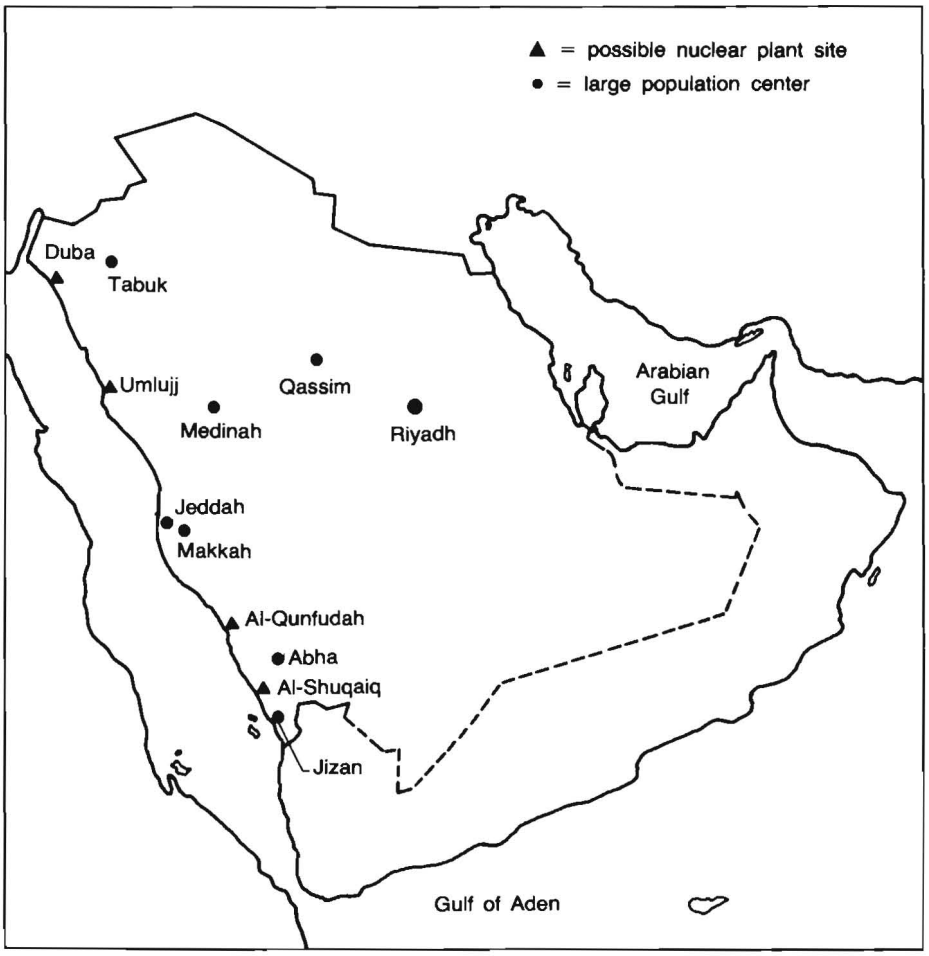

Fig. 1. Map of Saudi Arabia

including geology, topography, and flooding potential, population in the vicinity, vegetation, access to various transportation modes for purposes of construction and operation of the facility.

In the present study, twenty objectives with associated criteria (attributes) were identified for priority determination of the four sites chosen. (A team of experts in the fields of energy and topography as well as geologists and economists was consulted and their opinion about the relative importance of each attribute with respect to each site was considered). It was recommended to follow this procedure since the method used in this analysis is based on verbal judgement.

Table 1 is a summary of the attributes along with their relative importance (and reasons behind the judgement of this relative importance for the different attributes). For example, the four most important factors in deciding the location for the proposed power and desalination plant are power demand, water demand (and how may people for example will be served by the plant), the security of the plant, which is greatly affected by its location (it might be close to an enemy or be subject for sabotage, then such a location may be discarded altogether or get a low weight), and cooling water (which has a large influence on the cost of the plant since in the power plants large quantities of cooling water are required). Thus these factors are considered as very important and take the symbol V. Similarly for other factors which are assigned the symbol I for intermediate importance and so on.

