MULTI-CRITERIA DECISION MAKING IN SITE SELECTION FOR NUCLEAR POWER PLANTS

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ABSTRACT

MULTI-CRITERIA DECISION MAKING IN SITE SELECTION FOR NUCLEAR POWER PLANTS

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Nuclear energy is an important alternative energy source. However the construction of nuclear power plants (NPP) requires the consideration of various factors, such as environmental, economic, socioeconomic, health and safety. Accordingly, selection of the most suitable site for the construction of a nuclear power plant yields to a multi-criteria decision making problem. Seismic hazard, environmental conditions, population, health hazards, availability of water resources (for cooling purposes) are among the main factors which should be taken into consideration. The probabilistic methodology leading to the identification of the optimal alternative site will utilize probability, statistics, reliability, utility and multi-criteria decision making tools. In illustrating the implementation of the methodology that is developed in the study, two candidate NPP sites in Turkey are considered, namely, Mersin-Akkuyu and Sinop-Abalı. In the evaluation of these two sites, seismic hazard is taken as the main factor. Because of various sources of uncertainties, probabilistic seismic hazard methodology is used in the study. After identifying the other important criteria like extreme wind hazard, tsunami hazard, distance to facilities, population density etc. for site selection, multi-criteria decision analysis is utilized. The optimal alternative site which fulfills the selected criteria is identified and recommended as the output of the methodology.

Keywords: Nuclear energy, multi-criteria decision making, siting, nuclear power plant, utility function

ÖZ

NÜKLEER GÜÇ SANTRALLERİ İNŞAAT SAHASI SEÇİMİNDE ÇOK KRİTERLİ KARAR VERME

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Nükleer enerji önemli bir alternatif enerji kaynağıdır. Ancak Nükleer Güç Santrali'nin (NGS) inşaası, çevresel, ekonomik, sosyoekonomik, güvenlik ve sağlık gibi çeşitli faktörleri göz önünde bulundurmayı gerektirir. Dolayısıyla, inşaat sahası için en uygun alanı seçmek çok kriterli bir karar verme problemidir. Sismik tehlike, sağlık ile ilgili tehlikeler, nüfus, çevresel şartlar ve su kaynaklarının varlığı (soğutma amaçlı) değerlendirilmesi gereken temel kriterlerdendir. En uygun sahanın seçilmesine olanak sağlayan olasılıksal metotlar, olasılık hesabı, güvenilirlik, yararlılık ve çok kriterli karar verme araçlarını kullanır. Bu çalışmada, geliştirilen metodolojinin uygulamasını göstermek amacıyla, Türkiye'de bulunan iki aday nükleer güç santrali alanı, Mersin-Akkuyu ve Sinop-Abalı, incelenmiştir. Bu iki alanın değerlendirilmesinde ana faktör olarak sismik tehlike göz önünde bulundurulmuştur. Bu çalışmada, çeşitli belirsizliklerden dolayı, olasılıksal sismik tehlike metodolojisi kullanılmıştır. Saha seçimi için önemli olan aşırı rüzgar tehlikesi, tsunami tehlikesi, tesislere uzaklık, ve nüfus yoğunluğu gibi diğer kriterler belirlendikten sonra, çok kriterli karar analizi uygulanmıştır. Kriterleri sağlayan alternatif sahalar belirlenmiş ve kullanılan metodun sonucu olarak önerilmiştir.

Anahtar Kelimeler: Nükleer enerji, çok kriterli karar verme, konumlandrma, nükleer güç santrali, fayda fonksiyonu,

To my beloved family...

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TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1 The History of Nuclear Energy and Nuclear Power Plants

The nuclear research and development has started at the beginning of 1940s [1]. The World Nuclear Association states that the first nuclear reactor to produce electricity was the Experimental Breeder Reactor (EBR-1) constructed in Idaho, USA in 1951. In 1954, the first nuclear powered electricity generator in the world began operation at the Institute of Physics and Power Engineering (FEI) in Obninsk, Moscow [2].

In the United States, during the World War II, the atomic energy was considered in military terms especially as nuclear weapons under the Manhattan Project. The information related to the nuclear power was restricted. At the beginning of 1950s, the nation's atomic plans shifted. Although the main object remained same (weapon production), they started to think about the peaceful applications of the atomic energy like generating electricity from the atomic fission. A speech was given with the title "Atoms for Peace" by President Eisenhower [3]. In this speech, an increase in the military use of nuclear energy was mentioned and the possibility of peaceful applications of the atomic energy especially electricity production for the power-starved areas of the world was emphasized [4]. At the early stages of the peaceful use of nuclear energy, there were some uncertainties about the cost of nuclear plants and about the possible damages in case of a reactor accident. For this reason, the American industry was not ready to take the full responsibility so the government did it. This reluctance of the industry continued until 1957. With the insurance system which is governed by the Price-Anderson Act, an increase in the willingness of the industry has been observed and companies started to order nuclear plants [3]. On 28 March

1979, Three Mile Island accident occurred near Harrisburg, Pennsylvania. According to the International Atomic Energy Agency (IAEA), this serious accident resulted in both positive and negative impacts.The nuclear power industry was damaged by this accident. Many nuclear power projects on order or even under construction were delayed or cancelled. On the other hand, with this accident, much more importance was given to obtain safe reactors and many improvements have done related to the design, construction and operation of the nuclear power plants [5].

The studies about atomic nuclei have started in 1937 in Russia. Because of the ongoing World War II, a special physics laboratory (known as No. 2 Laboratory) was constructed for the purpose of nuclear weapon production in 1943 in Moscow. Throughout 1940s, the studies were developed concerning the nuclear reactors and in 1980s, several nuclear power plants were constructed [6]. As the World Nuclear Association indicated, a terrible accident occurred in Chernobyl nuclear power plant in 1986 causing the death of 30 operators and firemen within 3 months and several further deaths later. The accident brought some negative consequences to the nuclear power industry. Until mid-1990s, only one nuclear power station was constructed [7].

As mentioned by IAEA, Turkey became interested in nuclear energy in 1965 to build a nuclear power plant. After some feasibility studies, the project was cancelled due to the site selection problems and other issues. A second attempt was undertaken by Turkish Electricity Authority (TEA) to construct a prototype power plant in 1973 but this project was also cancelled. After this cancellation, TEA determined to build a nuclear power plant in southern Turkey. During 1974 and 1975, site selection studies were conducted and Akkuyu in Mersin province was chosen as a suitable location. Site licence for Akkuyu was given by Atomic Energy Commission (AEC). The investors giving the highest bids were selected for the nuclear power plant construction. Since the loan guarantee was cancelled , the project was called off. In 1980, a third attempt has been made for nuclear power plant construction. Three companies were granted to build four nuclear power plants (two of them would be in Akkuyu and other two would be in Sinop province). Since Turkey wanted to apply build-operate-transfer (BOT) method, in which a private entity receives a concession from the private or public sector to finance, design, construct, own and operate a facility stated in the concession contract [8], one of the companies quitted the bid. In addition, other companies wanted a governmental guarantee and with the rejection of this claim, the project was abandoned. In 2010, Turkey negotiated with Russia to construct a nuclear power plant with build-own-operate (BOO) model in Akkuyu. This is a public-private partnership project model in which a private organization builds, owns, operates a facility with some degree of encouragement from the government [9]. Also, Akkuyu Project Company (APC) was founded for the implementation of the project. APC started investigating the Akkuyu site and prepared several reports including the site characteristics and parameters. These reports were updated by considering the suggestions given by Turkish Atomic Energy Authority (TAEK) and then were approved by the authorities in 2017. Another nuclear power plant was planned to be installed in Sinop. Negotiations were organized with several candidate countries by the Ministry of Energy and Natural Resources. An agreement was signed with Japan in 2013 [10].

1.2 Site Selection for Nuclear Power Plants

The operation of nuclear power plants is one of the activities that contain radioactivity in nature. For this reason, in order to protect the public and the environment, numerous regulations were made by the IAEA [11]. Since the selection of the suitable site for a nuclear power plant is crucial in terms of safety, several criteria should be determined specific to the region which is desired for a nuclear power plant installation. Possible natural hazards like river flooding, vibratory ground motion due to earthquakes, volcanic eruptions and tsunami waves should be considered for a nuclear power plant installation. Also other extreme meteorological events like extreme wind speed, droughts, extreme temperatures or extreme precipitation should be taken into account [11]. Besides natural events, human induced events play an important role on the safety of nuclear power plants. Other nuclear installations, mining operations, surface transportation like railways and roads and airport zones can be classified as human induced events [11]. In addition to these criteria, IAEA emphasizes that the physical and infrastructural characteristics of the site, industrial facilities that may cause hazardous activities and availability of cooling water are other criteria that are needed to be evaluated [11].

1.3 Studies in the Literature

Several studies related to the siting of nuclear power plants take place in the literature. Keeney and Nair [12] studied about site selection procedures in order to discover new sites for nuclear power plants in Pacific Northwest. Initially, they chose several siting considerations and detailed them during the screening process. A probabilistic approach was used to eliminate the insignificant issues and keep the significant ones. As a result of this process, six criteria were chosen to be considered in the selection phase; site population factor, loss of salmonids, biological impacts at site, length of intertie to 500-kV system through environmentally sensitive areas, socioeconomic impact and annual differential cost between sites. These criteria were evaluated by using decision analysis. Subjective probabilities were used in the determination of utility functions without considering risk attitudes. At the end of the process, most suitable sites were determined and sensitivity analysis was carried out to see whether changing the weights of the criteria affects the results of the study .

Kirkwood [13] conducted an analysis for the selection of a suitable site for a nuclear power plant. Although he used the same method with Keeney and Nair [12], he made a few additions like coupling the candidate sites with candidate water sources and carrying out a risk analysis. Multi-criteria decision making (MCDM) methods were used for the selection. Utility functions were evaluated under subjective assessments of probabilities. The distance of nuclear power plants to faults, the distance from airports, the location with respect to designated land use areas and to areas that are biologically unique or diverse and the slope of the areas are considered as important criteria for the site suitability.

Omitaomu et.al. [14] used a GIS-based multi-criteria decision making (MCDM) approach to find suitable sites for the new generating plants (including advanced coal, concentrated solar and nuclear). The population, landslide hazards, stream flow and proximity to hazardous facilities were some of the criteria they used in their study.

Pwani et al. [15] have used the systems engineering method for the site selection of a nuclear power plant which was desired to be the first in Kenya. Focusing on the stakeholders' needs, system functions were generated and scores were obtained for each site.

Kassim and Kessel [16] were interested in selecting the most appropriate site for the first nuclear power plant in Yemen. Examining the population, seismic hazard, land topography, water supply, wind direction etc. in detail, and under the light of the IAEA and Nuclear Regulatory Commission (NRC) regulations, six candidate sites were investigated using Analytical Hierarchy Process (AHP).

Basri et al. [17] published a study that states the regulatory requirements necessary for a nuclear power plant construction in Malaysia. Although their studies do not include application of any specific method to select a suitable NPP site, they considered the requirements of both IAEA and their Atomic Energy Licensing Board (AELB) and combine these requirements. Geology and seismology, atmospheric dispersion, population zone, hydrology and transportation were main concerns that they were interested in their study.

Wang et al. [18] evaluated seven potential sites in Vietnam considering reliability and security, characteristics of the sites corresponding to environmental compatibility, costs of engineering, transmission, transportation, water costs and technical feasibility under Fuzzy MCDM approach.

Bazedi et al. [19] have studied the selection of suitable sites for small-medium nuclear desalination plants and nuclear reactors in 2018. Three main regions in Egypt were evaluated via Wilcoxon-Signed rank method in the study.

Siting studies started in Turkey, in 1965. TEA [20] published a general report that investigates several characteristics of candidate nuclear power plant sites in terms of safety and environment in 1975. According to the report, geographic, hydrologic and geologic properties of the sites should be examined and presented in detail. The availability of the cooling water, transportation of technical pieces, seismicity of the region, distribution of the population and meteorological events like precipitation, flooding, storms in terms of their speeds and directions should be considered broadly during the investigation. There is not a specific method to select the best NPP site in the report.

Again in 1975, seismic hazard analysis was conducted by Gürpınar et al. [21] which was supported by TEA. This study enabled to make comparisons between candidate sites, Çanakkale-Aksaz and Tekirdağ-Marmaraereğlisi, in terms of their seismicity. A number of statistical methods were used to predict the distribution of earthquakes within a time period of 1900-1970. As a result of the study, several recommendations were made and it was stated that more detailed feasibility studies should be conducted to obtain more accurate information about the suitability of the sites.

In 2013, Erol et al. [22] conducted a siting study that aimed to locate the candidate sites for nuclear power plants in Turkey. Four potential sites (Kırklareli-Poliçe, İstanbul-Çilingoz, Kocaeli-Kefken and Sinop-İnceburun) which were determined by TAEA were analyzed in the study. Population density, geological and seismological issues, atmospheric conditions and cost factors related to the construction and cooling systems were analyzed via fuzzy MCDM approach and the sites were ranked according to the output obtained from the method. İstanbul-Çilingoz region took the first place in the list while Sinop-İnceburun and Kocaeli-Kefken were the last two.

This study concerns multi-criteria decision analysis methodology to make a comparison between two candidate sites, Mersin-Akkuyu and Sinop-Abalı in terms of different objectives and related attributes and is the first one which evaluates three different risk attitudes for each attribute in utility functions. For risk averse and risk prone attitudes, both polynomial utility functions and exponential utility functions are constructed. Additionally, this is the first study that uses the results of Probabilistic Seismic Hazard Analysis (PSHA) to construct a multi-attribute utility function by combining it with other criteria like tsunami hazard, extreme wind hazard, population density, distance to airports, etc. Also, several scenarios take place in the study to cover all the possibilities related to the attributes. Since multi-attribute utility theory includes subjective probabilities, a sensitivity analysis is performed in the study to investigate the effects of these probabilities on the results of the utility functions.

1.4 Organization of the Study

This study consists of four chapters.

In Chapter 1, a brief summary of the history of nuclear power plants and previous studies are provided. Also the aim of the study and contributions to the literature are mentioned.

In Chapter 2, multi-attribute utility theory which is used in nuclear power plant site selection is explained in detail.

In Chapter 3, a comparison of Mersin-Akkuyu and Sinop-Abalı sites is made for the selection of the suitable site for a nuclear power plant. Moreover, assessment of single-attribute and multi-attribute utility functions are provided in this chapter. Finally, Chapter 4 consists of the summary of the results obtained in Chapter 3 and conclusions of the study.

CHAPTER 2

MULTI-CRITERIA DECISION MAKING METHODOLOGY

Turkey is preparing to construct two nuclear power plants to fulfill the energy demand of the future. Like any other energy facilities, nuclear power plant construction requires the selection of the best location in terms of different perspectives. These requirements create site selection problem. Any siting problem considers five general concerns including the environment, economics, socioeconomic, health and safety and public attitudes. Also, existence of numerous possible sites, multiple objectives, several uncertain impacts and the degree of them and value trade-offs make the siting problem more complicated. Therefore, formal analysis is needed for the siting procedure. Multi-Criteria Decision Making can be used in order to meet the requirements of the siting problem.

2.1 Decision Analysis Procedure for Nuclear Power Plant Site Selection

2.1.1 Determination of Candidate Sites

Siting studies start with a region of interest to determine the several candidate sites for the energy facility construction. In the literature, there are several methods for this step of the analysis like exclusion screening, inclusion screening and comparison screening [23].

After identifying candidate sites, a siting study requires specifying objectives and the corresponding attributes. Identification of the objectives requires taking into account five general concerns which are specified above and they should indicate minimizing, maximizing or optimizing some concerns rather than indicating specific values or thresholds.

2.1.2 Determination of Objectives and Attributes

The next step in decision analysis is to determine the attributes. Attributes are defined as the measure of effectiveness for the objectives [23]. They can be divided into two parts; direct attributes and proxy attributes. While direct attributes measure the achievement of the objectives directly, proxy attributes measure effectiveness indirectly, proxy attributes are suitable when there is not enough information or data about the direct attribute or when it is impossible to measure or count the attribute directly [23]. With the determination of the attributes, also specific levels of these attributes should be clarified. These levels can have either natural scales or constructed scales. To illustrate, number of deaths or cost exist naturally so they are members of natural scales but if one constructs several levels for some attributes, then these levels should be considered as constructed scales.

2.1.3 Describing and Evaluating Site Impacts

Describing possible impacts for each alternative site should come as a next procedure after the construction of objectives and attributes. Every candidate site has some specific values in terms of each attribute and these values exhibit some uncertainties about the impacts. After the collection of the relevant data, professional judgment should be carried out to overcome the uncertainties about the impacts.

In order to make a comparison among several candidate sites, comparable values should be obtained for each possible site. These values can be obtained by using three types of functions showing preferences; value function, measurable value function and utility function. The aim in this study is to find an overall utility function that contains all the information that the candidate sites have. This overall utility function is called as multi-attribute utility function when there are more than two attributes in the siting problem. The overall utility functions can be found by combining the single-attribute utility functions. Several forms of multi-attribute utility function exist depending on the numerous independence conditions.

2.1.3.1 Independence Conditions

Additive independence: Attributes $X_1, X_2, ..., X_n$ are additive independent if the preference order for lotteries does not depend on the joint probability distribution of these lotteries, but depends only on their marginal probability distributions. If the attributes are additive independent, then the utility function has the following form;

$$u(x_1, ...x_n) = \sum_{i=1}^{n} k_i u_i(x_i). \tag{2.1.1}$$

where $u_i(x_i)$ is a single-attribute utility function and k_i is the scaling constant for the attribute x_i.

Utility independence: Attribute X_1 is utility independent of attributes $X_2, ..., X_n$ if the preference order for lotteries involving only changes in the level of X_1 does not depend on the levels at which attributes $X_2, ..., X_n$ are fixed. If attribute $X_i, i = 1, ..., n$ is utility independent of the other attributes, then the utility function has the following form;

$$\begin{aligned} u(x_1, ...x_n) = & \sum_{i=1}^{n} k_i u_i(x_i) + \sum_{i=1}^{n} \sum_{j>i}^{n} k_{ij} u_i(x_i) u_j(x_j) \\ & + \sum_{i=1}^{n} \sum_{j>i}^{n} \sum_{h>j}^{n} k_{ijh} u_i(x_i) u_j(x_j) u_h(x_h) + ... + k_{1...n} u_1(x_1)...u_n(x_n). \end{aligned} \tag{2.1.2}$$

where $u_i(x_i)$ is a single-attribute utility function for $i = 1, 2, ..., n$ and k_i's are scaling constants.

Preferential independence: The pair of attributes (X_1, X_2) is preferentially independent of the other attributes $(X_3, ..., X_n)$ if the preference order for consequences involving only changes in the levels of X_1 and X_2 does not depend on the levels at which attributes $X_3, ...X_n$ are fixed.
If the attributes are preferentially independent and X_i is utility independent of the

other attributes, then the utility function is expressed as;

$$u(x_1, ..., x_n) = \sum_{i=1}^{n} k_i u_i(x_i) + k \sum_{i=1}^{n} \sum_{j>i}^{n} k_{ij} u_i(x_i) u_j(x_j)$$
$$+ k^2 \sum_{i=1}^{n} \sum_{j>i}^{n} \sum_{h>j}^{n} k_{ijh} u_i(x_i) u_j(x_j) u_h(x_h)$$
$$+ ... + k^{n-1} k_1 k_n u_1(x_1) ... u_n(x_n). \quad (2.1.3)$$

where $u_i(x_i)$ is a single-attribute utility function for $i = 1, 2, ..., n$ and k's and k_i's are general scaling constants and single-attribute scaling constants, respectively. Equation (2.1.3) reduces to additive utility function when $\sum_{i=1}^{n} k_i = 1$.
If $\sum_{i=1}^{n} k_i \neq 1$, then multiplying each side of the equation (2.1.3) by k and adding 1 leads to ;

$$ku(x_1, ...x_n) + 1 = \prod_{i=1}^{n} [k k_i u_i(x_i) + 1]. \quad (2.1.4)$$

where $u_i(x_i)$ is a single-attribute utility function for $i = 1, 2, ..., n$ and k and k's are general scaling constant and single-attribute scaling constants, respectively. Equation (2.1.4) is referred to as multiplicative utility function.

2.1.3.2 Assessing Single Attribute Utility Functions

After the form of the multi-attribute utility function is determined, single-attribute utility functions should be assessed. For each attribute X_i, the worst and the best levels should be obtained so that

$$u(x^0) = 0, u(x^*) = 1 \quad (2.1.5)$$

where x^0 and x^* stand for the worst and the best levels of an attribute, respectively.

Definition 1 *: A lottery is a statement of possible consequences that may occur and their corresponding probabilities [24].*

Definition 2 *: A non-degenerate lottery is the one where no single consequence has a probability of one of occurring [23].*

Several utility values can be determined by constructing several lotteries that use the utility values of the best and the worst levels. To illustrate, in order to find the utility value of x_i, where x_i is the specific value of the i^{th} attribute X_i, the following lotteries can be used;

Lottery 1: Obtaining x_i for certain.
Lottery 2: Obtaining x^0 with probability $1 - p$ and obtaining x^* with probability p.