Fuzzy Decision Technique

Only a brief discussion of this technique is given here since it is discussed in details by Zadeh (1972, 1976) and Abdul-Fattah (1982). In this technique, a number of criteria (attributes) may be used to describe (characterize) a set of "alternatives". Verbal ratings and weights are then assigned to each of the attributes. The weighted final ratings for each alternative can thus be computed and used to rank the alternatives. The ranking process thus proceeds as follows:

i) Weights of criteria.
ii) Rating of alternatives (sites in our case) with respect to each criterion.
iii) Ranking and preferability.

i) Criteria Weights

Since some criteria are more important than others, different weights were assigned to different criteria in order to indicate the differences of importance or preferability of one criteria over the other. To achieve this, verbal weights are used. The weights in the Fuzzy decision analysis may be represented by the Fuzzy set W_j, Abdul-Fattah (1986):

$$W_j = \{\omega_j, \mu_{W_j}(W_j)\} \qquad j = 1,2, \cdots ,n$$

where the values of ω_j, and $\mu_{W_j}(W_j)$ depend on the definition of W_j which varies according to the code proposed by Sofrata and Abdul-Fattah (1985) and given here for completeness (Table 2).

Table 1. Description of the attributes and their relative importance

Attributes	Relative importance	Reasons for judgement of relative importance (refer to description of each location for preference purposes)
Power demand	V	This is one of the two main reasons for building the power plant. Site 3 preferred in this regard.
Water demand	V	Same as above (the power plant is for power and water desalination). Site 3 is again preferred to all others with regard to this attribute.
Security	V	The strategic location of the country and its closeness to classical enemies makes this attribute one of the main attributes in deciding the location of the plant. Sites 3 and 4 (in the south) have more preference in this case.
Demography	I	The unique situation of the Kingdom, that is the influx of millions of people for pilgrimage and Omra gives this attribute its high importance. Site 1 has preference over the others.
Cooling water	V	Continuous supply of cooling water is required for the power plant. Cooling water with lower absolute temperature and lower temperature difference during the year at one location gives it preference over the others (because it means lower cost). The preference goes to site 4 in this case.
Construction	M	This is an economic factor which depends on land preparation, labour and existance of raw materials. Construction costs at site 1 are the least among all locations. Therefore it is preferred to all others.
Geology and Seismology	M	Since there are no active volcanos, earthquakes or main resources of deep underground water in the area (all may considerably affect the plant safety), this factor is of moderate importance in the decision process. Site 1 is slightly preferred.
Meteorology	I	Wind speed and direction may have an adverse effect in case of accidents. This may affect the neighbouring countries (as well as the Kingdom). Therefore, it is important to properly select the location of the plant. Slight preference goes to site 2.
Topography	R	In the west coast, topography is almost the same at all locations (all are near the Tehama Valley with no distinct topographical feature at any one location). All sites except site 3 have a similar weighting. Site 3 is slightly preferred.
Ecology	M	Fish and vegetation are part of the Kingdom's national income. Therefore, it is important to keep them protected from radioactive hazards or hot water from condenser cooling. All sites have (almost) the same weighting.

Table 1. (continued)

Attributes	Relative importance	Reasons for judgement of relative importance (refer to description of each location for preference purposes)
Economy	I	The cost of a nuclear power plant is high. It includes the plant and equipment cost as well as the intake water cost. This is an economic factor which may therefore change considerably from one location to another if any of its components changes. A slight preference goes to site 4.
Running Cost	I	Since this factor includes manpower and operation costs, the change in any of them may considerably change the total running cost. Site 4 is preferred to all others in this case.
Fresh Fuel Shipment	R	The shipment of fresh fuel depends mainly on the water passage and the nature of the beach as well as its depth. The difference in cost between locations due to this factor is expected to be small. Sites 2 and 4 are highly preferred. The worst site in this case is number 1.
Spent Fuel Shipment	M	The importance of this factor stems from the fact that it has a strategic side to it besides those mentioned in the previous factor. Therefore the rating is affected from that of the previous one and site 4 is preferred to all others followed by 3.
Product water pipeline and Transmission lines	M	The cost of the product water pipelines and transmission lines may change from one location to another depending on the areas to be served by the plant and the distances to these areas as well as the path through which these are constructed and the type of land to be used for its construction. The preference goes to site 2. Site 3 gets the worst ranking.
Land use	M	The type of land used for the construction of the plant (agricultural land, land of special use, etc.) is expected to affect the cost of the plant. Both sites 1 and 2 are good in this regard and thus get high preference over the others.
Services	M	Services are required especially during the construction stage of the plant. The cost due to this factor depends on distances from large service centers, airports and public areas. A slight preference goes to site 1.
Sea water	R	In a desalination plant, sea water plays an important role. The cost may thus depend on the water purity as well as its salinity. Site 4 is highly preferred to all others.
Soil	R	Some soil characteristics may make it difficult to construct power plants in the area or may increase the cost. Site 2 is slightly preferred.

V = Very important
I = Important
M = Moderately important
R = Rather important

Table 2. Rating of criteria

	Rating	Symbol
1	Very good	V
2	Good	G
3	Fair to good	T
4	Fair	F
5	Poor	P
6	Very poor	R
7	Not clear	N

ii) Rating of Alternatives (Sites)

The sites are rated verbally, each with respect to each criterion independent of all other sites. The ratings may then be represented by a Fuzzy rating set R_{ij} similar to the criteria weights set W_j, Abdul-Fattah (1982), *i.e.:*

$$R_{ij} = \{r_{ij},\ \mu_{R_{ij}}(r_{ij})\} \qquad \begin{matrix} i = 1,2,\cdots,3 \\ j = 1,2,\cdots,n \end{matrix}$$

The values of r_{ij} and $\mu_{R_{ij}}(r_{ij})$ depend on the definition of R_{ij} which takes the weights proposed by Abdul-Fattah (1986). The ratings of the four sites of this research are given in Table 3.

iii) Ranking and Preferability

The computer code IFDA, (Sofrata and Abdul-Fattah (1985)) which is based on the code MAFDA (Kenarangui (1980)) was used in this analysis to determine the final ranking of each alternative (site). It was also employed to obtain the preferability of the best site over the others. (Appendix A gives the input to IFDA for the present analysis). The results of the final ranking of the four sites are given in Table 4 and Figures 2 and 3. The results indicate that the fourth site (Al-Shuqaiq) is preferred to the other three and is thus ranked in first place. It also shows that the third site (Al-Qunfudah) is ranked in second place, followed by the first site (Duba); the second site (Ummluj) being the last one in ranking. For details of how the figures were obtained, the reader is referred to Sofrata and Abdul-Fattah (1985). (The authors have carried out a similar study, Hussein *et al.*

(1987), based on Saaty's pairwise comparison approach and obtained the same ranking for the first and second choices, that is, site 4 was ranked in first place followed by site 3. However, the ranking of the other two sites was different in the

Table 3. Rating of the four sites chosen for the Nuclear Power Plant

Criteria	Rating of Alternatives			
	Duba	**Ummluj**	**Al-Qunfudah**	**Al-Shuqaiq**
Power demand	Fair	Fair	Very good	Good
Water demand	Fair	Fair	Very good	Good
Security	Good	Good	Very good	Very good
Demography	Very good	Fair	Good	Good
Cooling water	Fair	Fair	Poor	Very good
Construction	Very poor	Poor	Good	Fair
Geology and Seismology	Good	Fair to good	Fair to good	Fair to good
Meteorology	Fair to good	Good	Fair	Fair to good
Topography	Fair to good	Fair to good	Good	Fair to good
Ecology	Fair	Fair	Fair	Fair to good
Economy	Fair to good	Fair to good	Fair to good	Good
Running cost	Good	Good	Good	Very good
Fresh Fuel Shipment	Fair	Very good	Good	Very good
Spent Fuel Shipment	Fair	Fair	Fair to good	Good
Product water pipelines	Good	Very good	Fair	Good
Transmission lines	Good	Very good	Fair	Good
Land use	Very good	Very good	Fair	Fair
Services	Good	Fair to good	Poor	Fair to good
Soil	Fair	Good	Fair	Fair
Sea water	Fair	Fair to good	Good	Very good

Table 4. The final rating and ranking of the four chosen sites

Site	The membership function	Final rating	Ranking
Duba	0.8559	0.7739	3
Ummluj	0.8363	0.7672	4
Al-Qunfudah	0.8688	0.7781	2
Al-Shuqaiq	1.000	0.8557	1