The answer of the question what value of p makes the researcher indifferent between the first and the second lottery gives the utility value of x_i implying that $u(x_i) = p$. After deciding adequate number of utility values, the next step involves finding the form of the single-attribute utility functions. The attitude of the researcher toward risk decides the form of the single-attribute utility function;

- If a decision maker is risk averse, then he prefers the non-degenerate lottery to the constructed lottery and the utility function has a concave form.
- If a decision maker is risk prone, then he chooses the lottery rather than the non-degenerate lottery and the utility function has a convex form.
- If a decision maker is risk neutral, the consequence of any non-degenerate lottery is indifferent to the constructed lottery and the utility function is linear.

According to these three cases mentioned above, the decision maker should choose the suitable form of the single-attribute utility functions and the utility values of site specific levels of the attributes should be assessed. Then, these single-attribute utility functions take place in the multi-attribute utility function with their corresponding scaling constants. The scaling constants can be determined in two steps; first, the attributes can be ranked intuitively in terms of their importance in siting. For finding the actual values of the scaling constants k_i's, lotteries can be used. For example, an attribute X_i is at its best level and all other attributes are at their worst level, then a lottery includes all attributes at their best level with probability p and all attributes at their worst level with probability $1 - p$. The aim is to find the value of p such that the decision maker is indifferent between the consequence and the lottery. Then, selecting the suitable form of the multi-attribute utility function from Equation (2.1.1) through Equation (2.1.4), and equating expected utilities, the value of k_i is found [23]. All the scaling constants k_i can be obtained with this approach. The existence of the scaling constant k can be investigated by looking at the summation of the scaling constants k_i's. When the summation is one, the scaling constant k becomes zero, otherwise it has some value and this value can be found from the multiplicative form of the overall utility function [23].

2.1.4 Analyzing and Comparing Candidate Sites

Possible candidate sites are evaluated using several attributes $X_1, ..., X_n$ and utility functions are constructed. Multi-attribute utility function is constructed using one of the forms and candidate sites are compared under different circumstances.

2.1.5 Sensitivity Analysis

Sensitivity analysis refers to the repeated evaluation of the candidate sites with some of the information changed in each case [24]. Since there are some uncertainties in the siting procedure, it is convenient to conduct a series of sensitivity analyses.

- Sensitivity analysis of the impacts can be conducted.
- Sensitivity analysis of the risk attitudes can be conducted to see the results of the study under different cases like less risk averse or risk neutral scenarios if the attribute is risk averse.
- Sensitivity analysis of the attributes can be conducted by deleting an attribute to see whether it has a significant effect on the result of the siting study.

CHAPTER 3

CASE STUDY: COMPARISON OF TWO NUCLEAR POWER PLANT SITES, MERSİN-AKKUYU AND SİNOP-ABALI

Turkey is planning to construct two nuclear power plants in the near future. These two nuclear power plants will be constructed in Mersin-Akkuyu and Sinop-Abalı. In this part of the study, multi-attribute decision analysis method is applied for the siting procedure in Turkey. A multi-attribute utility function is constructed and these sites are compared in terms of their utility values. Moreover, a sensitivity analysis is performed with respect to subjective probabilities and the results are summarized in this chapter.

3.1 Information about the Candidate Sites

Multi-attribute siting studies start with the selection of regions of interest and eliminating some of them to obtain a set of candidate sites. Turkey has selected two sites for the NPP construction, namely, Mersin-Akkuyu and Sinop-Abalı.

Mersin is a coastal city, located in the Mediterranean Region. It is surrounded by Antalya, Karaman, Konya, Niğde and Adana. Also, Mersin is the tenth most crowded city in Turkey. A nuclear power plant will be constructed in Gülnar district of Mersin. Akkuyu region with latitude 36°08'N and longitude 33°32'E is chosen as a suitable site for the construction of the NPP.

Sinop is another coastal city which is chosen for the second NPP construction. This province is located in the Black Sea Region with its neighbour cities Kastamonu, Çorum and Samsun. Abalı village with latitude 42°02'N and longitude 34°58'E is selected as the site to construct a nuclear power plant.

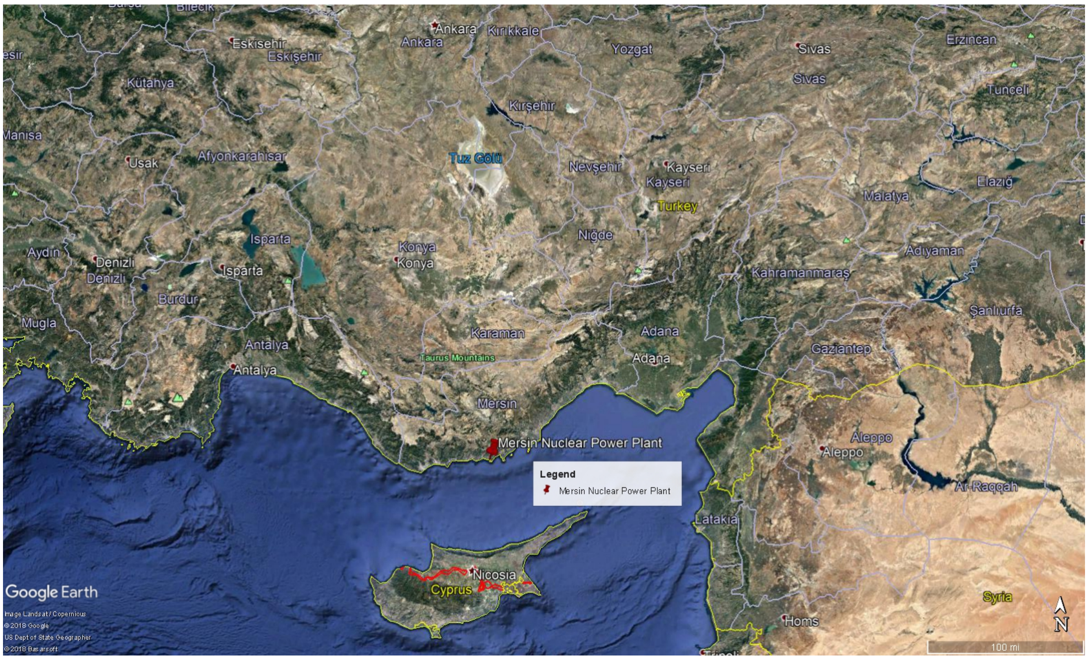

Figure 3.1.1: General view of Mersin-Akkuyu NPP construction site

General view of the candidate sites are given in Figures 3.1.1 and 3.1.2.

3.2 Specification of Objectives and Attributes

Site selection for nuclear power plants requires to determine some objectives and their corresponding measure of effectiveness, called attributes. Most of the siting studies consider general concerns related to the environment, health and safety, economy etc. In this study, several objectives are determined and to achieve these objectives, numerous attributes are specified.

The first objective is the protection of health and safety. During the installation and operating lifetime of a nuclear power plant, it is very important to consider possible detrimental effects that arise out of potential radiological hazards. The health of the individuals and the society should be protected against any kind of accident or radiological hazard [25].

The second objective is the protection of the environment. Since nuclear power plants occupy huge places, the land of interest should be investigated such that the forests and biodiversity are not affected negatively.

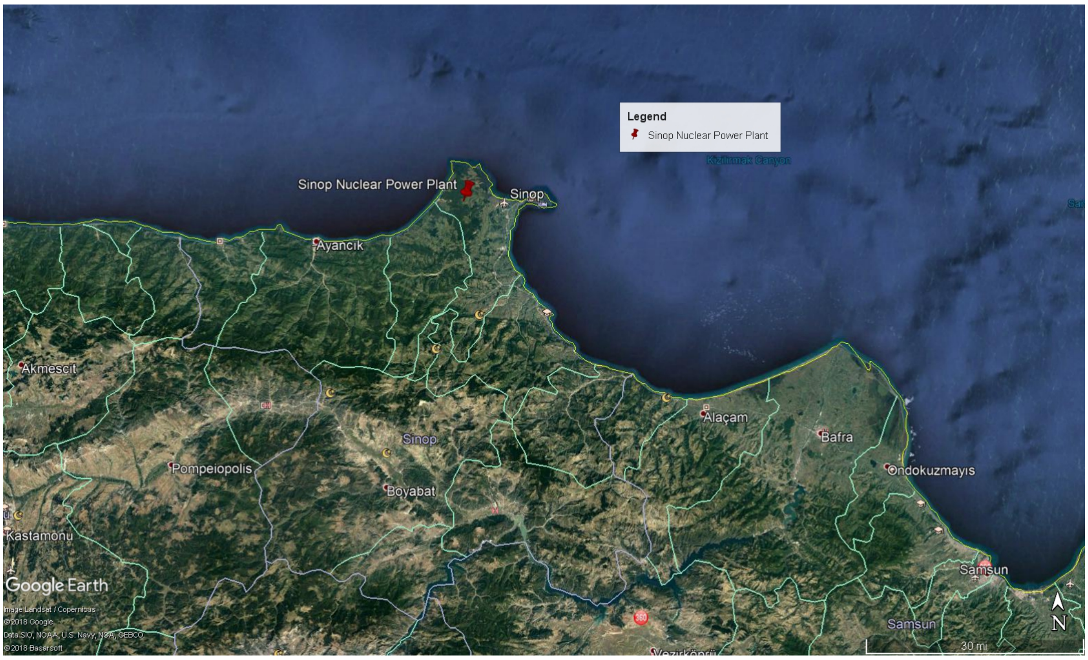

Figure 3.1.2: General view of Sinop-Abalı NPP construction site

Other important objective is to minimize the effect of natural hazards on NPP sites. To illustrate, earthquakes, tsunamis, extreme weather conditions including extreme precipitation, wind speed or droughts may have some negative impacts on the NPP. To overcome the negative effect natural hazards, the assessment of seismic, tsunami and extreme wind hazards are performed for both of the candidate sites.

Besides natural hazards, also human-induced hazards have an impact on the NPP [11]. For this reason, another objective is minimizing human-induced hazards. Distance between the NPP site and airport and bus terminal should be considered for the safety of the NPP and the community.

The last objective is optimizing socioeconomic impacts. The citizens of the candidate sites will face with a new energy facility construction including the plant itself, cooling towers and transmission facilities [24]. This brings up the aesthetic impact of the NPP. Additionally, during the construction of an NPP, there will be rapid increase and then decrease in human population, which is called as boom-bust cycle [24]. Also, socioeconomic impacts include the cultural heritage and the protection of it to maintain the existence of the community.

In the light of information about the objectives mentioned above, attributes are determined to effectively measure the objectives. For the comparison of Mersin-Akkuyu

and Sinop-Abalı sites, seismic, tsunami and extreme wind hazards are investigated as natural hazards. In order to assess the effects of human-induced hazards, distance to airports and bus terminals from the NPP site are used as attributes. The number and percent area of forests, natural parks, nature conservation areas, natural monuments are considered and biodiversity attribute including the number of endemic species, International Union for Conservation of Nature (IUCN) species and habitats unders monitoring are selected to measure the achievement degree of minimizing environmental impact. To ensure health and safety of the public, distance between NPP site and the city center and the population density of the sites are evaluated. For the socioeconomic impact, the number of immovable cultural heritage and the population density of the provinces are considered.
The next step after identifying the objectives and attributes is to determine the worst and best levels of the attributes. These levels are used for the identification of the utility functions. The worst level has the utility value of 0, while the best level for an attribute takes the best utility value of 1.0.

3.3 Describing and Evaluating Site Impacts

In this section, single-attribute utility functions are constructed for each attribute and utility values are obtained for the candidate sites, Mersin-Akkuyu and Sinop-Abalı.
To determine utility functions, indifferent lotteries are constructed and subjective probabilities are assigned to the lotteries. After that, the function which fits the assessed points with coefficient of determination 1.0 is obtained. Since the probabilities are subjective, a sensitivity analysis is performed in Section 3.5.
The general form of the lotteries can be expressed as follows;
Lottery 1: Receive R for certain.
Lottery 2: Receive R^* with probability p and receive R_* with probability $1-p$.
where R^* stands for the best value of the attribute and R_* represents the worst value.
When there is an indifference in preferring these two lotteries, the utility of R equals to the expected utility of the second lottery [26]. This is expressed as follows;

$$U(R) = p * U(R^*) + (1-p) * U(R_*) = p * (1) + (1-p) * (0) = p \quad (3.3.1)$$

Table 3.2.1: Summary of objectives and attributes

Objectives	Attributes	Subcategory
Minimizing natural hazards	Seismicity	-
	Tsunami	-
	Extreme wind hazard	-
Minimizing human-induced hazards	Distance to airports	Aircraft crash
		NPP crash
	Distance to bus terminals	-
Minimizing environmental impact	Forestry	City forests
		Seed orchads
		Gene conservation forests
		Protection forests
		Ramsar sites
		Wetland of local importance
		Nationally important wetlands
	Natural parks	-
	Nature conservation areas	-
	Natural monuments	-
	Biodiversity	Endemic species
		IUCN species
		Habitats under monitoring
Maximizing health and safety	Distance between NPP and city center	-
	Population density	Evacuation scenario
Optimizing socioeconomic impact	Immovable cultural heritage	-
	Population density	Job opportunity

Also these lotteries can be explained as follows;
"One is indifferent between the lotteries that states receiving R for certain or receiving R^* with probability p or receiving R_* with probability $1 - p$."
The assessment of the probability p is subjective and depends upon the logical comparison of the indifferent lotteries. The choice of p forms the utility function. It can be risk neutral, risk averse, or risk prone utility.
Risk neutral attitude indicates that the term R in the first lottery equals to the average of the best and worst values of the attribute and these lotteries are indifferent when $p = 0.5$. Then, the risk neutral attitude has a linear utility function;

$$U(x) = a + b * x \tag{3.3.2}$$

where x is an attribute in the NPP siting study and a and b are constants.
If two lotteries become indifferent in case of R equals to average of the best and worst values with utility equivalent $p > 1/2$, then the utility function has risk averse attitude and has a concave form. In this study, two different types of risk averse functions are considered, polynomial and exponential.
If two lotteries are indifferent when R equals to the average of the best and worst values with utility equivalent $p < 1/2$, then the utility function is risk prone and has a convex form. Similar to the risk averse functions, both polynomial and exponential utility forms are constructed and given below;

$$U(x) = a * x^2 + b * x + c \tag{3.3.3}$$

and

$$U(x) = a * exp(b * x) + c \tag{3.3.4}$$

where x represents an attribute and a,b and c are constants.
It is to be noted that the utility functions derived and the utility values computed from these functions are quite subjective and hypothetical to a certain extent. They are used for illustrative purposes in the case study and may not reflect the actual situation.

3.3.1 Probabilistic Seismic Hazard Analysis

Probabilistic Seismic Hazard Analysis (PSHA) combines information to produce an explicit description of the distribution of future shaking that may occur at a site [27].

Since there are several uncertainties in the size, location and resulting shaking intensity caused by an earthquake, PSHA is appropriate for the study.
In PSHA there are several components; one of these is the acceleration (g). Acceleration represents the changes in the velocity of an earthquake. Peak ground acceleration stands for the largest increase in velocity during an earthquake. It is a useful ground motion parameter in PSHA [28]. Another term related to the earthquake is the intensity. Intensity is the effect of an earthquake on the Earth's surface and it is a more meaningful measure of severity of an earthquake to the non-scientists [29]. Additionally, magnitude of an earthquake is also a common term which measures the energy released at the source of the earthquake [30]. There is a relationship among acceleration, intensity and magnitude of an earthquake. These relationships are illustrated in Table 3.3.1. The concept "return period" is the average waiting time for a specific acceleration in PSHA [28]. Another concept which is useful for PSHA is annual frequency of exceedance. It represents the expected number of exceedances in a year. Additionally, the ratio of annual rate of exceedance to annual occurence rate of an earthquake gives the probability of exceedance [27].

Table 3.3.1: Relationship among earthquake acceleration, magnitude and intensity [30, 29]

Instrumental intensity	Acceleration (g)	Magnitude	Perceived shaking	Potential damage
I	<0.0017	1.0-3.0	Not felt	None
II - III	0.0017-0.014	3.0-3.9	Weak	None
IV	0.014-0.039	4.0-4.9	Light	None
V	0.039-0.092	4.0-4.9	Moderate	Very light
VI	0.092-0.18	5.0-5.9	Strong	Light
VII	0.18-0.34	5.0-5.9	Very strong	Moderate
VIII	0.34-0.65	6.0-6.9	Severe	Moderate to heavy
IX	0.65-1.24	7.0 and higher	Violent	Heavy
X+	>1.24	7.0 and higher	Extreme	Very heavy

3.3.1.1 Data Collection for PSHA

One of the most important criteria for nuclear power plant site selection is the seismic potential of the corresponding region. IAEA suggests considering the seismic hazard analysis for the safety of the NPP. For this purpose, the data is collected using the following procedure below;

- For both of the candidate sites, Mersin-Akkuyu and Sinop-Abalı, the coordinates of the NPP are taken as the center and a circle with a 320 km radius is drawn in GoogleEarth Pro. Then, the coordinates of active fault lines are specified within this circle by using Geoscience MapViewer and Drawing Editor of General Directorate of Mineral Research and Exploration [31]. The general active fault map of Turkey is shown in Figure 3.3.1.

- The data on fault parameters like fault types (normal, strike slip, reverse etc.), fault depths (in km), expected maximum magnitudes (in moment magnitude) are obtained from Emre et. al. [32].

- By using the earthquake catalogue of Disaster and Emergency Management Presidency (AFAD) [33], the earthquakes occurred between the years 1900 and 2019 within a 320 km radius of the circle with NPP site as the center are compiled. In the catalogue the magnitudes other than moment magnitude, are converted to the moment magnitude by using the conversion equations [34] and only the earthquakes with moment magnitudes greater than or equal to four are considered.

- To construct a background seismic source, the coordinates of each active fault are determined and extended about fifty kilometers toward latitudes and rectangular regions are obtained. After that, the area which lies out of these rectangles is taken as the background seismic source.

Then, PSHA is conducted by using EZ-FRISK [35]. The output obtained from the analysis is presented in Appendix A and B.

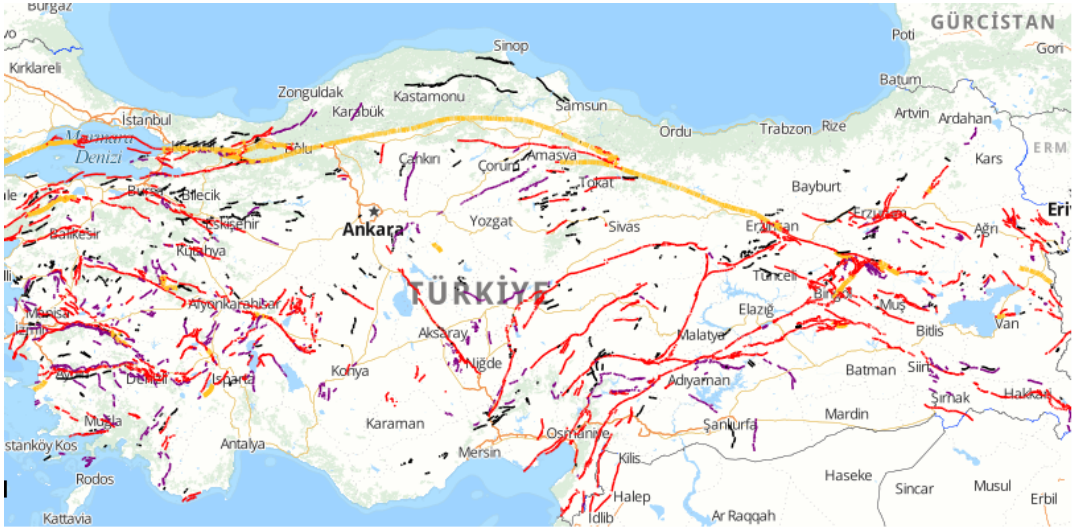

Figure 3.3.1: Active fault map of Turkey [31]

3.3.1.2 Probabilistic Seismic Hazard Analysis: Mersin-Akkuyu Site

Fifty six active faults are identified for the Mersin-Akkuyu NPP site. The peak ground acceleration (PGA) values for different return periods and the probabilities of exceeding a specified PGA (g) in a year are given in Table 3.3.2.

Table 3.3.2 indicates that, for return period of 2475 years, with an annual exceedance rate of 0.0004, with probability of exceedance 0.02 in 50 years, the PGA value is 0.1872g. For return period of 975 years, with an annual exceedance rate of 0.00102, with probability of exceedance 0.05 in 50 years, the PGA value is 0.137g. In addition to these, for return period of 475 years, with an annual exceedance rate of 0.0021, with probability of exceedance 0.1 in 50 years, the PGA value is 0.1079g.

Table 3.3.3 illustrates the PGA values with different return periods. For instance, for return period of 1 year, the PGA value is 0.0029g. Similarly, for return period of 50 years, the PGA value is 0.0445.

3.3.1.3 Probabilistic Seismic Hazard Analysis: Sinop-Abalı Site

Forty two active faults within the circle with 320 km radius with NPP site as the center are investigated in order to identify the seismic potential of Sinop-Abalı site. The results of seismic hazard analysis are given in Tables 3.3.4 and 3.3.5.