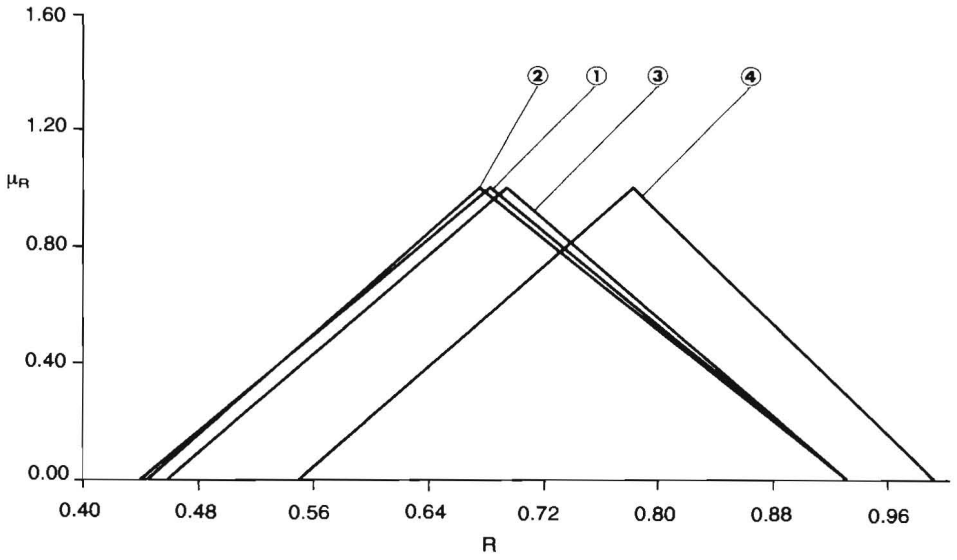

Fig. 2. Membership function of final rating for sites.

two approaches. This indicates that a simple verbal judgement technique such as used in the present study may be suitable for preliminary determination of preference among different alternatives). Figure 3 gives the membership function of preferability of the fourth site (Al-Shuqaiq) over the others. From Figure 3 and Table 4 it may be clear that the rating of the fourth site is much higher than the other three, which indicates that even if there was a slight misjudgement in the verbal rating of sites with respect to some attributes, the fourth site would still be ranked in first place (although the result might change for the others).

Conclusion

In this paper, four sites along the west coast of the Arabian peninsula were considered as potential sites for building a nuclear power plant to be used for water desalination and power production. Twenty criteria were used in the evaluation process employing the Fuzzy Decision analysis technique based on the computer code IFDA. The analysis ranked the fourth site (at Al-Shuqaiq) in first place, followed by the third site (at Al-Qunfudah). It also indicated that the difference in the ranking between the fourth site and the others is large which means that a slight misjudgement in the verbal rating will not affect the result regarding this site although it may change the ranking of the others. The final result would still not be affected since the purpose of this study is to determine the most preferable site among those chosen. Comparing the results of the present

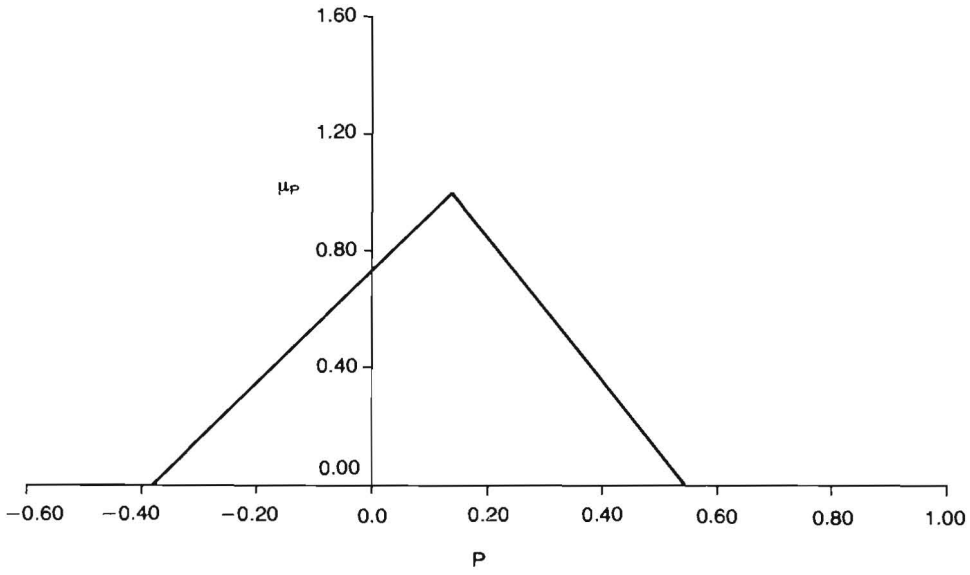

Fig. 3. Membership function of the preferability of alternative 04 over the others.

work with those of a previous study using Saaty's pairwise comparison technique, the two approaches agreed in ranking the first and second place sites. They however, differ in ranking the other two sites. Therefore a simple approach as the one used here is suitable for preliminary study since the main purpose is to determine the first choice site.