Table 3.3.4 shows the PGA values for different return periods, annual frequency of exceedance and probability of exceedance in fifty years. For return period of 2475 years, with an annual exceedance rate of 0.0004, with probability of exceedance 0.02 in fifty years, the PGA value is 0.1687. For return period of 975 years, with an annual exceedance rate of 0.00102, with probability of exceedance 0.05 in fifty years, the PGA value is 0.1250. Lastly, for return period of 475 years, with an annual exceedance rate of 0.0021, with probability of exceedance 0.1 in fifty years, the PGA value is 0.0989.
The PGA values for different return periods are obtained and presented in Table 3.3.5.

Table 3.3.2: PGA values corresponding to different rate of occurence criteria at Mersin-Akkuyu site

Return period (year)	Annual freq.of exceedance	prob. of exceedance in 50 years	PGA (g)
475	0.00210	0.10	0.1079
975	0.00102	0.05	0.1370
2475	0.00040	0.02	0.1872

Table 3.3.3: PGA values (g) for different return periods at Mersin-Akkuyu site

Return period (year)	PGA (g)
1	0.0029
5	0.01515
10	0.0216
15	0.0259
20	0.0295
25	0.0326
50	0.0445
100	0.0597
250	0.0854
500	0.1097
1000	0.1383
2500	0.1878
5000	0.2312
10000	0.2824

Table 3.3.4: PGA values corresponding to different rate of occurence criteria at Sinop-Abalı site

Return period (year)	Annual freq.of exceedance	prob. of exceedance in 50 years	PGA (g)
475	0.0021	0.1	0.0989
975	0.00102	0.05	0.1250
2475	0.0004	0.02	0.1687

Table 3.3.5: PGA values (g) for different return periods at Sinop-Abalı site

Return period (year)	PGA (g)
1	0.0023
5	0.0129
10	0.0183
15	0.0221
20	0.0252
25	0.0279
50	0.0383
100	0.0523
250	0.0765
500	0.1000
1000	0.1251
2500	0.1682
5000	0.2087
10000	0.2519

3.3.1.4 Utility Functions based on PSHA

In order to compare the seismic hazard levels of the candidate sites, a single-attribute utility function can be constructed by evaluating the acceleration levels of Mersin-Akkuyu and Sinop-Abalı sites since there is a relationship between the level of acceleration and its potential damage to the site.

The best and the worst levels of the PGA should be determined to assign utility values. According to Table 3.3.1, the acceleration values which are smaller than 0.0017g (correspond to the magnitude interval 1.0-3.0) cause no potential damage while, the acceleration values higher than 1.24g (correspond to the magnitude 7.0 or higher), may cause heavy damage. These two extreme values are taken as the best and the worst levels for the seismic hazard utility function, respectively.

Utility values are computed for the PGA values with return periods of 5000 and 10000 years. For the safety related structures or equipment of nuclear power plants, maximum ground motion should be considered and such an event has a return period of 10000 years [36]. For this reason, return periods of 5000 and 10000 years are used in this study. A summary of the levels of the seismic hazard utility function and corresponding data for the candidate sites are given in Table 3.3.6.

Three risk attitudes (risk neutral, risk averse and risk prone) which are mentioned in Chapter 2 are considered and utility functions are derived. (Table 3.3.7).

Table 3.3.6: Worst and best values of PGA and corresponding calculated PGA values for Mersin-Akkuyu and Sinop-Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
PGA (g) (5000 years)	1.24	0.001	0.2312	0.2087
PGA (g) (10000 years)	1.24	0.001	0.2824	0.2519

Table 3.3.7: Utility functions for seismic hazard attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having a PGA value of 0.6205g for certain. Lottery 2: Having a PGA value of 0.001g with probability 1/2 or having a PGA value of 1.24g with probability 1/2. Linear utility func.: $u(x) = 1.0008 - 0.8071 * x$
Risk Averse case:
Lottery 1: Having a PGA value of 0.65g for certain. Lottery 2: Having a PGA value of 1.24g with probability 0.25 or having a PGA value of 0.001g with probability 0.75. Polynomial utility func.: $u(x) = -0.7151 * x^2 + 0.0803 * x_1 + 0.9999$ Exponential utility func.: $u(x) = -1.234 * exp(0.4789 * x) + 2.234$
Risk prone case:
Lottery 1: Having a PGA value of 0.65g for certain. Lottery 2: Having a PGA value of 1.24g with probability 0.70 or having a PGA value of 0.001g with probability 0.3. Polynomial utility func.: $u(x) = 0.4601 * x^2 - 1.3781 * x + 1.0014$ Exponential utility func.: $u(x) = 2.168 * exp(-0.4994 * x) - 1.167$ where x denotes the PGA (g).

Table 3.3.8: Utility values for seismic hazard attribute under risk neutral, risk averse and risk prone cases

Return Period (year)	Attitude for utility function	Akkuyu site PGA (g)	Abalı site PGA (g)	Akkuyu site utility	Abalı site utility
5000	Risk neutral	0.2312	0.2087	0.8141	0.8323
10000	Risk neutral	0.2824	0.2519	0.7728	0.7974
5000	Risk averse-poly.	0.2312	0.2087	0.9802	0.9854
10000	Risk averse-poly.	0.2824	0.2519	0.9655	0.9747
5000	Risk averse-expo.	0.2312	0.2087	0.8555	0.8702
10000	Risk averse-expo.	0.2824	0.2519	0.8213	0.8417
5000	Risk prone-poly.	0.2312	0.2087	0.7073	0.7337
10000	Risk prone-poly.	0.2824	0.2519	0.6489	0.6834
5000	Risk prone-expo.	0.2312	0.2087	0.7645	0.7863
10000	Risk prone-expo.	0.2824	0.2519	0.7158	0.7447

3.3.2 Utility Evaluation of Tsunami Hazard

Tsunami hazard is one of the most important criteria for nuclear power plant siting study. Candidate sites Mersin-Akkuyu and Sinop-Abalı are on the coast of the Mediterranean Sea and the Black Sea, respectively, because of the necessity of cooling water source. In case of a tsunami, the primary effect of the waves on a plant site is flooding and loss of cooling water. Thus, tsunami hazard is also evaluated in this study in terms of tsunami runup height for the candidate sites.
Given in Table 3.3.9 are the maximum (worst) and the minimum (best) levels of the attribute runup height observed in Mediterranean and Black Sea and the runup height values of candidate sites for 5000 years return period (Prof. Dr. A.C. Yalçıner, 2019). Based on risk neutral, risk averse and risk prone cases, the utility functions are obtained and illustrated in Table 3.3.10.
Utility values for the tsunami hazard attribute are calculated and presented in Table 3.3.11.

Table 3.3.9: Worst and best values for tsunami hazard and runup heights for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Tsunami runup height (in meters)	7.5	1.0	6.75	4.5

3.3.3 Utility Evaluation of Extreme Wind Hazard

Extreme wind is another important natural hazard to be considered in NPP site selection. Wind speed should be investigated due to the safety of tall structures like cooling towers, transmission line towers etc. [37]. Also extreme wind events may affect the power supply and the combination of such a hazard with other natural hazards like heavy rain, extremely low or high temperatures may have negative impact on the NPP and its vicinity [38]. It is recommended that a nuclear reactor should be shut down at least two hours before strong winds arrive the nuclear power plant site. The threshold

Table 3.3.10: Utility functions for tsunami hazard attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having 4.25 m of runup height for certain. Lottery 2: Having 7.5 m of runup height with probability 1/2 or 1 m of runup height with probability 1/2. Linear utility func.: $u(x) = 1.1538 - 0.1538 * x$
Risk Averse case:
Lottery 1: Having 5 m of runup height for certain. Lottery 2: Having 7.5 m of runup height with probability 0.4 or having 1 m of runup height with probability 0.6. Polynomial utility func.: $u(x) = -0.0215 * x^2 + 0.0292 * x + 0.9923$ Exponential utility func.: $u(x) = -0.1475 * exp(0.279 * x) + 1.195$
Risk prone case:
Lottery 1: Having 5 m of runup height for certain. Lottery 2: Having 7.5 m of runup height with probability 0.80 or having 1 m of runup height with probability 0.2. Polynomial utility func.: $u(x) = 0.0185 * x^2 - 0.3108 * x + 1.2923$ Exponential utility func.: $u(x) = 1.582 * exp(-0.2728 * x) - 0.2046$ where x denotes the runup height (m).

speed for this precaution is 121 km per hour [39].

Wind speed data for candidate sites is obtained from various sources. Maximum wind speed for Mersin-Akkuyu site is calculated by taking the average of annual maximum wind speed data between 1975 and 2009 [40]. For Sinop-Abalı site, the maximum wind speed data between the years 1960 and 2016 are utilized [41]. A decreasing utility function is appropriate for extreme wind hazard attribute. The best value is taken as the average of annual wind speeds for Akkuyu and Abalı sites. The worst value is determined under the information mentioned above. Utility functions are presented in Table 3.3.13 and Table 3.3.14 shows the utility values of the candidate sites for the extreme wind hazard attribute.

Table 3.3.11: Utility values of tsunami hazard attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Runup height (m)	Risk neutral	6.75	4.5	0.1156	0.4617
	Risk averse-poly.	6.75	4.5	0.2098	0.6883
	Risk averse-expo.	6.75	4.5	0.2252	0.6773
	Risk prone-poly.	6.75	4.5	0.0373	0.2683
	Risk prone-expo.	6.75	4.5	0.0462	0.2589

Table 3.3.12: Worst and best values of extreme wind hazard attribute and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Wind speed (km/hr)	140	10.5	79.85	135.72

3.3.4 Forestry

The forestry criterion is evaluated under seven subcategories; city forests, seed orchads, gene conservation forests, protection forests, Ramsar sites, wetland of local importance and nationally important wetlands [42]. Another related criteria can be the number of national parks. However, since both of the cities where candidate sites are located has no national parks [42], they are not considered in this study. Seed orchads are places that are used for seed production with high quality. Gene conservation forests protect the genetic diversity in their natural environment. Protection forests consist of forests that prevent landslide prone areas from landslide or prevent regions from sand or dust storms. Ramsar sites are special kind of wetlands which are specified within Ramsar Convention. These areas are especially important for waterfowls. In addition, nationally important wetlands are crucial for the continuity of the ecological environment and genetic diversity. Wetlands that are not listed in the nationally important wetlands and Ramsar sites can be listed in the wetland of local importance.

For the analysis, in addition to the number of city forests, seed orchads etc., per-

Table 3.3.13: Utility functions of extreme wind hazard attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having a wind speed of 75.25 km/hr for certain. Lottery 2: Having a wind speed of 140 km/hr with probability 1/2 or having a wind speed of 10.5 km/hr with probability 1/2. Linear utility func.: $u(x) = 1.0811 - 0.0077 * x$
Risk Averse case:
Lottery 1: Having a wind speed of 80 km/hr for certain. Lottery 2: Having a wind speed of 140 km/hr with probability 0.25 or having a wind speed of 10.5 km/hr with probability 0.75. Polynomial utility func.: $u(x) = -7 * 10^{-5} * x^2 + 0.0026 * x + 0.98$ Exponential utility func.: $u(x) = -7.056 * 10^{-2} * exp(1.953 * 10^{-2} * x) + 1.087$
Risk prone case:
Lottery 1: Having a wind speed of 80 km/hr for certain. Lottery 2: Having a wind speed of 140 km/hr with probability 0.65 or having a wind speed of 10.5 km/hr with probability 0.35. Polynomial utility func.: $u(x) = 3 * 10^{-5} * x^2 - 0.0118 * x + 1.121$ Exponential utility func.: $u(x) = 1.772 * exp(-7.249 * 10^{-3} * x) - 0.6424$ where x denotes the wind speed (km/hour).

centage area of them in the corresponding totals in Turkey are also considered. For instance, the percentage area of city forests of candidate provinces in the total area of city forests in Turkey are used as an attribute value.
Related data is obtained from the Ministry of Agriculture and Forestry, Directorate of Nature Conservation and National Parks [42]. Information about city forests, seed orchards, gene conservation forests, protection forests, Ramsar sites, wetland of local importance and nationally important wetlands are investigated and the number of corresponding places and their area (in km square) are recorded.
Table 3.3.15 shows the worst and best levels for the number of categories of forestry and relevant data for the candidate sites. The forestry data for Turkey is examined

Table 3.3.14: Utility values of extreme wind hazard attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Wind speed (km/hr)	Risk neutral	79.85	135.72	0.4662	0.036
	Risk averse-poly.	79.85	135.72	0.7413	0.0434
	Risk averse-expo.	79.85	135.72	0.7274	0.0163
	Risk prone-poly.	79.85	135.72	0.3700	0.0721
	Risk prone-expo.	79.85	135.72	0.3509	0.0201

and the minimum and maximum number of corresponding categories are taken as the best and worst values, respectively.

Table 3.3.15: Worst and best values in terms of number of forestry in Turkey and related data for Akkuyu and Abalı sites

Subcategories of Forestry	Worst value (number)	Best value (number)	Akkuyu site	Abalı site
City forests	12	0	1	2
Seed orchads	18	0	6	2
Gene conservation forests	24	0	21	15
Protection forests	6	0	1	0
Ramsar sites	2	0	1	0
Wetlands of local importance	2	0	0	1
Nationally important wetlands	7	0	1	0

Evaluation of the number of forests alone may not reflect the possible loss in forests. For this reason, the percentage area of forests for candidate sites to total area of forests in Turkey is investigated. Similar to the determination of the best and worst levels of number of forestry, percentages for all provinces in Turkey are computed and the maximum and minimum values of percent area of forests are chosen as the worst and best levels for the relevant subcategory, respectively. The worst, best levels of the subcategories and the corresponding data are given in Table 3.3.16.

Table 3.3.16: Worst and best values for percentage area of forestry attribute and related data for Akkuyu and Abalı sites

Subcategories of Forestry	Worst value (% area)	Best value (% area)	Akkuyu Site (% area)	Abalı site (% area)
City forests	17.1783	0.0000	1.0633	0.4353
Seed orchads	16.0259	0.0000	3.9039	0.8684
Gene conservation forests	7.1575	0.0000	7.1575	4.0429
Protection forests	29.0031	0.0000	1.1529	0.0000
Ramsar sites	18.7292	0.0000	8.1306	0.0000
Wetlands of local importance	56.1858	0.0000	0.0000	8.0265
Nationally important wetlands	18.7789	0.0000	0.1262	0.0000

3.3.4.1 Utility Evaluation of City Forests

For the attribute city forests, three attitudes toward risk are considered and utility functions are constructed for each of the attitude.

Utility Evaluation of Number of City Forests:

Table 3.3.17 and 3.3.18 shows the utility functions and corresponding utility values of the candidate sites for the number of city forests, respectively.

Utility Evaluation of City Forests in terms of Percentage Area:

Utility functions for the percentage area of city forests are constructed and shown in Table 3.3.19. Also, utility values are found for the candidate sites Mersin-Akkuyu and Sinop-Abalı and given in Table 3.3.20.

3.3.4.2 Utility Evaluation of Seed Orchads

Utility Evaluation of Number of Seed Orhads:

The number of seed orchads evaluated according to three different risk attitudes and utility functions are given in Table 3.3.21. The utility values for the candidates sites are calculated and presented in Table 3.3.22.

Utility Evaluation of Seed Orchads in terms of Percentage Area:

In this part, the percentage area of seed orchads of the candidate sites are evaluated

Table 3.3.17: Utility functions for forestry-city forests attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1:Losing 6 city forests for certain. Lottery 2: Losing 12 city forests with probability 0.5 or losing 0 city forest with probability 0.5 Linear utility func.: $u(x) = 1 - 0.0833 * x$
Risk Averse case:
Lottery 1: Losing 7 city forests for certain. Lottery 2: Losing 12 city forests with probability 0.45 or 0 city forest with probability 0.55. Polynomial utility func.: $u(x) = -0.0038 * x^2 - 0.0376 * x + 1$ Exponential utility func.: $u(x) = -0.506 * exp(0.09089 * x) + 1.506$
Risk prone case:
Lottery 1: Losing 5 city forests for certain. Lottery 2:Losing 12 city forests with probability 0.6 or 0 city forest with probability 0.4. Polynomial utility func.: $u(x) = 0.0052 * x^2 - 0.1462 * x + 1$ Exponential utility func.: $u(x) = 1.282 * exp(-0.1263 * x) - 0.2816$ where x denotes the number of city forests.

Table 3.3.18: Utility values of forestry-city forests attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of city forests	Risk neutral	1	2	0.9167	0.8334
	Risk averse-poly.	1	2	0.9586	0.9096
	Risk averse-expo.	1	2	0.9518	0.8991
	Risk prone-poly.	1	2	0.859	0.7284
	Risk prone-expo.	1	2	0.8482	0.7142

Table 3.3.19: Utility functions for forestry-city forests attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 8.5891% of city forests for certain. Lottery 2: Losing 17.1783% of city forests with probability 1/2 or losing 0% of city forests with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0582 * x$
Risk Averse case:
Lottery 1: Losing 7.6601% of city forests for certain. Lottery 2: Losing 17.1783% of city forests with probability 0.35 or 0% of city forests with probability 0.65. Polynomial utility func.: $u(x) = -0.0013 * x^2 - 0.0356 * x + 1$ Exponential utility func.: $u(x) = -0.8189 * exp(0.04645 * x) + 1.819$
Risk prone case:
Lottery 1: Losing 7.6601% of city forests for certain. Lottery 2: Losing 17.1783% of city forests with probability 0.55 or 0% of city forests with probability 0.45. Polynomial utility func.: $u(x) = 0.0014 * x^2 - 0.0827 * x + 1$ Exponential utility func.: $u(x) = 1.757 * exp(-0.04902 * x) - 0.7569$
where x denotes the percentage area of city forests.

Table 3.3.20: Utility values of % area of forestry-city forests attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
% area of city forests	Risk neutral	1.0633	0.4353	0.9381	0.9746
	Risk averse-poly.	1.0633	0.4353	0.9606	0.9842
	Risk averse-expo.	1.0633	0.4353	0.9586	0.9833
	Risk prone-poly.	1.0633	0.4353	0.9136	0.9642
	Risk prone-expo.	1.0633	0.4353	0.9108	0.963

Table 3.3.21: Utility functions of number of forestry-seed orhads attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 9 seed orchads for certain. Lottery 2: Losing 18 seed orchads with 1/2 probability or losing 0 seed orchad with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.0556 * x$
Risk Averse case:
Lottery 1: Losing 8 seed orchads for certain. Lottery 2: Losing 18 seed orchads with probability 0.4 or losing 0 seed orchad with probability 0.6. Polynomial utility func.: $u(x) = -0.0006 * x^2 - 0.0456 * x + 1$ Exponential utility func.: $u(x) = -2.282 * exp(0.02019 * x) + 3.282$
Risk prone case:
Lottery 1:Losing 8 seed orchads for certain. Lottery 2:Losing 18 seed orchads with probability 0.55 or losing 0 seed orchad with probability 0.45. Polynomial utility func.: $u(x) = 0.0013 * x^2 - 0.0793 * x + 1$ Exponential utility func.: $u(x) = 1.741 * exp(-0.04746 * x) - 0.7408$ where x denotes the number of seed orchads.

Table 3.3.22: Utility values of number of forestry-seed orchads attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of seed orchads	Risk neutral	6	2	0.6664	0.8888
	Risk averse-poly.	6	2	0.7048	0.9064
	Risk averse-expo.	6	2	0.7061	0.9059
	Risk prone-poly.	6	2	0.571	0.8466
	Risk prone-expo.	6	2	0.5687	0.8425

Table 3.3.23: Utility functions of % area of forestry-seed orchads attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 8.0129% of seed orchads for certain. Lottery 2: Losing 16.0259% of seed orchads with probability 1/2 or losing 0% of seed orchads with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0624 * x$
Risk Averse case:
Lottery 1: Losing 7.1704% of seed orchads for certain. Lottery 2: Losing 16.0259% of seed orchads with probability 0.35 or 0% of seed orchads with probability 0.65. Polynomial utility func.: $u(x) = -0.0015 * x^2 - 0.0378 * x + 1$ Exponential utility func.: $u(x) = -0.8011 * exp(0.05055 * x) + 1.801$
Risk prone case:
Lottery 1: Losing 7.1704% of seed orchads for certain . Lottery 2: Losing 16.0259% of seed orchads with probability 0.55 or 0% of seed orchads with probability 0.45. Polynomial utility func.: $u(x) = 0.0016 * x^2 - 0.0883 * x + 1$ Exponential utility func.: $u(x) = 1.774 * exp(-0.05176 * x) - 0.7739$ where x denotes the percentage area of seed orchads.

for three risk attitudes. Utility functions and the corresponding utility values for the candidate sites are presented Tables 3.3.23 and 3.3.24.

Table 3.3.24 shows that Sinop-Abalı site has higher utility value than Mersin-Akkuyu site for all risk attitudes.

3.3.4.3 Utility Evaluation of Gene Conservation Forests

Utility Evaluation of Number of Gene Conservation Forests:
Utility functions are constructed and provided in Table 3.3.25.

Table 3.3.24: Utility values of % area of forestry-seed orchads attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site (%)	Abalı site (%)	Akkuyu site utility	Abalı site utility
% area of seed orchads	Risk neutral	3.9039	0.8684	0.7563	0.9458
	Risk averse-poly.	3.9039	0.8684	0.8295	0.9660
	Risk averse-expo.	3.9039	0.8684	0.7061	0.9059
	Risk prone-poly.	3.9039	0.8684	0.6796	0.9245
	Risk prone-expo.	3.9039	0.8684	0.6755	0.9221

Utility values for the number of gene conservation forests are given in Table 3.3.26.

Utility Evaluation of Gene Conservation Forests in terms of Percentage Area:
The utility functions for the percentage area of gene conservation forests is evaluated and illustrated in Table 3.3.27. Table 3.3.28 shows the utility values for the candidate sites.

As it is seen from Table 3.3.28, Mersin-Akkuyu site has utility value of zero since it has the highest percentage area of gene conservation forests in Turkey.

3.3.4.4 Utility Evaluation of Protection Forests

Utility Evaluation of Number of Protection Forests:
Table 3.3.29 illustrates the utility functions assessed for the number of protection forests. After constructing utility functions, utility values for the candidate sites are summarized in Table 3.3.30.

Utility Evaluation of % area of Protection Forests:
Utility functions are constructed for the % area of protection forests and presented in Table 3.3.31. The corresponding utility values for the candidate sites under risk neutral, risk averse and prone cases are demonstrated in Table 3.3.32.

Table 3.3.25: Utility functions for the number of forestry-gene conservation forests attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 12 gene conservation forests for certain. Lottery 2: Losing 24 gene conservation forests with 1/2 probability or losing 0 gene conservation forest with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.0417 * x$
Risk Averse case:
Lottery 1: Losing 11 gene conservation forests for certain. Lottery 2: Losing 24 gene conservation forests with probability 0.25 or 0 gene conservastion forest with probability 0.75. Polynomial utility func.: $u(x) = -0.0015 * x^2 - 0.0067 * x + 1$ Exponential utility func.: $u(x) = -0.1888 * exp(0.0766 * x) + 1.189$
Risk prone case:
Lottery 1: Losing 11 gene conservation forests for certain. Lottery 2: Losing 24 gene conservation forests with probability 0.6 or 0 gene conservation forest with probability 0.4 Polynomial utility func.: $u(x) = 0.001 * x^2 - 0.0654 * x + 1$ Exponential utility func.: $u(x) = 1.46 * exp(-0.04809 * x) - 0.4605$ where x denotes the number of gene conservation forests.

Table 3.3.26: Utility values of number of forestry-gene conservation forests attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
number of gene conservation forests	Risk neutral	21	15	0.1243	0.3745
	Risk averse-poly.	21	15	0.1978	0.562
	Risk averse-expo.	21	15	0.2446	0.5927
	Risk prone-poly.	21	15	0.0676	0.244
	Risk prone-expo.	21	15	0.0713	0.2491

Table 3.3.27: Utility functions of % area forestry-gene conservation forests attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 3.5787% of gene conservation forests for certain. Lottery 2: Losing 7.1575% of gene conservation forests with probability 1/2 or losing 0% of gene conservation forests with probability 1/2. Linear utility func.: $u(x) = 1 - 0.1397 * x$
Risk Averse case:
Lottery 1: Losing 2.3757% of gene conservation forests for certain. Lottery 2: Losing 7.1575% of gene conservation forests with probability 0.25 or losing 0% of gene conservation forests with probability 0.75. Polynomial utility func.: $u(x) = -0.0072 * x^2 - 0.0881 * x + 1$ Exponential utility func.: $u(x) = -0.8446 * exp(0.1091 * x) + 1.845$
Risk prone case:
Lottery 1: Losing 2.3757% of gene conservation forests for certain. Lottery 2: Losing 7.1575% of gene conservation forests with probability 0.55 or losing 0% of gene conservation forests with probability 0.45. Polynomial utility func.: $u(x) = 0.0192 * x^2 - 0.2771 * x + 1$ Exponential utility func.: $u(x) = 1.176 * exp(-0.2674 * x) - 0.1759$ where x denotes the percent area of gene conservation forests.

Table 3.3.28: Utility values of % area of forestry-gene conservation forests attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site (%)	Abalı site (%)	Akkuyu site utility	Abalı site utility
% area of gene conservation forests	Risk neutral	7.1575	4.0429	0	0.4352
	Risk averse-poly.	7.1575	4.0429	0	0.5261
	Risk averse-expo.	7.1575	4.0429	0	0.5321
	Risk prone-poly.	7.1575	4.0429	0	0.1935
	Risk prone-expo.	7.1575	4.0429	0	0.223

Table 3.3.29: Utility functions of number of forestry-protection forests attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 3 protection forests for certain. Lottery 2: Losing 6 protection forests with 1/2 probability or losing 0 protection forest with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.1667 * x$
Risk Averse case:
Lottery 1: Losing 2 protection forests for certain. Lottery 2: Losing 6 protection forests with probability 0.3 or 0 protection forest with probability 0.7. Polynomial utility func.: $u(x) = -0.0042 * x^2 - 0.1417 * x + 1$ Exponential utility func.: $u(x) = -2.797 * exp(0.05095 * x) + 3.797$
Risk prone case:
Lottery 1: Losing 2 protection forests for certain. Lottery 2: Losing 6 protection forests with probability 0.6 or 0 protection forest with probability 0.4 Polynomial utility func.: $u(x) = 0.0333 * x^2 - 0.3667 * x + 1$ Exponential utility func.: $u(x) = 1.106 * exp(-0.3911 * x) - 0.1058$ where x denotes the number of protection forests.

Table 3.3.30: Utility values of number of forestry-protection forests attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
number of protection forests	Risk neutral	1	0	0.8333	1
	Risk averse-poly.	1	0	0.8541	1
	Risk averse-expo.	1	0	0.8538	1
	Risk prone-poly.	1	0	0.6666	1
	Risk prone-expo.	1	0	0.6422	1

Table 3.3.31: Utility functions of % area of forestry-protection forests attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 14.5015% of protection forests for certain. Lottery 2: Losing 29.0031% of protection forests with probability 1/2 or losing 0% of protection forests with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0345 * x$
Risk Averse case:
Lottery 1: Losing 7.9516% of protection forests for certain. Lottery 2: Losing 29.0031% of protection forests with probability 0.25 or losing 0% of protection forest with probability 0.75. Polynomial utility func.: $u(x) = -10^{-4} * x^2 - 0.0303 * x + 1$ Exponential utility func.: $u(x) = -3.557 * exp(0.008541 * x) + 4.557$
Risk prone case:
Lottery 1: Losing 7.9516% of protection forests for certain. Lottery 2: Losing 29.0031% of protection forests with probability 0.45 or losing 0% of protection forest with probability 0.55. Polynomial utility func.: $u(x) = 0.0011 * x^2 - 0.0649 * x + 1$ Exponential utility func.: $u(x) = 1.239 * exp(-0.05677 * x) - 0.2387$ where x denotes the percent area of protection forests.

Table 3.3.32: Utility values of % area of forestry-protection forests attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site (%)	Abalı site (%)	Akkuyu site utility	Abalı site utility
% area of protection forests	Risk neutral	1.1529	0	0.96022	1
	Risk averse-poly.	1.1529	0	0.9649	1
	Risk averse-expo.	1.1529	0	0.9648	1
	Risk prone-poly.	1.1529	0	0.9266	1
	Risk prone-expo.	1.1529	0	0.9218	1

3.3.4.5 Utility Evaluation of Ramsar Sites

Utility Evaluation of Number of Ramsar Sites: The number of Ramsar sites is evaluated in this part of the study. The utility functions are constructed and presented in Table 3.3.33. The corresponding utility values for the candidate sites are provided in Table 3.3.34.

Utility Evaluation of Ramsar Sites in terms of Percentage Area: The area of the Ramsar sites is investigated in this part. Risk neutral, risk averse and risk prone utility functions are summarized in Table 3.3.35. The utility values for Mersin-Akkuyu and Sinop-Abalı sites are presented in Table 3.3.36.

3.3.4.6 Utility Evaluation of Wetlands of Local Importance

The number and percentage area of wetlands of local importance is evaluated in the NPP siting study.
Utility Evaluation of Number of Wetlands of Local Importance:
The utility functions are assessed and shown in Table 3.3.37.

Utility values for Akkuyu and Abalı sites are calculated by using the functions given in Table 3.3.37 and presented in Table 3.3.38. It is seen from the table that Akkuyu site does not have any wetland of local importance so it takes the highest utility, which is 1.0, in the evaluation of the attribute.

Table 3.3.33: Utility functions of the number of forestry-Ramsar sites attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 1 Ramsar site for certain. Lottery 2: Losing 2 Ramsar sites with 1/2 probability or losing 0 Ramsar site with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.5 * x$
Risk Averse case:
Lottery 1: Losing 1 Ramsar site for certain. Lottery 2: Losing 2 Ramsar sites with probability 0.45 or losing 0 Ramsar site with probability 0.55. Polynomial utility func.: $u(x) = -0.05 * x^2 - 0.4 * x + 1$ Exponential utility func.: $u(x) = -2.025 * exp(0.2007 * x) + 3.025$
Risk prone case:
Lottery 1: Losing 1 Ramsar site for certain. Lottery 2: Losing 2 Ramsar sites with probability 0.55 or losing 0 Ramsar site with probability 0.45. Polynomial utility func.: $u(x) = 0.05 * x^2 - 0.6 * x + 1$ Exponential utility func.: $u(x) = 3.025 * exp(-0.2007 * x) - 2.025$ where x denotes the number of Ramsar sites.

Table 3.3.34: Utility values of number of forestry-Ramsar sites attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of Ramsar sites	Risk neutral	1	0	0.5000	1
	Risk averse-poly.	1	0	0.5500	1
	Risk averse-expo.	1	0	0.5499	1
	Risk prone-poly.	1	0	0.4500	1
	Risk prone-expo.	1	0	0.4499	1

Table 3.3.35: Utility functions of % area of forestry-Ramsar sites attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: : Losing 9.3646% of Ramsar sites for certain. Lottery 2: : Losing 18.7292% of Ramsar sites with probability 1/2 or losing 0% of Ramsar sites with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0534 * x$
Risk Averse case:
Lottery 1: Losing 8.1306% of Ramsar sites for certain. Lottery 2: Losing 18.7292% of Ramsar sites with probability 0.25 or losing 0% of Ramsar site with probability 0.75. Polynomial utility func.: $u(x) = -0.0021 * x^2 - 0.0134 * x + 1$ Exponential utility func.: $u(x) = -0.2413 * exp(0.08745 * x) + 1.241$
Risk prone case:
Lottery 1: Losing 8.1306% of Ramsar sites for certain. Lottery 2: Losing 18.7292% of Ramsar sites with probability 0.65 or losing 0% of Ramsar site with probability 0.35. Polynomial utility func.: $u(x) = 0.0025 * x^2 - 0.1003 * x + 1$ Exponential utility func.: $u(x) = 1.197 * exp(-0.09629 * x) - 0.1972$ where x denotes the percent area of Ramsar sites.

Table 3.3.36: Utility values of % area of forestry-Ramsar sites attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site (%)	Abalı site (%)	Akkuyu site utility	Abalı site utility
% area of Ramsar sites	Risk neutral	8.1306	0	0.5658	1
	Risk averse-poly.	8.1306	0	0.7522	1
	Risk averse-expo.	8.1306	0	0.7496	1
	Risk prone-poly.	8.1306	0	0.3497	1
	Risk prone-expo.	8.1306	0	0.3499	1

Table 3.3.37: Utility functions of number of forestry-wetlands of local importance attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 1 wetland of local importance for certain. Lottery 2: Losing 2 wetlands of local importance with 1/2 probability or losing 0 wetland of local importance with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.5 * x$
Risk Averse case:
Lottery 1: Losing 1 wetland of local importance for certain. Lottery 2: Losing 2 wetlands of local importance with probability 0.45 or losing 0 wetland of local importance with probability 0.55. Polynomial utility func.: $u(x) = -0.05 * x^2 - 0.4 * x + 1$ Exponential utility func.: $u(x) = -2.025 * exp(0.2007 * x) + 3.025$
Risk prone case:
Lottery 1: Losing 1 wetland of local importance for certain. Lottery 2: Losing 2 wetlands of local importance with probability 0.55 or losing 0 wetland of local importance with probability 0.45. Polynomial utility func.: $u(x) = 0.05 * x^2 - 0.6 * x + 1$ Exponential utility func.: $u(x) = 3.025 * exp(-0.2007 * x) - 2.025$ where x denotes the number of wetland of local importance.

Table 3.3.38: Utility values of number of forestry-wetlands of local importance attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
number of wetland of local importance	Risk neutral	0	1	1	0.5000
	Risk averse-poly.	0	1	1	0.5500
	Risk averse-expo.	0	1	1	0.5499
	Risk prone-poly.	0	1	1	0.4500
	Risk prone-expo.	0	1	1	0.4499

Table 3.3.39: Utility functions of % area forestry-wetlands of local importance attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 28.0929% of wetlands of local importance for certain. Lottery 2: Losing 56.1858% of wetlands of local importance with probability 1/2 or losing 0% of wetlands of local importance with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0178 * x$
Risk Averse case:
Lottery 1: Losing 21.1225% of wetlands of local importance for certain. Lottery 2: Losing 56.1858% of wetlands of local importance with probability 0.3 or 0% of wetlands of local importance with probability 0.7. Polynomial utility func.: $u(x) = -10^{-4} * x^2 - 0.012 * x + 1$ Exponential utility func.: $u(x) = -1.044 * exp(0.01195 * x) + 2.044$
Risk prone case:
Lottery 1: Losing 21.1225% of wetlands of local importance for certain. Lottery 2: Losing 56.1858% of wetlands of local importance with probability 0.6 or 0% of wetlands of local importance with probability 0.4. Polynomial utility func.: $u(x) = 3 * 10^{-4} * x^2 - 0.0348 * x + 1$ Exponential utility func.: $u(x) = 1.176 * exp(-0.033785 * x) - 0.1763$ where x denotes the percent area of wetland of local importance.

Utility Evaluation of Wetlands of Local Importance in terms of Percentage Area: The utility functions for the percentage area of wetlands of local importance are found and pointed out in Table 3.3.39.

Table 3.3.40 shows the corresponding utility values for the candidate sites, Akkuyu and Abalı.

Table 3.3.40: Utility values of % area of forestry-wetlands of local importance attribute under risk neutral,risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site (%)	Abalı site (%)	Akkuyu site utility	Abalı site utility
% area of wetlands of local importance	Risk neutral	0	8.0265	1	0.8571
	Risk averse-poly.	0	8.0265	1	0.8972
	Risk averse-expo.	0	8.0265	1	0.8949
	Risk prone-poly.	0	8.0265	1	0.74
	Risk prone-expo.	0	8.0265	1	0.7204

3.3.4.7 Utility Evaluation of Nationally Important Wetlands

Both the number and percentage area of nationally important wetlands are investigated.

Utility Evaluation of Number of Nationally Important Wetlands:
Utility functions are constructed and presented in Table 3.3.41.

Utility values are computed using utility functions described in Table 3.3.41 and presented in Table 3.3.42. As it is seen from Table 3.3.42, Sinop province does not have any nationally important wetlands so it takes the highest utility value 1.0 in the evaluation of this attribute.

Utility Evaluation of Nationally Important Wetlands in terms of Percentage Area:
Utility functions for three risk attitudes are obtained and shown in Table 3.3.43. The resulting utility values of Mersin-Akkuyu and Sinop-Abalı sites for percent area of nationally important wetlands attribute are provided in Table 3.3.44.

3.3.5 Natural Parks

Natural parks are places that people rest and enjoy the beauty of the scene and fresh air. Such places may be destroyed in order to construct new roads for the transportation of huge materials used in nuclear power plant construction. In addition to this, these parks may vanish in case of an NPP accident. Thus, the number of natural parks

Table 3.3.41: Utility functions of number of forestry-nationally important wetlands attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 3.5 nationally important wetlands for certain. Lottery 2: Losing 7 nationally important wetlands with 1/2 probability or losing 0 nationally important wetland with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.1419 * x$
Risk Averse case:
Lottery 1: Losing 3 nationally important wetlands for certain. Lottery 2: Losing 7 nationally important wetlands with probability 0.3 or losing 0 nationally important wetland with probability 0.7 Polynomial utility func.: $u(x) = -0.0107 * x^2 - 0.0679 * x + 1$ Exponential utility func.: $u(x) = -0.4954 * exp(0.1578 * x) + 1.495$
Risk prone case:
Lottery 1: Losing 3 nationally important wetlands for certain. Lottery 2: Losing 7 nationally important wetlands with probability 0.6 or losing 0 nationally important wetland with probability 0.4. Polynomial utility func.: $u(x) = 0.0143 * x^2 - 0.2429 * x + 1$ Exponential utility func.: $u(x) = 1.323 * exp(-0.2014 * x) - 0.3231$ where x denotes the number of nationally important wetlands.

Table 3.3.42: Utility values of number of forestry-nationally important wetlands under risk neutral,risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
number of nationally important wetlands	Risk neutral	1	0	0.8581	1
	Risk averse-poly.	1	0	0.9214	1
	Risk averse-expo.	1	0	0.9149	1
	Risk prone-poly.	1	0	0.7714	1
	Risk prone-expo.	1	0	0.7585	1

Table 3.3.43: Utility functions of % area forestry-nationally important wetlands attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 9.3894% of nationally important wetlands for certain. Lottery 2: Losing 18.7789% of nationally important wetlands with probability 1/2 or losing 0& of nationally important wetlands with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0533 * x$
Risk Averse case:
Lottery 1: Losing 5.1888% of nationally important wetlands for certain. Lottery 2: Losing 18.7789% of nationally important wetlands with probability 0.25 or 0% of nationally important wetlands with probability 0.75. Polynomial utility func.: $u(x) = -4 * 10^{-4} * x^2 - 0.0462 * x + 1$ Exponential utility func.: $u(x) = -3.242 * exp(0.01432 * x) + 4.242$
Risk prone case:
Lottery 1: Losing 5.1888% of nationally important wetlands for certain. Lottery 2: Losing 18.7789% of nationally important wetlands with probability 0.55 or losing 0% of nationally important wetlands with probability 0.45. Polynomial utility func.: $u(x) = 0.0039 * x^2 - 0.1261 * x + 1$ Exponential utility func.: $u(x) = 1.083 * exp(-0.1366 * x) - 0.08337$ where x denotes the percent area of nationally important wetlands.

Table 3.3.44: Utility values of % area of forestry-nationally important wetlands under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
% area of nationally important wetlands	Risk neutral	0.1262	0	0.9932	1
	Risk averse-poly.	0.1262	0	0.9941	1
	Risk averse-expo.	0.1262	0	0.9941	1
	Risk prone-poly.	0.1262	0	0.9841	1
	Risk prone-expo.	0.1262	0	0.9811	1

is considered for the NPP siting study. The percentage area of them in the total area of natural parks is also evaluated. The information arising from the results of utility functions is synthesized.

The data for natural parks is obtained from the Ministry of Agriculture and Forestry, Directorate of Nature Conservation and National Parks [42]. The minimum (the best) and maximum (the worst) values are determined by examining the corresponding data for Turkey.

Table 3.3.45 shows the maximum and minimum number of natural parks in Turkey. These are considered as the worst and best levels of the attribute, respectively in utility evaluation.

The worst and best levels for the percentage area of natural parks are determined by ranking the percentage areas of natural parks of all cities in Turkey. The minimum percentage is taken as the best value, which is 0, whereas the maximum percentage of area is taken as the worst. Mersin-Akkuyu and Sinop-Abalı sites are evaluated according to these values and the results are given in Table 3.3.46.

Table 3.3.45: Worst and best values for natural parks in Turkey and the number of natural parks in Mersin and Sinop cities.

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Number of natural parks	26	0	9	4

Table 3.3.46: Worst and best values for percentage area of natural parks in Turkey and number of natural parks in Mersin and Sinop cities.

Criteria	Worst value	Best value	Akkuyu site	Abalı site
% of natural parks	19.1987	0	0.1708	0.5591

Utility Evaluation of Number of Natural Parks:

Utility functions are constructed for risk neutral, averse and prone cases and presented in Table 3.3.47. The corresponding utility values for the candidate sites are provided in Table 3.3.48.

Utility Evaluation of Natural Parks in terms of Percentage Area:

Utility functions are constructed for three risk attitudes and shown in Table 3.3.49.

Table 3.3.47: Utility functions of natural parks attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 13 natural parks for certain. Lottery 2: Losing 26 natural parks with probability 1/2 or losing 0 natural park with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0385 * x$
Risk Averse case:
Lottery 1: Losing 8 natural parks for certain. Lottery 2: Losing 26 natural parks with probability 0.25 or losing 0 natural park with probability 0.75. Polynomial utility func.: $u(x) = -0.0004 * x^2 - 0.028 * x + 1$ Exponential utility func.: $u(x) = -1.316 * exp(0.02174 * x) + 2.316$
Risk prone case:
Lottery 1: Losing 8 natural parks for certain. Lottery 2: Losing 26 natural parks with probability 0.55 or losing 0 natural park with probability 0.45. Polynomial utility func.: $u(x) = 0.0017 * x^2 - 0.0822 * x + 1$ Exponential utility func.: $u(x) = 1.129 * exp(-0.0835 * x) - 0.1288$ where x denotes the number of natural parks.