Appendix A. Input to IFDA for the Dual purpose nuclear power plant priority determination

START OF LISTING

```
1   20      0     4     3
2   .2          .6          .8
3   F  T  V  V  V  V  G  P  T  F  T  T  G  G  F  T  F  F  F  G
4   F  F  F  G  G  V  F  R  G  V  G  T  T  G  F  T  F  F  F  G
5   P  G  G  F  F  F  F  G  P  G  T  G  F  V  F  T  T  V  V  G
6   V  V  V  G  G  F  F  F  T  G  T  T  T  V  T  G  G  G  G  V
7   V  R  R  M  M  M  R  M  R  I  M  R  I  V  M  I  M  V  V  I
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دراسة تحديد (اختيار) أنسب موقع في الجزيرة العربية لبناء محطة نووية لتوليد الكهرباء وازالة ملوحة المياه باستخدام نظرية العوامل المبهمة

فهمي محمود حسين و حامد محمود صفراطه و خالد الملاحي و محمد عبدالفتاح عبيد

كلية الهندسة ـ جامعة الملك سعود ـ ص. ب ٨٠٠ ـ الرياض ١١٤٢١
المملكة العربية السعودية

في هذا البحث تم استخدام نظرية العوامل المبهمة لتحديد أنسب موقع لبناء محطة نووية لتوليد الكهرباء وازالة ملوحة المياه على الشاطىء الغربي من شبه الجزيرة العربية. وقد تم اختيار أربعة مواقع (اثنان منها في الشمال والأثنان الأخران في الجنوب) من بين عدة مواقع مقترحة وذلك لاجراء دراسة تفصيلية لاختيار الموقع الأكثر مناسبة حيث أن المواقع الأربعة حققت الشروط الأساسية اللازمة ـ وتم استبعاد المناطق الأخرى لأسباب مختلفة ـ فمثلا تم استبعاد المنطقة الوسطى لبعدها عن كل من الخليج العربي والبحر الأحمر حيث تحتاج عملية التبريد كمية كبيرة من المياه ـ ويتكلف مد أنابيب مياه التبريد كثيراً مما يجعل المشروع غير اقتصادي. وتم استبعاد المنطقة الشرقية (بالقرب من الخليج العربي) لقربها من دول الخليج مما يجعل الخطورة كبيرة في حالة حدوث حادث لاقدر الله ـ وأيضاً لقربها من آبار البترول ـ كما تم استبعاد الجزء الأوسط من المنطقة الغربية نظراً لقربها من الأماكن المقدسة (مكة المكرمة والمدينة المنورة) وامكانية حدوث الخطر وخاصة في مواسم الحج والعمرة.

والمواقع الأربعة التي حققت الشروط الأساسية في الدراسة الأولية هي:

١ ـ ضبا وتقع على بعد ١٢٠ كم غرب تبوك ـ ووجود محطة فيها يخدم المنطقة الوسطى ولكن بتكلفة عالية.

٢ ـ أملج وهى على بعد ٢٠٠ كم شمال غرب المدينة المنورة ووجود محطة فيها

يخدم المدينة وكذلك يخدم جدة ومكة المكرمة وكذلك المنطقة الوسطى ولكن مع زيادة التكلفة.

٣ ـ القنفده وهى على بعد ١٣٠ كم شمال أبها و ١٥٠ كم جنوب الباحة ـ وهما منطقتان زراعيتان ـ ولذلك فإن محطة في هذا الموقع تخدم كلاً من أبها والباحة ـ وكذلك تخدم مكة المكرمة ولكن مع زيادة في التكلفة نتيجة مد خطوط المياه والكهرباء لمسافات طويلة.

٤ ـ الشقيق وهى على بعد ٧٠ كم شمال جيزان، ٦٠ كم جنوب غرب أبها والمحطة في هذا الموقع لاتخدم الباحة وجيزان فقط ولكن المناطق الأخرى وخاصة مكة المكرمة وجده (ولكن مع زيادة كبيرة في التكلفة).

وفي عملية التفضيل بين المواقع المختارة أخذ في الاعتبار عشرون عاملا في الدراسة حيث تم ترتيبها بحسب الأهمية إلى ٤ درجات ـ ومن أهم تلك العوامل ـ الطاقة الكهربائية ومدى الحاجة إليها ـ المياه العذبة ومدى الحاجة إليها ـ الأمان ـ التوزيع السكاني ـ مياه التبريد ـ المباني ـ الارصاد الجوية ـ الطبيعة الأرضية . . . الخ.

كما تم ترتيب المواقع الأربعة بالنسبة للعشرين عاملا من حيث الكيفية.

وتم تطبيق برنامج IFDA عليها والذي ينبني على نظرية العوامل المبهمة ونتج عنه ترتيب الموقع الرابع في الجنوب في المقام الأول يتبعه في ذلك الموقع الثالث (في الجنوب أيضاً) في المقام الثاني.