Table 3.3.48: Utility values of number of natural parks under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of natural parks	Risk neutral	9	4	0.6535	0.846
	Risk averse-poly.	9	4	0.7156	0.8816
	Risk averse-expo.	9	4	0.7155	0.8804
	Risk prone-poly.	9	4	0.3979	0.6984
	Risk prone-expo.	9	4	0.4037	0.6796

Table 3.3.49: Utility functions of % area natural parks attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 9.5993% of natural parks for certain. Lottery 2: Losing 19.1987 % of natural parks with probability 1/2 or losing 0% of natural parks with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0521 * x$
Risk Averse case:
Lottery 1: Losing 4.8824% of natural parks for certain. Lottery 2: Losing 19.1987% of natural parks with probability 0.2 or losing 0% of natural parks with probability 0.8. Polynomial utility func.: $u(x) = -8 * 10^{-4} * x^2 - 0.0372 * x + 1$ Exponential utility func.: $u(x) = -1.2 * exp(0.03157 * x) + 2.2$
Risk prone case:
Lottery 1: Losing 4.8824% of natural parks for certain. Lottery 2: Losing 19.1987% of natural parks with probability 0.4 or losing 0% of natural parks with probability 0.6. Polynomial utility func.: $u(x) = 0.0021 * x^2 - 0.0921 * x + 1$ Exponential utility func.: $u(x) = 1.318 * exp(-0.0741 * x) - 0.3177$ where x denotes the percent area of natural parks.

The related utility values for the candidate sites are obtained and given in Table 3.3.50.

3.3.6 Utility Evaluation of Nature Conservation Areas

Nature conservation areas contain endangered species or ecosystems. These areas are protected and only used for scientific studies or educational purposes. For this reason, such places should be protected against possible damages. In case of an NPP accident, such places may disappear. Also, NPPs require construction of new structures and new roads for the transportation of huge materials and all these may

Table 3.3.50: Utility values of % area of natural parks under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site (%)	Abalı site (%)	Akkuyu site utility	Abalı site utility
% area of natural parks	Risk neutral	0.1708	0.5591	0.9911	0.9708
	Risk averse-poly.	0.1708	0.5591	0.9936	0.9789
	Risk averse-expo.	0.1708	0.5591	0.9935	0.9786
	Risk prone-poly.	0.1708	0.5591	0.9843	0.9491
	Risk prone-expo.	0.1708	0.5591	0.9837	0.9468

cause destruction of them, nature conservation areas are considered as an attribute. In this part of the study, the number and percentage area of nature conservation forests are evaluated. The data is obtained from the Ministry of Agriculture and Forestry, Directorate of Nature Conservation and National Parks [42] and the minimum and maximum number of these areas and their area are determined so that they can be used as the best and the worst levels in the siting study, respectively. All the information about the attribute is provided in Table 3.3.51 and Table 3.3.52.

Table 3.3.51: Worst and best values of the number of nature conservation areas and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Number of nature conservation areas	3	0	0	1

Table 3.3.52: Worst and best values of the percentage area of nature conservation areas and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
% of nature conservation areas	35.3621	0	0	1.0452

Utility Evaluation of Number of Nature Conservation Areas:

Utility functions for the number of nature conservation areas are provided in Table

3.3.53. Utility values are found and shown in Table 3.3.54.

Table 3.3.53: Utility functions of number of nature conservation areas attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 1.5 nature conservation areas for certain. Lottery 2: Losing 3 nature conservation areas with probability 1/2 or losing 0 nature conservation area with probability 1/2. Linear utility func.: $u(x) = 1 - 0.3333 * x$
Risk Averse case:
Lottery 1: Losing 1 nature conservation area for certain. Lottery 2: Losing 3 nature conservation areas with probability 0.2 or losing 0 nature conservation area with probability 0.8. Polynomial utility func.: $u(x) = -0.0667 * x^2 - 0.1333 * x + 1$ Exponential utility func.: $u(x) = -0.3562 * exp(0.4457 * x) + 1.356$
Risk prone case:
Lottery 1: Losing 1 nature conservation area for certain. Lottery 2: Losing 3 nature conservation areas with probability 0.6 or losing 0 nature conservation area with probability 0.4. Polynomial utility func.: $u(x) = 0.1333 * x^2 - 0.7333 * x + 1$ Exponential utility func.: $u(x) = 1.106 * exp(-0.7821 * x) - 0.1058$ where x denotes the number of nature conservation areas.

Utility Evaluation of Nature Conservation Areas in terms of Percentage Area: The utility functions are constructed for the three risk attitudes and stated in Table 3.3.55.

Utility values for Mersin-Akkuyu and Sinop-Abalı sites are obtained and shown in Table 3.3.56.

Table 3.3.54: Utility values of number of nature conservation areas under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of nature conservation areas	Risk neutral	0	1	1	0.6667
	Risk averse-poly.	0	1	1	0.8000
	Risk averse-expo.	0	1	1	0.7997
	Risk prone-poly.	0	1	1	0.4000
	Risk prone-expo.	0	1	1	0.4001

3.3.7 Utility Evaluation of Natural Monuments

Natural monuments are pieces of the nature that have scientific importance and they should be protected. Thus, another criteria to be considered is the number and percentage area of the natural monuments in the NPP siting study.
The data is obtained from the Ministry of Agriculture and Forestry, Directorate of Nature Conservation and National Parks [42]. The minimum (the best) and maximum (the worst) values are determined by examining the corresponding data for Turkey.
Table 3.3.57 and 3.3.58 show the worst and best values and related data for the candidate sites, Akkuyu and Abalı, for the number of natural monuments and their percentage area, respectively.

Utility Evaluation of Number of Natural Monuments:
The utility functions are found by using the indifferent lotteries and presented in Table 3.3.59. After the utility functions are obtained, the next step is to find the utility values. They are obtained and shown in Table 3.3.60.

Utility Evaluation of Natural Monuments in terms of Percentage Area:
Utility functions are assessed for the percentage area of natural monuments for risk neutral, averse and prone cases. They are given in Table 3.3.61.
Table 3.3.62 shows the utility values of the candidate sites for the percentage area of natural monuments.

Table 3.3.55: Utility functions of % area of nature conservation areas attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 17.681% of nature conservation areas for certain. Lottery 2: Losing 35.3621 % of nature conservation areas with probability 1/2 or losing 0% of nature conservation areas with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0283 * x$
Risk Averse case:
Lottery 1: Losing 12.8221% of nature conservation areas for certain. Lottery 2: Losing 35.3621% of nature conservation areas with probability 0.25 or losing 0% of nature conservation areas with probability 0.75. Polynomial utility func.: $u(x) = -4 * 10^{-4} * x^2 - 0.0145 * x + 1$ Exponential utility func.: $u(x) = -0.5432 * exp(0.02953 * x) + 1.543$
Risk prone case:
Lottery 1: Losing 12.8221% of nature conservation areas for certain. Lottery 2: Losing 35.3621% of nature conservation areas with probability 0.6 or losing 0% of nature conservation areas with probability 0.4. Polynomial utility func.: $u(x) = 8 * 10^{-4} * x^2 - 0.0573 * x + 1$ Exponential utility func.: $u(x) = 1.151 * exp(-0.05746 * x) - 0.1508$ where x denotes the percent area of nature conservation areas.

Table 3.3.56: Utility values of % area of nature conservation areas under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
% area of nature conservation areas	Risk neutral	0	1.0452	1	0.9704
	Risk averse-poly.	0	1.0452	1	0.9844
	Risk averse-expo.	0	1.0452	1	0.9827
	Risk prone-poly.	0	1.0452	1	0.9409
	Risk prone-expo.	0	1.0452	1	0.9331

Table 3.3.57: Worst and best values of the number of natural monuments and data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Number of natural monuments	12	0	4	4

Table 3.3.58: Worst and best values of percentage of natural monuments and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
% area of natural monuments	66.6735	0.0000	3.0309	0.8416

3.3.8 Utility Evaluation of Biodiversity

Biodiversity is another criteria to be considered for the siting problem and will be examined in three parts; the number of endemic species, species followed by IUCN and the number of habitats under monitoring. Any species whose range is restricted to a limited geographical area is called as endemic species [43]. Loss of forests unconsciously, fires, urbanization and structuring may cause loss of several endemic species. Species followed by IUCN contain three levels; vulnerable (VU), endangered (EN) and critically endangered (CR). All these three levels imply the extinction of the species with a high risk, very high risk and extremely high risk, respectively. The construction of an NPP may affect the existence of these kind of species so it is considered as an attribute.

The data is collected from the biodiversity database of Ministry of Agriculture and Forestry [44]. Since the studies about the biodiversity statistics have not been completed in the database of the ministry yet, the number of endemic species, IUCN species and habitats under monitoring of other provinces are used for the determination of maximum and minimum values of the attribute. Table 3.3.63 shows the worst and best values for the subcategories of the biodiversity attribute.

Utility Evaluation of Endemic Species:

Table 3.3.59: Utility functions of number of natural monuments attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 6 natural monuments for certain. Lottery 2: Losing 12 natural monuments with probability 1/2 or losing 0 natural monument with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0833 * x$
Risk Averse case:
Lottery 1: Losing 3 natural monuments for certain. Lottery 2: Losing 12 natural monuments with probability 0.15 or losing 0 natural monument with probability 0.85. Polynomial utility func.: $u(x) = -0.0037 * x^2 - 0.0389 * x + 1$ Exponential utility func.: $u(x) = -0.4241 * exp(0.1009 * x) + 1.424$
Risk prone case:
Lottery 1: Losing 3 natural monuments for certain. Lottery 2: Losing 12 natural monuments with probability 0.45 or losing 0 natural monument with probability 0.55. Polynomial utility func.: $u(x) = 0.0074 * x^2 - 0.1722 * x + 1$ Exponential utility func.: $u(x) = 1.166 * exp(-0.1626 * x) - 0.1656$ where x denotes the number of natural monuments.

Table 3.3.60: Utility values of number of natural monuments under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of natural monuments	Risk neutral	4	4	0.6668	0.6668
	Risk averse-poly.	4	4	0.7852	0.7852
	Risk averse-expo.	4	4	0.789	0.789
	Risk prone-poly.	4	4	0.4296	0.4296
	Risk prone-expo.	4	4	0.4428	0.4428

Table 3.3.61: Utility functions of % area of natural monuments attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 33.3367% area of natural monuments for certain. Lottery 2: Losing 66.6735% area of natural monuments with 1/2 probability or losing 0% of the area with 1/2 probability. Linear utility func.: $u(x) = 1 - 0.015 * x$
Risk Averse case:
Lottery 1: Losing 25% area of natural monuments for certain. Lottery 2: Losing 66.6735% area of natural monuments with probability 0.2 or 0% area of natural monuments with probability 0.8. Polynomial utility func.: $u(x) = -2 * 10^{-4} * x^2 - 0.0038 * x + 1$ Exponential utility func.: $u(x) = -0.2258 * exp(0.02537 * x) + 1.226$
Risk prone case:
Lottery 1: Losing 25% area of natural monuments for certain. Lottery 2: Losing 66.6735% area of natural monuments with probability 0.4 or 0% area of natural monuments with probability 0.6. Polynomial utility func.: $u(x) = 2 * 10^{-5} * x^2 - 0.0166 * x + 1$ Exponential utility func.: $u(x) = 5.235 * exp(-3.179 * 10^{-3} * x) - 4.235$ where x denotes the percent area of natural monuments.

Table 3.3.62: Utility values of % area of natural monuments under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
% area of natural monuments	Risk neutral	3.0309	0.8416	0.9545	0.9873
	Risk averse-poly.	3.0309	0.8416	0.9866	0.9966
	Risk averse-expo.	3.0309	0.8416	0.9821	0.9953
	Risk prone-poly.	3.0309	0.8416	0.9498	0.986
	Risk prone-expo.	3.0309	0.8416	0.9498	0.986

Table 3.3.63: Worst and best values of biodiversity attribute and related data for Akkuyu and Abalı sites

Subcategories of biodiversity	Worst value	Best value	Akkuyu site	Abalı site
Number of endemic species	1500	500	987	608
Number of IUCN species	120	15	73	41
Number of habitats under monitoring	30	0	22	12

The utility functions are constructed and shown in Table 3.3.64. Utility values are presented in Table 3.3.65. It is seen from the table that Abalı site has higher utility value for all the risk attitudes.

Utility Evaluation of Number of IUCN Species:
Utility functions are stated in Table 3.3.66. Utility values are obtained using the utility functions and stated in Table 3.3.67.

Utility Evaluation of Number of Habitats under Monitoring:
Utility functions are found for three risk attitudes and presented in Table 3.3.68. Utility values are shown in Table 3.3.69.

3.3.9 Utility Evaluation of Immovable Cultural Heritage

Most countries with long histories wish to preserve sites and structures having particular historical or cultural significance [45]. Thus, another criteria to be evaluated is the existence of such structures. Immovable cultural heritage is a collection of protected avenues, administrative structures, cultural structures, military constructions, cemeteries, industrial and commercial buildings and religious structures. Total number of these components is used for the siting study. The data for the cities is obtained from the Ministry of Culture and Tourism, General Directorate of Cultural Heritage and Museums [46]. The worst and best values are decided after examining the list of number of immovable cultural heritage of provinces of Turkey. The minimum and maximum number of immovable cultural heritage are selected as the best and the worst values of the utility function, respectively.

Table 3.3.64: Utility functions of number of biodiversity-endemic species attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 1000 endemic species for certain. Lottery 2: Losing 1500 endemic species with probability 1/2 or losing 500 endemic species with probability 1/2. Linear utility func.: $u(x) = 1.5 - 0.001 * x$
Risk Averse case:
Lottery 1: Losing 700 endemic species for certain. Lottery 2: Losing 1500 endemic species with probability 0.1 or losing 0 endemic species with probability 0.9. Polynomial utility func.: $u(x) = -6 * 10^{-7} * x^2 + 0.0002 * x + 1.0313$ Exponential utility func.: $u(x) = -0.1334 * exp(1.509 * 10^{-3} * x) + 1.284$
Risk prone case:
Lottery 1: Losing 700 endemic species for certain. Lottery 2: Losing 1500 endemic species with probability 0.3 or losing 0 endemic species with probability 0.7. Polynomial utility func.: $u(x) = 6 * 10^{-7} * x^2 - 0.0023 * x + 1.9688$ Exponential utility func.: $u(x) = 2.6 * exp(-1.143 * 10^{-3} * x) - 0.4683$ where x denotes the number of endemic species.

Utility functions and utility values are presented in Tables 3.3.71 and 3.3.72, respectively.

3.3.10 Utility Evaluation of Distance Between Nuclear Power Plant and City Center

City centers are the most crowded places of the provinces since they include main roads, shopping malls, state buildings and majority of the population. Therefore, a nuclear power plant should be as far as possible from the city center for safety. Thus,

Table 3.3.65: Utility values of number of endemic species under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
number of endemic species	Risk neutral	987	608	0.513	0.892
	Risk averse-poly.	987	608	0.6441	0.9311
	Risk averse-expo.	987	608	0.6924	0.9501
	Risk prone-poly.	987	608	0.2832	0.7921
	Risk prone-expo.	987	608	0.3731	0.8293

Table 3.3.66: Utility functions of number of IUCN species attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 67 IUCN species for certain. Lottery 2: Losing 120 IUCN species with probability 1/2 or losing 15 IUCN species with probability 1/2. Linear utility func.: $u(x) = 1.1429 - 0.0095 * x$
Risk Averse case:
Lottery 1: Losing 100 IUCN species for certain. Lottery 2: Losing 120 IUCN species with probability 0.7 or losing 0 IUCN species with probability 0.3. Polynomial utility func.: $u(x) = -6 * 10^{-5} * x^2 - 0.0008 * x + 1.0269$ Exponential utility func.: $u(x) = -0.3191 * exp(0.0122 * x) + 1.383$
Risk prone case:
Lottery 1: Losing 100 IUCN species for certain. Lottery 2: Losing 120 IUCN species with probability 0.9 or losing 0 IUCN species with probability 0.1. Polynomial utility func.: $u(x) = 5 * 10^{-5} * x^2 - 0.0167 * x + 1.2387$ Exponential utility func.: $u(x) = 1.621 * exp(-1.334 * 10^{-2} * x) - 0.3271$ where x denotes the number of IUCN species.

Table 3.3.67: Utility values of number of IUCN species under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of IUCN species	Risk neutral	73	41	0.4494	0.7534
	Risk averse-poly.	73	41	0.6487	0.8932
	Risk averse-expo.	73	41	0.6043	0.8563
	Risk prone-poly.	73	41	0.2860	0.6380
	Risk prone-expo.	73	41	0.285	0.611

another attribute to be evaluated is the distance between the city center and the NPP site. It is desired that NPP site is constructed reasonably far from the city center. The distance (in km) between the NPP site and the city center is calculated by using Google Earth Pro [47]. The worst and the best values of the attribute are determined as 5 and 200 kilometers, respectively. An increasing utility function is appropriate for the attribute. The worst (minimum distance) and the best (maximum distance) and related data are presented in Table 3.3.73. Utility functions are constructed and utility values are obtained for the candidate sites. Also, they are shown in Table 3.3.74 and 3.3.75, respectively.

3.3.11 Utility Evaluation of Population Density

Population is another important criteria for the nuclear power plant siting for safety considerations and environmental impact. The radiological impact of the NPP on people during its operation should be considered. Another reason to consider the population density is the evacuation of people in case of an NPP accident. Lower population density results in easier implementation of emergency plans [37]. In addition, population density is important to understand the demographic characteristic of the regions, provinces etc. To calculate the number of people per square kilometer for each candidate city, the area of the cities are obtained from General Directorate of Mapping [48].The information about the population of Mersin and Sinop provinces are obtained from the Turkish Statistical Institute [49] and population density is cal-

Table 3.3.68: Utility functions of number of habitats under monitoring attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 15 habitats for certain. Lottery 2: Losing 30 habitats with probability 1/2 or losing 0 habitat with probability 1/2. Linear utility func.: $u(x) = 1 - 0.0333 * x$
Risk Averse case:
Lottery 1: Losing 20 habitats for certain. Lottery 2: Losing 30 habitats with probability 0.55 or losing 0 habitat with probability 0.45. Polynomial utility func.: $u(x) = -0.0006 * x^2 - 0.0158 * x + 1$ Exponential utility func.: $u(x) = -0.5699 * exp(0.0337 * x) + 1.57$
Risk prone case:
Lottery 1: Losing 20 habitats for certain. Lottery 2: Losing 30 habitats with probability 0.8 or losing 0 habitat with probability 0.2. Polynomial utility func.: $u(x) = 0.0007 * x^2 - 0.0533 * x + 1$ Exponential utility func.: $u(x) = 1.356 * exp(-4.457 * 10^{-2} * x) - 0.3562$ where x denotes the number of habitats under monitoring.

Table 3.3.69: Utility values of number of habitats under monitoring under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of habitats under monitoring	Risk neutral	22	12	0.2674	0.6004
	Risk averse-poly.	22	12	0.3620	0.724
	Risk averse-expo.	22	12	0.3717	0.7152
	Risk prone-poly.	22	12	0.1662	0.4612
	Risk prone-expo.	22	12	0.1524	0.4380

Table 3.3.70: Worst and best values of number of immovable cultural heritage attribute and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Number of immovable cultural heritage	5000	50	1322	698

culated.

In this study, the number of people per square kilometer in the provinces is evaluated from two different aspects; the first one is in terms of job opportunity for people during the construction and lifetime of an NPP. The other aspect is related to the evacuation of people in case of an NPP accident.

3.3.11.1 Utility Evaluation of Population Density in terms of Job Opportunity

When population density is considered for the job opportunity, it is suitable to use an increasing utility function. In other words, densely populated areas are advantageous when compared to the sparsely populated areas (i.e., low population density) for the job opportunities during the construction and lifetime of an NPP.

The worst and best values of the population density and the related data for Mersin and Sinop provinces are shown in Table 3.3.76.

Utility functions for the evaluation of population density for job opportunity are seen in Table 3.3.77. Utility values are found in Table 3.3.78.

3.3.11.2 Utility Evaluation of Population Density in terms of Evacuation

Evacuation means moving people from a dangerous place to somewhere safe. It is an important part of the NPP emergency plannings.

In case of an NPP accident, the evacuation of people as soon as possible is crucial. So sparsely populated areas (i.e., areas with low population density) are much more suitable for the nuclear power plant construction.

The worst and best values of the population density attribute and related data for

Table 3.3.71: Utility functions of the number of immovable cultural heritage attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Losing 2525 immovable cultural heritage for certain. Lottery 2: Losing 5000 immovable cultural heritage with probability 1/2 or losing 50 immovable cultural heritage with probability 1/2. Linear utility func.: $u(x) = 1.0101 - 0.0002 * x$
Risk Averse case:
Lottery 1: Losing 2000 immovable cultural heritage for certain. Lottery 2: Losing 5000 immovable cultural heritage with probability 0.3 or losing 0 immovable cultural heritage with probability 0.7. Polynomial utility func.: $u(x) = -2 * 10^{-8} * x^2 - 0.0001 * x + 1.0061$ Exponential utility func.: $u(x) = -0.779 * exp(1.659 * 10^{-4} * x) + 1.785$
Risk prone case:
Lottery 1: Losing 2000 immovable cultural heritage for certain. Lottery 2: Losing 5000 immovable cultural heritage with probability 0.6 or losing 0 immovable cultural heritage with probability 0.4. Polynomial utility func.: $u(x) = 4 * 10^{-8} * x^2 - 0.0004 * x + 1.0189$ Exponential utility func.: $u(x) = 1.238 * exp(-3.484 * 10^{-4} * x) - 0.217$ where x denotes the number of immovable cultural heritage.

Table 3.3.72: Utility values of the number of immovable cultural heritage under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Number of immovable cultural heritage	Risk neutral	1322	698	0.7457	0.8705
	Risk averse-poly.	1322	698	0.8389	0.9265
	Risk averse-expo.	1322	698	0.8149	0.9103
	Risk prone-poly.	1322	698	0.5600	0.7591
	Risk prone-expo.	1322	698	0.5640	0.7537

Table 3.3.73: Worst and best values of the distance between the NPP site and the city center attribute and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Distance between the NPP site and city center (km)	5	200	123.56	14.49

Table 3.3.74: Utility functions of the distance between the NPP site and the city center attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having 102.5 km between the NPP site and the city center for certain. Lottery 2: Having 5 km between the NPP site and the city center with probability 1/2 or having 200 km between the NPP site and the city center with probability 1/2. Linear utility func.: $u(x) = -0.0256 + 0.0051 * x$
Risk Averse case:
Lottery 1: Having 100 km between the NPP site and the city center for certain. Lottery 2: Having 200 km between the NPP site and the city center with probability 0.4 or having 5 km between the NPP site and the city center with probability 0.6. Polynomial utility func.: $u(x) = -0.00001 * x^2 + 0.0076 * x - 0.0375$ Exponential utility func.: $u(x) = -1.707 * exp(-4.694 * 10^{-3} * x) + 1.688$
Risk prone case:
Lottery 1: Having 100 km between the NPP site and the city center for certain. Lottery 2: Having 200 km between the NPP site and the city center with probability 0.6 or having 5 km between the NPP site and the city center with probability 0.4. Polynomial utility func.: $u(x) = 9 * 10^{-6} * x^2 + 0.0032 * x - 0.0165$ Exponential utility func.: $u(x) = 0.9549 * exp(3.627 * 10^{-3} * x) - 0.9723$ where x denotes the distance between NPP and city center.

Table 3.3.75: Utility values of the distance between the NPP site and the city center under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Distance between the NPP site and the city center (km)	Risk neutral	123.56	14.49	0.6045	0.0482
	Risk averse-poly.	123.56	14.49	0.7488	0.0705
	Risk averse-expo.	123.56	14.49	0.7322	0.0932
	Risk prone-poly.	123.56	14.49	0.5162	0.0317
	Risk prone-expo.	123.56	14.49	0.5225	0.0341

Table 3.3.76: Worst and best values of the population density-job opportunity and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Population density (people per km^2)	11	2759	113	38

Akkuyu and Abalı sites are shown in Table 3.3.79. These values are determined similar to the job opportunity case. Only difference is that the maximum population density is used as the worst level and minimum value as the best level for the utility function.

Utility functions are constructed and presented in Table 3.3.80. Utility values can be found for the candidate sites by using the utility functions. Table 3.3.81 states the utility values of Akkuyu and Abalı sites.

3.3.12 Utility Evaluation of Distance to Airports

Nuclear power plants produce electricity from atomic energy, so they contain some danger in their nature. For this reason, while constructing nuclear power plants, it is necessary to consider the possible impacts of nearby installations like airports in case of an accident. In this study, two different scenarios are considered; the first one is an NPP collapse due to an aircraft crash and the other one is evacuation of people in case of an NPP crash. The distance in kilometers between airports and NPP site is

Table 3.3.77: Utility functions of population density-job opportunity attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1:Having 1385 people per square km for certain. Lottery 2: Having 11 people per square km with probability 1/2 or having 2759 people per square km with probability 1/2. Linear utility func.: $u(x) = -0.004 + 0.0004 * x$
Risk Averse case:
Lottery 1: Having 1500 people per square km for certain. Lottery 2: Having 11 people per square km with probability 0.3 or having 2759 people per square km with probability 0.7. Polynomial utility func.: $u(x) = -8 * 10^{-8} * x^2 + 0.0006 * x - 0.0066$ Exponential utility func.: $u(x) = -1.359 * exp(-4.9 * 10^{-4} * x) + 1.352$
Risk prone case:
Lottery 1: Having 1500 people per square km for certain. Lottery 2: Having 11 people per square km with probability 0.6 or having 2759 people per square km with probability 0.4. Polynomial utility func.: $u(x) = 8 * 10^{-8} * x^2 + 0.0002 * x - 0.0017$ Exponential utility func.: $u(x) = 0.4573 * exp(4.21 * 10^{-4} * x) - 0.4595$ where x denotes the number of people per square kilometer.

calculated by using Google Earth Pro [47].

3.3.12.1 Utility Evaluation of Aircraft Crash Scenario

The first scenario to be assessed is the aircraft crash. Most of the air crashes occur during the take-off and landing phases of a flight [37]. Therefore, the existence of an airport in the vicinity of NPP site increases the potential of NPP collapse due to an aircraft crash. Such an undesirable scenario may be evaluated using the increasing utility functions.

Table 3.3.78: Utility values of population density-job opportunity under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Population density (people per km^2) for job opportunity	Risk neutral	113	38	0.0412	0.0112
	Risk averse-poly.	113	38	0.0601	0.016
	Risk averse-expo.	113	38	0.0662	0.018
	Risk prone-poly.	113	38	0.0219	0.006
	Risk prone-expo.	113	38	0.02	0.0051

Table 3.3.79: Worst and best values of the population density-evacuation and data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Population density (people per km^2)	2759	11	113	38

The worst (lowest distance) and the best (highest distance) values are determined by logical comparisons of several distances. Since 5 kilometers radius within a nuclear power plant reactor is a protective zone, the worst value is assumed as 5 kms. The best value is chosen as 200 kms. These values and the related data for the candidate sites are given in Table 3.3.82.

There is no airport in Mersin. The passengers use the Adana airport for travelling purposes. For this reason, the distance of the nearest airport from the nuclear power plant is 182.19 kilometers. This provides an advantage to Mersin-Akkuyu site in terms of its utility. Clearly, it will take higher utility than Sinop-Abalı site since NPP site is just 8.78 kilometer far from the Sinop Airport.

Utility functions are obtained and shown in Table 3.3.83 and the corresponding utility values are computed and given in Table 3.3.84.

Table 3.3.80: Utility functions of population density-evacuation attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having 1385 people per square km for certain. Lottery 2: Having 2759 people per square km with probability 1/2 or having 11 people per square km with probability 1/2. Linear utility func.: $u(x) = 1.004 - 0.0004 * x$
Risk Averse case:
Lottery 1: Having 1500 people per square km for certain. Lottery 2: Having 2759 people per square km with probability 0.3 or having 11 people per square km with probability 0.7. Polynomial utility func.: $u(x) = -10^{-7} * x^2 - 7 * 10^{-6} * x + 1.0001$ Exponential utility func.: $u(x) = -0.145 * exp(7.494 * 10^{-4} * x) + 1.146$
Risk prone case:
Lottery 1: Having 1500 people per square km for certain. Lottery 2: Having 2759 people per square km with probability 0.6 or having 11 people per square km with probability 0.4. Polynomial utility func.: $u(x) = 3 * 10^{-8} * x^2 - 0.0004 * x + 1.0049$ Exponential utility func.: $u(x) = 2.655 * exp(-1.724 * 10^{-4} * x) - 1.65$ where x denotes the number of people per square kilometer.

3.3.12.2 Utility Evaluation of NPP Crash Scenario

Evacuation of people in case of an NPP crash should be considered for NPP site selection process. In this sense, the distance between the NPP site and major transportation should be one of the criteria for the siting. The distance between the NPP site and airport is evaluated and considered as an attribute in the study.Since the closer airports to the NPP site means reduction in the duration of evacuation, a decreasing utility function is preferred.

Utility functions for the distance to airport for the evacuation of people are provided in Table 3.3.86. Moreover, Table 3.3.87 shows the utility values of Mersin-Akkuyu

Table 3.3.81: Utility values of population density-evacuation scenario under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Population density for evacuation scenario (people per km^2)	Risk neutral	113	38	0.9588	0.9888
	Risk averse-poly.	113	38	0.9980	0.9996
	Risk averse-expo.	113	38	0.9881	0.9968
	Risk prone-poly.	113	38	0.96	0.9897
	Risk prone-expo.	113	38	0.9537	0.9876

Table 3.3.82: Worst and best values of the distance to airports-aircraft crash and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Distance to airports (km) (aircraft crash scenario)	5	200	182.19	8.78

and Sinop-Abalı sites for the distance to airport for evacuation of people in case of an NPP crash scenario.

3.3.13 Utility Evaluation of Distance to Bus Terminal

Another transportation choice for the evacuation of people in case of an NPP accident is the road transportation. As a result, another criteria is the distance to bus terminals. The distance (in km) between bus terminal and NPP site is calculated by using Google Earth Pro [47]. A decreasing utility function is appropriate since lower distance between NPP site and bus terminal is preferred. The worst, best values of the attribute and related data are shown in Table 3.3.88.

Utility functions are obtained and shown in Table 3.3.89. Utility values obtained from the utility functions are given in Table 3.3.90.

Table 3.3.83: Utility functions of distance to airports-aircraft crash scenario attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having 102.5 km between the NPP site and airport for certain. Lottery 2: Having 5 km between the NPP site and airport with probability 1/2 or having 200 km between the NPP site and airport with probability 1/2. Linear utility func.: $u(x) = -0.0256 + 0.0051 * x$
Risk Averse case:
Lottery 1: Having 90 km between the NPP site and airport for certain. Lottery 2: Having 5 km between the NPP site and airport with probability 0.35 or having 200 km between the NPP site and airport with probability 0.65. Polynomial utility func.: $u(x) = -2.29 * 10^{-5} * x^2 + 0.0098 * x - 0.0485$ Exponential utility func.: $u(x) = -1.257 * exp(-9.166 * 10^{-3} * x) + 1.201$
Risk prone case:
Lottery 1: Having 90 km between the NPP site and airport for certain. Lottery 2: Having 5 km between the NPP site and airport with probability 0.7 or having 200 km between the NPP site and airport with probability 0.3. Polynomial utility func.: $u(x) = 10^{-5} * x^2 + 0.0021 * x - 0.0111$ Exponential utility func.: $u(x) = 0.1437 * exp(0.0104 * x) - 0.1514$ where x denotes the distance between NPP site and airport (km).

3.4 Comparing Candidate Sites in terms of Utility Functions

In Section 3.3, single attribute utility functions are constructed under different attitudes toward risk for the NPP siting study and utility values are obtained for the candidate sites, Mersin-Akkuyu and Sinop-Abalı. Now, these single attribute utility values are combined in order to obtain a multi-attribute utility value for each candidate site.

It is assumed that the attributes are additive independent and multi-attribute utility

Table 3.3.84: Utility values of distance to airport-aircraft crash scenario under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Distance to airports (km) (aircraft crash scenario)	Risk neutral	182.19	8.78	0.9035	0.0191
	Risk averse-poly.	182.19	8.78	0.9808	0.0359
	Risk averse-expo.	182.19	8.78	0.9643	0.0411
	Risk prone-poly.	182.19	8.78	0.7034	0.0081
	Risk prone-expo.	182.19	8.78	0.8043	0.006

Table 3.3.85: Worst and best values of the distance to airports-NPP crash scenario attribute and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Distance to airports (km) (NPP crash scenario)	200	5	182.19	8.78

function has the following form;

$$u(x_1, ...x_n) = \sum_{i=1}^{n} k_i u_i(x_i) \tag{3.4.1}$$

where, k_i represents the weight of the i^{th} attribute in the multi-attribute utility function and sum up to 1.0.

For the comparison of the candidate sites in terms of their utilities, first, the candidate sites are compared in terms of single-attribute utility values. Then, several scenarios are constructed for the comparison of the candidate sites.

3.4.1 Comparison of the Candidate Sites in terms of Single-Attribute Utility Values

- For all of the attitudes toward risk, Abalı site is better than Akkuyu site in terms of the utilities of seismic hazard, tsunami hazard, forestry, natural parks, natural monuments, biodiversity immovable cultural heritage and distance to bus terminal. On the other hand, Akkuyu site has higher utility values for the

Table 3.3.86: Utility functions of distance to airport-NPP crash scenario attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having 102.5 km between the NPP site and airport for certain. Lottery 2:Having 200 km between the NPP site and airport with probability 1/2 or having 5 km between the NPP site and airport with probability 1/2. Linear utility func.: $u(x) = 1.0256 - 0.0051 * x$
Risk Averse case:
Lottery 1: Having 90 km between the NPP site and airport for certain. Lottery 2: Having 200 km between the NPP site and airport with probability 0.35 or having 5 km between the NPP site and airport with probability 0.65. Polynomial utility func.: $u(x) = -9 * 10^{-6} * x^2 - 0.0032 * x + 1.0165$ Exponential utility func.: $u(x) = -0.9367 * exp(3.677 * 10^{-3} * x) + 1.954$
Risk prone case:
Lottery 1: Having 90 km between the NPP site and airport for certain. Lottery 2: Having 200 km between the NPP site and airport with probability 0.55 or having 5 km between the NPP site and airport with probability 0.45. Polynomial utility func.: $u(x) = 1.22 * 10^{-5} * x^2 - 0.00763 * x + 1.0378$ Exponential utility func.: $u(x) = 1.696 * exp(-4.749 * 10^{-3} * x) - 0.6559$ where x denotes the distance between NPP and airport.

attributes of nature conservation areas, distance between the NPP site and city center and for the extreme wind hazard.

- In terms of the number of natural parks, although the utility of Abalı site is better than Akkuyu site, Akkuyu site has higher utility value in terms of percentage area.

- Another important point is that although the number of natural monuments are equal for both sites, Abalı site has higher utility value than Akkuyu site for the percent area of natural monuments.

- Abalı site has higher utility in terms of biodiversity attribute. For all of the sub-

Table 3.3.87: Utility values of distance to airport-NPP crash scenario under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Distance to airports (km) (NPP crash scenario)	Risk neutral	182.19	8.78	0.0964	0.9808
	Risk averse-poly.	182.19	8.78	0.1347	0.9877
	Risk averse-expo.	182.19	8.78	0.1236	0.9865
	Risk prone-poly.	182.19	8.78	0.0526	0.9717
	Risk prone-expo.	182.19	8.78	0.058	0.9708

Table 3.3.88: Worst and best values of the distance to bus terminals attribute and related data for Akkuyu and Abalı sites

Criteria	Worst value	Best value	Akkuyu site	Abalı site
Distance to bus terminal (km)	200	5	119.59	9.27

categories, number of endemic species, species followed by IUCN, and number of habitats under monitoring, Abalı site has higher utility.

3.4.2 Comparison of the Candidate Sites under Different Scenarios

Scenario 1: Comparison with respect to all attributes having equal weights

The first scenario takes all of the attributes into consideration with equal weights. Every single attribute which consists of several subcategories, are evaluated as the average of their corresponding subcategories and then they are weighted equally. The results are summarized in Table 3.4.1.

Part a: On the overall comparison, Akkuyu site has slightly higher utility values than Abalı site in terms of risk averse multi-attribute utility. For risk neutral and risk prone, Abalı site has higher utility values.

Part b: Population density and distance to airports are evaluated from different aspects. Population density is assessed in terms of job opportunity as a first aspect and in terms of evacuation as a second. Similarly, distance to airport is investigated in

Table 3.3.89: Utility functions of distance to bus terminal attribute under risk neutral, risk averse and risk prone cases

Assessments of indifference points
Risk neutral case:
Lottery 1: Having 102.5 km between the NPP site and bus terminal for certain. Lottery 2: Having 200 km between the NPP site and bus terminal with probability 1/2 or having 5 km between the NPP site and bus terminal with probability 1/2. Linear utility func.: $u(x) = 1.0256 - 0.0051 * x$
Risk Averse case:
Lottery 1: Having 90 km between the NPP site and bus terminal for certain. Lottery 2: Having 200 km between the NPP site and bus terminal with probability 0.3 or having 5 km between the NPP site and bus terminal with probability 0.7. Polynomial utility func.: $u(x) = -10^{-5} * x^2 - 0.0021 * x + 1.0378$ Exponential utility func.: $u(x) = -0.4403 * exp(5.972 * 10^{-3} * x) + 1.454$
Risk prone case:
Lottery 1: Having 90 km between the NPP site and bus terminal for certain. Lottery 2: Having 200 km between the NPP site and bus terminal with probability 0.6 or having 5 km between the NPP site and bus terminal with probability 0.4. Polynomial utility func.: $u(x) = -2 * 10^{-5} * x^2 - 0.0087 * x + 1.0432$ Exponential utility func.: $u(x) = 1.399 * exp(-6.901 * 10^{-3} * x) - 0.352$ where x denotes the distance between NPP site and bus terminal.

Table 3.3.90: Utility values of distance to bus terminal attribute under risk neutral, risk averse and risk prone cases

Criteria	Attitude for utility function	Akkuyu site	Abalı site	Akkuyu site utility	Abalı site utility
Distance to bus terminal (km)	Risk neutral	119.59	9.27	0.4156	0.9783
	Risk averse-poly.	119.59	9.27	0.6169	0.9907
	Risk averse-expo.	119.59	9.27	0.5546	0.9886
	Risk prone-poly.	119.59	9.27	0.2888	0.9642
	Risk prone-expo.	119.59	9.27	0.2609	0.9603

Table 3.4.1: Utility values corresponding to scenario 1

Attitude for utility function	Function	Utility for Akkuyu site	Utility for Abalı site
Risk neutral	Linear	0.6081	0.6421
Risk averse	Polynomial	0.7131	0.7046
Risk averse	Exponential	0.6942	0.6920
Risk prone	Polynomial	0.5080	0.5704
Risk prone	Exponential	0.5168	0.5684

terms of NPP collapse due to an aircraft crash and evacuation of people in case of an NPP crash. These different aspects can be combined to obtain utility values. The resulting four combinations are presented in Table 3.4.2 and explained below;

- *Combination of population density for job opportunity and an NPP crash due to aircraft crash scenario:* Akkuyu site has better utility values for risk neutral and risk averse cases when the population density is assessed for job opportunity and distance to airport is evaluated for potential NPP collapse due to an aircraft crash. Akkuyu site is slightly better than Abalı site for risk prone case. Since Abalı NPP site is closer to the airport, it has a negative impact on the utility of this site.

- *Combination of population density for job opportunity and evacuation due to NPP crash scenario:* Abalı site is better than Akkuyu site for all attitudes toward risk.

- *Combination of population density for evacuation and NPP crash due to an aircraft crash scenario:* Akkuyu site has higher utility for risk neutral and risk averse utility functions and slightly higher utility for the risk prone function since it is far from the airport.

- *Combination of population density for evacuation and NPP crash scenario:* Abalı site has higher utility since it is advantageous for both evacuation and NPP crash scenario for distance to airport.

Table 3.4.2: Utility values of four combinations of the attributes for scenario 1

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.6039	0.5675
	Risk averse-poly.	0.7096	0.6302
	Risk averse-expo.	0.6911	0.618
	Risk prone-poly.	0.497	0.4955
	Risk prone-expo.	0.5096	0.4935
Combination of job opportunity and NPP crash	Risk neutral	0.5418	0.6415
	Risk averse-poly.	0.6445	0.7034
	Risk averse-expo.	0.6264	0.6907
	Risk prone-poly.	0.4469	0.5697
	Risk prone-expo.	0.4522	0.5677
Combination of evacuation and aircraft crash	Risk neutral	0.6745	0.6427
	Risk averse-poly.	0.7817	0.7058
	Risk averse-expo.	0.762	0.6933
	Risk prone-poly.	0.5692	0.5712
	Risk prone-expo.	0.5814	0.5691
Combination of evacuation and NPP crash	Risk neutral	0.6124	0.7167
	Risk averse-poly.	0.7166	0.779
	Risk averse-expo.	0.6974	0.766
	Risk prone-poly.	0.5191	0.6453
	Risk prone-expo.	0.524	0.6433

Scenario 2: Comparison of utility values of candidate sites under the dominance of natural hazards-type 1

Numerous attributes are examined related to the siting. Some of these attributes are natural hazards like seismic hazard, tsunami hazard and extreme wind hazard and some of them are related to the non-natural phenomena. These hazards can be interfered but natural hazards can not. When only natural hazards are evaluated with equally allocated weights, it is seen that Akkuyu site is better than Abalı site in terms of utility value. The utility values are given in Table 3.4.3.

In order to evaluate candidate sites by all attributes, more weights are given to natural hazards and the remaining weight is prorated among other attributes. 60% of the total weight (which is 1.0) is given to natural hazards and several cases are constructed for the distribution of the weights.

Table 3.4.3: Utility values corresponding to scenario 2-evaluation of natural hazards only

Attitude for utility function	Function	Utility for Akkuyu site	Utility for Abalı site
Risk neutral	Linear	0.4583	0.4374
Risk averse	Polynomial	0.6412	0.5705
Risk averse	Exponential	0.5969	0.5164
Risk prone	Polynomial	0.3617	0.3496
Risk prone	Exponential	0.3790	0.3481

- *Case 1: Equal allocation of the weights to the natural hazards:* 60 % of the weight is distributed equally to three types of natural hazards. Other attributes are weighted as 0.04 in this case.
- *Case 2: More weight to seismic hazard attribute:* In this case, the weight 0.3 is given to seismic hazard and 0.15 to remaining two natural hazards, tsunami and extreme wind hazard. The weights of the other attributes are taken as 0.04 (as in case 1).
- *Case 3: More weight to tsunami hazard attribute:* The weight 0.3 is given to tsunami hazard in this case and 0.15 is given to the other natural hazards, extreme wind hazard and seismic hazard. The weight for other attributes is taken as 0.04.
- *Case 4: More weight to extreme wind hazard attribute:* This time, weight of 0.3 is given to the attribute that considers extreme wind speed of the candidate sites. While, the weight for the other natural hazards is taken as 0.15 each and 0.04 for the remaining attributes.

The utility values for these cases are summarized in Table 3.4.4. As it is seen from the table; on the overall comparison, Akkuyu site has higher utility for the risk neutral, risk averse and risk prone-exponential function in case 1. Abalı site has higher utility value for risk neutral and risk prone utility functions for case 2. In case 3, Abalı site is better in terms of utility for all the attitudes toward risk. On the other hand, Akkuyu site has higher utility than Abalı site for the case 4.

Table 3.4.4: Utility values corresponding to scenario 2

Cases	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Case 1	Risk neutral	0.4879	0.4818
	Risk averse-poly.	0.6219	0.5718
	Risk averse-expo.	0.5907	0.5396
	Risk prone-poly.	0.4007	0.4116
	Risk prone-expo.	0.4123	0.4098
Case 2	Risk neutral	0.5382	0.5384
	Risk averse-poly.	0.6716	0.6333
	Risk averse-expo.	0.6269	0.5906
	Risk prone-poly.	0.4481	0.4655
	Risk prone-expo.	0.4665	0.4724
Case 3	Risk neutral	0.4365	0.4855
	Risk averse-poly.	0.5572	0.5895
	Risk averse-expo.	0.5349	0.5638
	Risk prone-poly.	0.352	0.3994
	Risk prone-expo.	0.3624	0.3964
Case 4	Risk neutral	0.4891	0.4216
	Risk averse-poly.	0.6369	0.4928
	Risk averse-expo.	0.6102	0.4646
	Risk prone-poly.	0.4019	0.37
	Risk prone-expo.	0.4081	0.3605

As in the first scenario, population density and distance to airport are evaluated by constructing four combinations. The utility values of these combinations for the candidate sites are given in Table 3.4.5 - 3.4.8.

Table 3.4.5: Utility values of four combinations of the attributes for scenario 2-case 1

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.4857	0.4430
	Risk averse-poly.	0.6201	0.5331
	Risk averse-expo.	0.5890	0.5012
	Risk prone-poly.	0.3950	0.3727
	Risk prone-expo.	0.4086	0.3708
Combination of job opportunity and NPP crash	Risk neutral	0.4535	0.4815
	Risk averse-poly.	0.5826	0.5712
	Risk averse-expo.	0.5554	0.5390
	Risk prone-poly.	0.3689	0.4112
	Risk prone-expo.	0.3787	0.4094
Combination of evacuation and aircraft crash	Risk neutral	0.5224	0.4821
	Risk averse-poly.	0.6576	0.5725
	Risk averse-expo.	0.6259	0.5403
	Risk prone-poly.	0.4325	0.4120
	Risk prone-expo.	0.4459	0.4101
Combination of evacuation and NPP crash	Risk neutral	0.4902	0.5206
	Risk averse-poly.	0.6237	0.6106
	Risk averse-expo.	0.5923	0.5781
	Risk prone-poly.	0.4064	0.4506
	Risk prone-expo.	0.4160	0.4487

Table 3.4.6: Utility values of four combinations of the attributes for scenario 2-case 2

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.5360	0.4996
	Risk averse-poly.	0.6698	0.5946
	Risk averse-expo.	0.6252	0.5521
	Risk prone-poly.	0.4424	0.4265
	Risk prone-expo.	0.4627	0.4334
Combination of job opportunity and NPP crash	Risk neutral	0.5037	0.5381
	Risk averse-poly.	0.6359	0.6326
	Risk averse-expo.	0.5916	0.5899
	Risk prone-poly.	0.4164	0.4651
	Risk prone-expo.	0.4329	0.4720
Combination of evacuation and aircraft crash	Risk neutral	0.5727	0.5387
	Risk averse-poly.	0.7073	0.6339
	Risk averse-expo.	0.6621	0.5912
	Risk prone-poly.	0.4799	0.4659
	Risk prone-expo.	0.5001	0.4727
Combination of evacuation and NPP crash	Risk neutral	0.5404	0.5772
	Risk averse-poly.	0.6735	0.6720
	Risk averse-expo.	0.6285	0.6290
	Risk prone-poly.	0.4539	0.5044
	Risk prone-expo.	0.4702	0.5113

Table 3.4.7: Utility values of four combinations of the attributes for scenario 2-case 3

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.4343	0.4467
	Risk averse-poly.	0.5553	0.5508
	Risk averse-expo.	0.5330	0.5253
	Risk prone-poly.	0.3463	0.3605
	Risk prone-expo.	0.3586	0.3574
Combination of job opportunity and NPP crash	Risk neutral	0.4020	0.4851
	Risk averse-poly.	0.5215	0.5889
	Risk averse-expo.	0.4996	0.5631
	Risk prone-poly.	0.3202	0.3990
	Risk prone-expo.	0.3288	0.3960
Combination of evacuation and aircraft crash	Risk neutral	0.4710	0.4858
	Risk averse-poly.	0.5929	0.5901
	Risk averse-expo.	0.5701	0.5644
	Risk prone-poly.	0.3838	0.3998
	Risk prone-expo.	0.3960	0.3967
Combination of evacuation and NPP crash	Risk neutral	0.4387	0.5242
	Risk averse-poly.	0.5590	0.6282
	Risk averse-expo.	0.5365	0.6022
	Risk prone-poly.	0.3578	0.4384
	Risk prone-expo.	0.3661	0.4353

Table 3.4.8: Utility values of four combinations of the attributes for scenario 2-case 4

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.4869	0.3828
	Risk averse-poly.	0.6351	0.4541
	Risk averse-expo.	0.6086	0.4261
	Risk prone-poly.	0.3962	0.3310
	Risk prone-expo.	0.4043	0.3216
Combination of job opportunity and NPP crash	Risk neutral	0.4546	0.4213
	Risk averse-poly.	0.6012	0.4921
	Risk averse-expo.	0.5750	0.4639
	Risk prone-poly.	0.3702	0.3696
	Risk prone-expo.	0.3745	0.3602
Combination of evacuation and aircraft crash	Risk neutral	0.5236	0.4219
	Risk averse-poly.	0.6726	0.4934
	Risk averse-expo.	0.6455	0.4653
	Risk prone-poly.	0.4337	0.3704
	Risk prone-expo.	0.4417	0.3609
Combination of evacuation and NPP crash	Risk neutral	0.4913	0.4604
	Risk averse-poly.	0.6387	0.5315
	Risk averse-expo.	0.6118	0.5031
	Risk prone-poly.	0.4077	0.4089
	Risk prone-expo.	0.4118	0.3995

It is inferred from Table 3.4.5 - 3.4.8 that;

- Giving more weights to seismic hazard and extreme wind hazard (case 2 and case 4) does not change the superiority of Akkuyu site when the population density and distance to airport are evaluated in terms of job opportunity and aircraft crash, respectively. Giving more weight to tsunami hazard (case 3) changes the result and the utility value of Abalı site becomes higher. The same results are observed in the combination of evacuation and aircraft crash scenarios.

- Giving more weights to seismic hazard and extreme wind hazard (case 2 and case 4) changes the results of the study when the population and distance to airports are evaluated in terms of job opportunity and evacuation of people due to NPP crash scenario, respectively. Abalı site loses its superiority in these cases. However, giving more weight to tsunami hazard (case 3) does not change the results. Abalı site has higher utility.

- Giving more weights to seismic and tsunami hazard (case 2 and case 3) does not change the superiority of Abalı site for the combination of evacuation and NPP crash scenario.

Scenario 3: Comparison of utility values of the candidate sites under the dominance of natural hazards-type 2

Another scenario is constructed similar to the second one but having different weights. Now, 75% of the total weight is given to the natural hazards and remaining are distributed equally to the other attributes. Several cases are constructed and explained as follows:

- *Case 1: Equal allocation of the weights to the natural hazards:* This case considers the equal weight, 0.25, for each of the natural hazards. All other attributes have the weight of 0.025 each.

- *Case 2: More weight to seismic hazard attribute:* To examine whether the changes on the weights affect the result of the multi-attribute utility, weight of 0.45 is given to seismic hazard attribute and 0.15 to the other natural hazards. Remaining attributes are evaluated by allocating weight of 0.025 for each.

- *Case 3: More weight to tsunami hazard attribute:* This case indicates the dominance of tsunami hazard with weight of 0.45. The weight of 0.15 are assessed for seismic hazard and extreme wind hazard and 0.025 weight for each of the remaining attributes.

- *Case 4: More weight to extreme wind hazard attribute:* The last case in scenario 3 considers the dominance of extreme wind hazard. The sites are evaluated under the weight of 0.45 for extreme wind hazard, weight of 0.15 for seismic and tsunami hazards and weight of 0.025 for each of the other attributes.

The resulting utility values are given in Table 3.4.9 for Akkuyu and Abalı sites.

As it is seen from Table 3.4.9; for case 1, Akkuyu site is better in terms of utility for the risk neutral and risk avoider attitudes. For risk prone case, Abalı site has higher utility value. For cases 2 and 3, Abalı site has higher utility for risk neutral and risk prone cases. However, Akkuyu site has higher utility for all attitudes toward risk in case 4.
Utility values of the candidate sites for four combinations of population density and distance to airport attributes are given in Table 3.4.10 - 3.4.13. From these tables, it can be concluded that;

- Giving more weight to natural hazards does not change the superiority of Akkuyu site for the combination of job opportunity and aircraft crash and combination of evacuation and aircraft crash.

- When more weight is given to natural hazards, results of the combination of job opportunity and NPP crash scenario and the combination of the evacuation and NPP crash scenario are affected. Giving more weight to extreme wind hazard (case 4) results in the superiority of Akkuyu site. When more weights are given to seismic and tsunami hazards (case 2 and case 3), Abalı site loses its superiority for risk averse case.

Scenario 4: Comparison of the candidate sites under the dominance of the attributes other than natural hazards
In this case, the opposite of the previous scenarios 2 and 3 is constructed. 88% of the

Table 3.4.9: Utility values corresponding to scenario 3

Cases	Attitude for utility func.	Function	Utility for Akkuyu site	Utility for Abalı site
Case 1	Risk neutral	Linear	0.4767	0.465
	Risk averse	Polynomial	0.6290	0.5711
	Risk averse	Exponential	0.5928	0.5307
	Risk prone	Polynomial	0.3860	0.3882
	Risk prone	Exponential	0.3998	0.3865
Case 2	Risk neutral	Linear	0.5772	0.5782
	Risk averse	Polynomial	0.7284	0.6939
	Risk averse	Exponential	0.6653	0.6325
	Risk prone	Polynomial	0.4809	0.4959
	Risk prone	Exponential	0.5081	0.5117
Case 3	Risk neutral	Linear	0.6075	0.6172
	Risk averse	Polynomial	0.7641	0.7369
	Risk averse	Exponential	0.7010	0.6753
	Risk prone	Polynomial	0.5042	0.5290
	Risk prone	Exponential	0.5321	0.5449
Case 4	Risk neutral	Linear	0.5094	0.3835
	Risk averse	Polynomial	0.6946	0.456
	Risk averse	Exponential	0.6677	0.4235
	Risk prone	Polynomial	0.4118	0.3381
	Risk prone	Exponential	0.4153	0.3213

Table 3.4.10: Utility values of four combinations of the attributes for scenario 3-case 1

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.4753	0.4407
	Risk averse-poly.	0.6278	0.5469
	Risk averse-expo.	0.5918	0.5066
	Risk prone-poly.	0.3824	0.3639
	Risk prone-expo.	0.3974	0.3621
Combination of job opportunity and NPP crash	Risk neutral	0.4552	0.4648
	Risk averse-poly.	0.6067	0.5707
	Risk averse-expo.	0.5708	0.5303
	Risk prone-poly.	0.3662	0.3879
	Risk prone-expo.	0.3788	0.3862
Combination of evacuation and aircraft crash	Risk neutral	0.4983	0.4652
	Risk averse-poly.	0.6513	0.5715
	Risk averse-expo.	0.6149	0.5311
	Risk prone-poly.	0.4059	0.3884
	Risk prone-expo.	0.4208	0.3867
Combination of evacuation and NPP crash	Risk neutral	0.4781	0.4892
	Risk averse-poly.	0.6301	0.5953
	Risk averse-expo.	0.5938	0.5547
	Risk prone-poly.	0.3896	0.4125
	Risk prone-expo.	0.4021	0.4108

Table 3.4.11: Utility values of four combinations of the attributes for scenario 3-case 2

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.5759	0.5539
	Risk averse-poly.	0.7273	0.6697
	Risk averse-expo.	0.6642	0.6084
	Risk prone-poly.	0.4773	0.4715
	Risk prone-expo.	0.5057	0.4873
Combination of job opportunity and NPP crash	Risk neutral	0.5557	0.5780
	Risk averse-poly.	0.7061	0.6935
	Risk averse-expo.	0.6432	0.6321
	Risk prone-poly.	0.4611	0.4956
	Risk prone-expo.	0.4871	0.5114
Combination of evacuation and aircraft crash	Risk neutral	0.5988	0.5784
	Risk averse-poly.	0.7507	0.6943
	Risk averse-expo.	0.6873	0.6329
	Risk prone-poly.	0.5008	0.4961
	Risk prone-expo.	0.5291	0.5119
Combination of evacuation and NPP crash	Risk neutral	0.5786	0.6024
	Risk averse-poly.	0.7296	0.7181
	Risk averse-expo.	0.6663	0.6566
	Risk prone-poly.	0.4845	0.5202
	Risk prone-expo.	0.5104	0.5360

Table 3.4.12: Utility values of four combinations of the attributes for scenario 3-case 3

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.6062	0.5929
	Risk averse-poly.	0.7629	0.7128
	Risk averse-expo.	0.7000	0.6513
	Risk prone-poly.	0.5006	0.5047
	Risk prone-expo.	0.5298	0.5206
Combination of job opportunity and NPP crash	Risk neutral	0.5860	0.6170
	Risk averse-poly.	0.7418	0.7365
	Risk averse-expo.	0.6790	0.6749
	Risk prone-poly.	0.4843	0.5288
	Risk prone-expo.	0.5111	0.5447
Combination of evacuation and aircraft crash	Risk neutral	0.6291	0.6174
	Risk averse-poly.	0.7864	0.7373
	Risk averse-expo.	0.7230	0.6758
	Risk prone-poly.	0.5240	0.5293
	Risk prone-expo.	0.5531	0.5451
Combination of evacuation and NPP crash	Risk neutral	0.6089	0.6414
	Risk averse-poly.	0.7652	0.7611
	Risk averse-expo.	0.7020	0.6994
	Risk prone-poly.	0.5078	0.5534
	Risk prone-expo.	0.5345	0.5692

Table 3.4.13: Utility values of four combinations of the attributes for scenario 3-case 4

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.5080	0.3593
	Risk averse-poly.	0.6935	0.4318
	Risk averse-expo.	0.6667	0.3994
	Risk prone-poly.	0.4082	0.3138
	Risk prone-expo.	0.4130	0.2969
Combination of job opportunity and NPP crash	Risk neutral	0.4878	0.3833
	Risk averse-poly.	0.6723	0.4556
	Risk averse-expo.	0.6457	0.4230
	Risk prone-poly.	0.3919	0.3379
	Risk prone-expo.	0.3943	0.3211
Combination of evacuation and aircraft crash	Risk neutral	0.5309	0.3837
	Risk averse-poly.	0.7169	0.4563
	Risk averse-expo.	0.6897	0.4239
	Risk prone-poly.	0.4316	0.3384
	Risk prone-expo.	0.4363	0.3215
Combination of evacuation and NPP crash	Risk neutral	0.5108	0.4078
	Risk averse-poly.	0.6958	0.4801
	Risk averse-expo.	0.6687	0.4475
	Risk prone-poly.	0.4153	0.3624
	Risk prone-expo.	0.4177	0.3456

total weight is given to the other attributes and remaining 12% is assigned to natural hazards with equal allocation so that each natural hazard has weight of 0.04 and each of the other attributes has the weight of 0.088. Utility values are illustrated in Table 3.4.14.

Table 3.4.14: Utility values corresponding to scenario 4

Attitude for utility function	Function	Utility for Akkuyu site	Utility for Abalı site
Risk neutral	Linear	0.6297	0.6715
Risk averse	Polynomial	0.7234	0.7239
Risk averse	Exponential	0.7082	0.7173
Risk prone	Polynomial	0.5291	0.6022
Risk prone	Exponential	0.5366	0.6001

It is seen from Table 3.4.14 that Abalı site has higher utility for risk neutral and risk prone utility functions. Additionally, it is slightly better in terms of risk averse utility value.

Four combinations of the population density and distance between NPP and airport attributes are not affected from the changes on the weights of the attributes. The utility values of the candidate sites for the combinations are given in Table 3.4.15.

Scenario 5: Comparison of the candidate sites under randomly allocated weights for the attributes

In this scenario, all weights are allocated randomly by generating thirteen random numbers between 0 and 1 so that they add up to 1.0. These numbers are assigned to the attributes, respectively. The weight of each attribute is given in Table 3.4.16. Utility values are obtained and presented in Table 3.4.17.

When the attributes are evaluated with these weights, it is found that Abalı site has better utility value for risk neutral and risk prone cases.

Four combinations of the population density and distance to airports attributes are evaluated and resulting values are provided in Table 3.4.18.

Table 3.4.15: Utility values of four combinations of the attributes for scenario 4

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.6248	0.5862
	Risk averse-poly.	0.7194	0.6388
	Risk averse-expo.	0.7047	0.6326
	Risk prone-poly.	0.5165	0.5166
	Risk prone-expo.	0.5284	0.5144
Combination of job opportunity and NPP crash	Risk neutral	0.5538	0.6708
	Risk averse-poly.	0.6449	0.7225
	Risk averse-expo.	0.6307	0.7158
	Risk prone-poly.	0.4592	0.6014
	Risk prone-expo.	0.4627	0.5993
Combination of evacuation and aircraft crash	Risk neutral	0.7056	0.6722
	Risk averse-poly.	0.8019	0.7253
	Risk averse-expo.	0.7858	0.7188
	Risk prone-poly.	0.5990	0.6031
	Risk prone-expo.	0.6105	0.6009
Combination of evacuation and NPP crash	Risk neutral	0.6345	0.7569
	Risk averse-poly.	0.7275	0.8091
	Risk averse-expo.	0.7118	0.8020
	Risk prone-poly.	0.5418	0.6879
	Risk prone-expo.	0.5449	0.6858

Table 3.4.16: Weights and the attributes for the scenario 5

Attribute	Weight	Attribute	Weight
Seismic hazard	0.1056	Immovable cultural heritage	0.0909
Tsunami hazard	0.1018	Distance between NPP and city center	0.0348
Forestry	0.0253	Population density	0.1167
Natural parks	0.0185	Distance to airports	0.0396
Nature conservation areas	0.0774	Distance to bus terminal	0.0786
Natural monuments	0.1491	Wind conditions	0.1086
Biodiversity	0.0529		

Table 3.4.17: Utility values corresponding to scenario 5

Attitude for utility function	Function	Utility for Akkuyu site	Utility for Abalı site
Risk neutral	Linear	0.5992	0.6365
Risk averse	Polynomial	0.7130	0.7086
Risk averse	Exponential	0.6907	0.6903
Risk prone	Polynomial	0.5021	0.5594
Risk prone	Exponential	0.5097	0.5581

Table 3.4.18: Utility values of four combinations of the attributes for scenario 5

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.5616	0.5605
	Risk averse-poly.	0.6750	0.6323
	Risk averse-expo.	0.6535	0.6144
	Risk prone-poly.	0.4602	0.4829
	Risk prone-expo.	0.4700	0.4817
Combination of job opportunity and NPP crash	Risk neutral	0.5297	0.5985
	Risk averse-poly.	0.6415	0.6700
	Risk averse-expo.	0.6202	0.6519
	Risk prone-poly.	0.4344	0.5210
	Risk prone-expo.	0.4405	0.5199
Combination of evacuation and aircraft crash	Risk neutral	0.6687	0.6745
	Risk averse-poly.	0.7844	0.7471
	Risk averse-expo.	0.7611	0.7287
	Risk prone-poly.	0.5697	0.5977
	Risk prone-expo.	0.5790	0.5963
Combination of evacuation and NPP crash	Risk neutral	0.6368	0.7126
	Risk averse-poly.	0.7509	0.7848
	Risk averse-expo.	0.7278	0.7661
	Risk prone-poly.	0.5439	0.6358
	Risk prone-expo.	0.5494	0.6345

It is seen from Table 3.4.18 that randomly allocated weights cause some changes in the results of the combination of population density and the distance between NPP and the airport. Akkuyu site has higher utility for the combination of the population density for the job opportunity and NPP crash due to an aircraft crash scenario for all risk attitudes but Abalı site has better utility value after the random allocation of the weights for risk prone case. Moreover, some changes are observed in the combination of evacuation of people in case of an NPP accident and NPP crash due to an aircraft crash. Akkuyu site loses its superiority for risk neutral and prone cases for this combination. The results of the other combinations remain the same for this scenario.

Scenario 6: Comparison of the candidate sites under the dominance of attributes which are related to human life

The last scenario regards the attributes which may affect human health or may result in loss of human life. More weights are given to such attributes and relatively low weights are given to the remaining attributes. Accordingly, seismic and tsunami hazards, distance between NPP and city center, population density, distance to airport and bus terminal and extreme wind hazard are evaluated with weight of 0.1 for each and the remaining six attributes, forestry, natural parks, nature conservation areas, natural monuments, biodiversity and immovable cultural heritage with the weight of 0.05. The utility values are given in Table 3.4.19.

Table 3.4.19: Utility values corresponding to scenario 6

Attitude for utility function	Function	Utility for Akkuyu site	Utility for Abalı site
Risk neutral	Linear	0.5650	0.5839
Risk averse	Polynomial	0.6823	0.6476
Risk averse	Exponential	0.6587	0.6324
Risk prone	Polynomial	0.4682	0.5224
Risk prone	Exponential	0.4778	0.5206

The output of the multi-attribute utility function of this scenario indicates that Abalı site has better utility value for risk neutral and risk prone cases. The utility values obtained from the combinations of the attributes are provided in Table 3.4.20.

Table 3.4.20: Utility values of four combinations of the attributes for scenario 6

Combination of Attributes	Attitude for utility func.	Utility for Akkuyu site	Utility for Abalı site
Combination of job opportunity and aircraft crash	Risk neutral	0.5595	0.4869
	Risk averse-poly.	0.6777	0.5508
	Risk averse-expo.	0.6546	0.5362
	Risk prone-poly.	0.4538	0.4250
	Risk prone-expo.	0.4685	0.4233
Combination of job opportunity and NPP crash	Risk neutral	0.4788	0.5831
	Risk averse-poly.	0.5931	0.6460
	Risk averse-expo.	0.5706	0.6308
	Risk prone-poly.	0.3887	0.5214
	Risk prone-expo.	0.3938	0.5197
Combination of evacuation and aircraft crash	Risk neutral	0.6513	0.5847
	Risk averse-poly.	0.7715	0.6492
	Risk averse-expo.	0.7468	0.6341
	Risk prone-poly.	0.5476	0.5234
	Risk prone-expo.	0.5618	0.5215
Combination of evacuation and NPP crash	Risk neutral	0.5705	0.6808
	Risk averse-poly.	0.6869	0.7444
	Risk averse-expo.	0.6628	0.7286
	Risk prone-poly.	0.4825	0.6198
	Risk prone-expo.	0.4872	0.6180

Table 3.4.20 indicates that giving more weights to the attributes that are related to human life do not change the results of the combinations of population density and the distance between NPP and the airport.

Since this scenario emphasizes the importance of human life, another assessment is performed by considering the attributes related to the evacuation of people in case of an NPP accident. Population density, distance to airport and bus terminal attributes are evaluated for evacuation purpose regardless of the other attributes. Utility values for Mersin-Akkuyu and Sinop-Abalı sites are given in Table 3.4.21.

Table 3.4.21: Utility values corresponding to scenario 6-assessment of evacuation-related attributes

Attitude for utility function	Function	Utility for Akkuyu site	Utility for Abalı site
Risk neutral	Linear	0.4902	0.9798
Risk averse	Polynomial	0.5831	0.9925
Risk averse	Exponential	0.5554	0.9905
Risk prone	Polynomial	0.4337	0.9751
Risk prone	Exponential	0.4242	0.9728

Table 3.4.21 shows that Sinop-Abalı site is better than Mersin-Akkuyu site in terms of utility value when the attributes related to evacuation of people are considered.

3.4.3 Comparison of the Candidate Sites under Different Risk Attitudes

In the previous comparisons, different scenarios are constructed and candidate sites are compared in terms of utility values within the same risk attitude, risk neutral, averse or prone cases. In this part of the study, utility values from different risk attitudes are combined and candidate sites are compared in terms of multi-attribute utility value. The attributes which are related to human life are considered in risk averse attitude. On the other hand, attributes related to the environmental impact are evaluated in risk neutral attitude and immovable cultural heritage attribute is investigated in risk prone attitude. The utility values of the candidate sites are given in Table 3.4.22.

Table 3.4.22: Utility values corresponding to different risk attitude assessments

Function	Utility for Akkuyu site	Utility for Abalı site
Polynomial	0.6693	0.6690
Exponential	0.6522	0.6579

It is inferred from Table 3.4.22 that when polynomial utility functions are evaluated, Akkuyu site is better than Abalı site in terms of utility value. However, when exponential utility functions are considered, Abalı site is slightly better than Akkuyu site.

3.5 Sensitivity Analysis of the Multi-attribute Siting Study

Determination of the best site under multi-attribute utility theory requires using probabilities in the assessment of the single-attribute utility functions. In risk averse and risk prone functions, the probabilities are subjective but still depends on educated guesses. The sensitivity analysis is conducted to diminish the effect of subjectiveness. It also enables to see whether the changes in the assessment of subjective probabilities have a significant impact on the utility values of the candidate sites. An attribute is chosen from each different types of attributes. Specifically, seismic hazard from natural hazards, distance to bus terminal from human-induced hazards and population density from other attributes are selected to examine the utility values under different subjective assessments and indifference points are given in Table 3.5.1.

Table 3.5.1: Indifference points for sensitivity analysis

Attribute	Risk averse assessment	Risk prone assessment
Seismic hazard	u(0.65)=0.6 u(0.65)=0.7	u(0.65)=0.2 u(0.65)=0.4
Distance to bus terminal	u(90)=0.6 u(90)=0.8	u(90)=0.3 u(90)=0.5
Population density (job opportunity)	u(1500)=0.6 u(1500)=0.8	u(1500)=0.3 u(1500)=0.5
Population density (evacuation)	u(1500)=0.6 u(1500)=0.65	u(1500)=0.3 u(1500)=0.45

Single-attribute utility functions are obtained using the indifference points stated in Table 3.5.1. The worst and best levels remain the same in the sensitivity analysis.

3.5.1 Reassessment of Utilities for Seismic Hazard Attribute

The first reassessment is conducted under risk averse case. Utility functions for the new assessments are given in Table 3.5.2.

Table 3.5.2: Risk averse functions for seismic hazard attribute

Risk averse assessment	Function type	Function
u(0.65)=0.6	Polynomial	$-0.3233 * x^2 - 0.4058 * x + 1.0004$
	Exponential	$-0.5764 * exp(0.8116 * x) + 1.557$
u(0.65)=0.7	Polynomial	$-0.5845 * x^2 - 0.0817 * x + 1.0001$
	Exponential	$-0.1757 * exp(1.533 * x) + 1.176$

The second reassessment is performed under risk prone case. The utility functions in both polynomial and exponential forms are provided in Table 3.5.3.

Utility values for risk averse and risk prone functions are obtained and presented in Tables 3.5.4 and 3.5.5.

Results of sensitivity study for seismic hazard attribute indicate that Abalı site is better than Akkuyu site in terms of utility for both return periods, 5000 and 10000 years. This is the same result obtained in the single attribute utility assessment for the seismic hazard.

Table 3.5.3: Risk prone functions for seismic hazard attribute

Risk prone assessment	Function type	Function
u(0.65)=0.2	Polynomial	$0.7213 * x^2 - 1.7022 * x + 1.0017$
	Exponential	$1.086 * exp(-2.064 * x) - 0.084$
u(0.65)=0.4	Polynomial	$0.199 * x^2 - 1.054 * x + 1.0011$
	Exponential	$2.168 * exp(-0.4994 * x) - 1.167$

Table 3.5.4: Utility values for seismic hazard attribute with return period of 5000 years

Attitude for utility function	Assessment	Function type	Utility for Akkuyu site	Utility for Abalı site
Risk averse	u(0.65)=0.6	Polynomial	0.8892	0.9015
	u(0.65)=0.7	Polynomial	0.9499	0.9575
	u(0.65)=0.6	Exponential	0.8816	0.8941
	u(0.65)=0.7	Exponential	0.9255	0.934
Risk prone	u(0.65)=0.2	Polynomial	0.6467	0.6777
	u(0.65)=0.4	Polynomial	0.768	0.7897
	u(0.65)=0.2	Exponential	0.5898	0.6217
	u(0.65)=0.4	Exponential	0.7645	0.7863

Table 3.5.5: Utility values for seismic hazard attribute with return period of 10000 years

Attitude for utility function	Assessment	Function type	Utility for Akkuyu site	Utility for Abalı site
Risk averse	u(0.65)=0.6	Polynomial	0.86	0.8776
	u(0.65)=0.7	Polynomial	0.9304	0.9424
	u(0.65)=0.6	Exponential	0.8521	0.8698
	u(0.65)=0.7	Exponential	0.9051	0.9174
Risk prone	u(0.65)=0.2	Polynomial	0.5785	0.6186
	u(0.65)=0.4	Polynomial	0.7193	0.7482
	u(0.65)=0.2	Exponential	0.5222	0.5616
	u(0.65)=0.4	Exponential	0.7158	0.7447

3.5.2 Reassessment of Utilities for the Distance to Bus Terminal Attribute

Distance to bus terminal attribute is evaluated with different assessments under risk averse and risk prone cases. Corresponding functions are provided in Tables 3.5.6 and 3.5.7.

Utility values can be found with the help of polynomial and exponential utility functions. The results are shown in Table 3.5.8.

Table 3.5.6: Risk averse functions for the distance to bus terminal attribute

Risk averse assessment	Function type	Function
u(90)=0.6	Polynomial	$-4 * 10^{-6} * x^2 - 0.0043 * x + 1.0218$
	Exponential	$-2.9 * exp(0.0015 * x) + 3.922$
u(90)=0.8	Polynomial	$-3 * 10^{-5} * x^2 + 4 * 10^{-5} * x + 1.0004$
	Exponential	$-0.117 * exp(0.0113 * x) + 1.124$

Table 3.5.7: Risk prone functions for the distance to bus terminal attribute

Risk prone assessment	Function type	Function
u(90)=0.3	Polynomial	$3 * 10^{-5} * x^2 - 0.0109 * x + 1.0539$
	Exponential	$1.183 * exp(-0.0116 * x) - 0.116$
u(90)=0.5	Polynomial	$7 * 10^{-6} * x^2 - 0.0065 * x + 1.0325$
	Exponential	$2.505 * exp(-0.0026 * x) - 1.472$

Table 3.5.8: Utility values for the distance to bus terminal attribute

Attitude for utility function	Assessment	Function type	Utility for Akkuyu site	Utility for Abalı site
Risk averse	u(90)=0.6	Polynomial	0.4503	0.9815
	u(90)=0.8	Polynomial	0.5761	0.9981
	u(90)=0.6	Exponential	0.4484	0.9811
	u(90)=0.8	Exponential	0.6715	0.994
Risk prone	u(90)=0.3	Polynomial	0.1794	0.9554
	u(90)=0.5	Polynomial	0.3552	0.9728
	u(90)=0.3	Exponential	0.1791	0.9462
	u(90)=0.5	Exponential	0.3506	0.972

Results from Table 3.5.8 reveals that Abalı site has higher utility value for all of the attitudes toward risk and for all assessments.

3.5.3 Reassessment of Utilities for the Population Density Attribute

Population density is reassessed from two different aspects; job opportunity and evacuation of people in case of an NPP accident. Risk averse and prone utility functions are constructed and presented in Table 3.5.9 and 3.5.10.

Table 3.5.9: Risk averse functions for the population density in terms of job opportunity attribute

Risk averse assessment	Function type	Function
u(1500)=0.6	Polynomial	$-3 * 10^{-8} * x^2 - 0.0004 * x - 0.0049$
	Exponential	$-2.655 * exp(-1.7241 * 10^{-4} * x) + 2.65$
u(1500)=0.8	Polynomial	$- * 10^{-7} * x^2 - 0.0007 * x - 0.0082$
	Exponential	$-1.111 * exp(-8.726 * 10^{-4} * x) - 1.1$

Table 3.5.10: Risk prone functions for the population density in terms of job opportunity attribute

Risk prone assessment	Function type	Function
u(1500)=0.3	Polynomial	$10^{-7} * x^2 + 7 * 10^{-6} * x - 9 * 10^{-5}$
	Exponential	$0.145 * exp(-7.494 * 10^{-4} * x) - 0.1462$
u(1500)=0.5	Polynomial	$2 * 10^{-8} * x^2 - 0.0003 * x - 0.0033$
	Exponential	$2.498 * exp(-1.224 * 10^{-4} * x) - 2.501$

Utility values of candidate sites can be obtained from these functions to compare them in terms of job opportunity. Corresponding results are given in Table 3.5.11.

Utility values are shown that Akkuyu site is better than Abalı site in terms of job opportunity.

Table 3.5.11: Utility values for the population density in terms of job opportunity attribute

Attitude for utility function	Assessment	Function type	Utility for Akkuyu site	Utility for Abalı site
Risk averse	u(1500)=0.6	Polynomial	0.0399	0.0102
	u(1500)=0.8	Polynomial	0.0696	0.0182
	u(1500)=0.6	Exponential	0.0462	0.0123
	u(1500)=0.8	Exponential	0.0933	0.0252
Risk prone	u(1500)=0.3	Polynomial	0.0019	0.0003
	u(1500)=0.5	Polynomial	0.0308	0.0081
	u(1500)=0.3	Exponential	0.0116	0.0029
	u(1500)=0.5	Exponential	0.0317	0.0086

The next evaluation considers the evacuation scenario for the population density. Risk averse and prone utility functions are constructed and shown in Tables 3.5.12 and 3.5.13.

Table 3.5.12: Risk averse functions for the population density in terms of evacuation attribute

Risk averse assessment	Function type	Function
u(1500)=0.6	Polynomial	$-8 * 10^{-8} * x^2 - 0.0002 * x + 1.0017$
	Exponential	$-0.4573 * exp(4.206 * 10^{-4} * x) + 1.459$
u(1500)=0.65	Polynomial	$-10^{-7} * x^2 - 8 * 10^{-5} * x + 1.0009$
	Exponential	$-0.2542 * exp(5.79 * 10^{-4} * x) + 1.256$

Utility values are obtained and displayed in Table 3.5.14 in order to compare the candidate sites in terms of evacuation of people in case of an NPP crash.

Table 3.5.14 indicates that Abalı site has higher utility value in terms of evacuation of people in case of an NPP accident.
Sensitivity results imply that changes in the subjective probabilities for the assessment

Table 3.5.13: Risk prone functions for the population density in terms of evacuation attribute

Risk prone assessment	Function type	Function
u(1500)=0.3	Polynomial	$8 * 10^{-8} * x^2 - 0.0006 * x + 1.0066$
	Exponential	$1.359 * exp(-4.9 * 10^{-4} * x) - 0.3516$
u(1500)=0.45	Polynomial	$4 * 10^{-9} * x^2 - 0.0004 * x + 1.0041$
	Exponential	$11.18 * exp(-3.407 * 10^{-5} * x) - 10.17$

Table 3.5.14: Utility values for the population density in terms of evacuation attribute

Attitude for utility function	Assessment	Function type	Utility for Akkuyu site	Utility for Abalı site
Risk averse	u(1500)=0.6	Polynomial	0.978	0.9939
	u(1500)=0.65	Polynomial	0.9905	0.9977
	u(1500)=0.6	Exponential	0.9794	0.9943
	u(1500)=0.65	Exponential	0.9846	0.9961
Risk prone	u(1500)=0.3	Polynomial	0.9398	0.9839
	u(1500)=0.45	Polynomial	0.9589	0.9889
	u(1500)=0.3	Exponential	0.9341	0.9823
	u(1500)=0.45	Exponential	0.967	0.9955

of the single attribute utility functions do not change the superiority of the candidate site. For seismic hazard, distance to bus terminal and population density for the evacuation, Abalı site has better utlity value than Akkuyu site. On the other hand, Akkuyu site is better than Abalı site in terms of utility value of population density for the job opportunity attribute.

CHAPTER 4

SUMMARY AND CONCLUSIONS

Nuclear power plants require detailed siting procedures to protect the community and the environment from different potential hazards. Environmental, economic, socioeconomic, health and safety issues should be considered while choosing the suitable site for a nuclear power plant.

Previous studies about NPP siting procedures used subjective probabilities for the construction of single-attribute utility functions without considering risk attitudes or under a selected risk attitude for the attributes. This study concerns each type of risk attitude, risk neutral, risk averse and risk prone and enables to evaluate the candidate sites according to these attitudes. Additionally, thirteen attributes that measure the degree of achievement of different objectives are investigated for Mersin-Akkuyu and Sinop-Abalı sites. Another contribution of the study is to conduct PSHA for the candidate sites and to use the peak ground acceleration values obtained from PSHA for the construction of seismic hazard utility function. This provides more realistic results for the evaluation of the attribute. Besides, this study involves also a multi-hazard assessment analysis with respect to natural hazards, where earthquake, tsunami and extreme wind effects are considered.

In this study, two candidate nuclear power plant sites in Turkey are compared using multi-criteria decision making. First of all, objectives are determined and the attributes which meet the objectives are chosen. Then, the data related to the attributes are collected. Natural hazards, human-induced hazards and other attributes related to the health and safety of community and the environment are evaluated under multi-attribute utility theory. For seismic hazard attribute, active fault lines are determined and the coordinates of them are recorded. Then, PSHA is carried out for both of the candidate sites and the results obtained from this analysis are used for the construction of single attribute utility functions. Expert opinion is taken for tsunami hazard attribute and data is collected from several sources for the remaining attributes. Accordingly, single attribute utility functions are constructed for three different risk attitudes which have not been conducted before. For risk neutral case, linear utility functions and for risk averse and risk prone cases, polynomial and exponential utility functions are obtained. After that, single-attribute utility values are found for each of the attribute and Mersin-Akkuyu and Sinop-Abalı sites are compared with respect to their utility values. Then, multi attribute utility value is calculated by constructing many scenarios. The results derived from single-attribute polynomial and exponential functions show that preferred candidate site remains the same for both polynomial and exponential functions.

Six different scenarios are constructed by giving different weights to each attribute. In the first scenario, equal weights are given to all of the attributes. Abalı site is found to have a higher utility value than the Akkuyu site.

In scenario 2, the importance of natural hazards is emphasized and remaining attributes are assessed with equal weights. Akkuyu site is found better than Abalı site in terms of utility value according to scenario 2.

When much higher importance is given to natural hazards, like in scenario 3, Akkuyu site is preferred to Abalı site.

When the weight of natural hazards are decreased and more weight is given to the other attributes, Abalı site becomes more favorable in most of the cases.

In scenario 5, all of the weights are assigned to the attributes randomly and it is observed that Abalı site is better in terms of utility value.

As the last scenario (scenario 6), more weight is given to the attributes which are related to protecting human life and other attributes get relatively low weights. In this scenario, the same result is observed as in the last two scenarios. When only the attributes related to evacuation of people in case of an NPP accident are evaluated, Sinop-Abalı site is found better in terms of utility value.

When the candidate sites are compared in terms of the attributes having different risk attitudes, Mersin-Akkuyu site is better than Sinop-Abalı site when polynomial utility functions are considered for risk averse and risk prone cases. While, Abalı site has higher utility value when exponential functions are taken into consideration.

Since the probabilities assigned to the attributes are subjective in risk averse and risk prone attitudes, the sensitivity analysis is performed to see the possible effects of the changes in the assessments of probabilities on the result. Three attributes are selected from natural hazards, human-induced hazards and other type of attributes. Sensitivity analysis indicates that changing the subjective probabilities does not change the conclusion with respect to the preferred site based on the single-attribute utility functions.

Table 4.0.1: Overall comparison of the candidate sites under different scenarios (X indicates preferred site with respect to the computed utility values.)

Scenario	Combination of the attributes	Akkuyu site	Abalı site
Scenario 1	Overall comparison		X
Scenario 2	Case 1-overall comparison	X	
Scenario 2	Case 2-overall comparison		X
Scenario 2	Case 3-overall comparison		X
Scenario 2	Case 4-overall comparison	X	
Scenario 3	Case 1-overall comparison	X	
Scenario 3	Case 2-overall comparison		X
Scenario 3	Case 3-overall comparison		X
Scenario 3	Case 4-overall comparison	X	
Scenario 4	Overall comparison		X
Scenario 5	Overall comparison		X
Scenario 6	Overall comparison		X

It is seen from Table 4.0.1 that Akkuyu site has higher utility value than Abalı site for the first and the last cases of the second and third scenarios. In the remaining cases, Abalı site is better than Akkuyu site in terms of assessed utility values.
As a result, when all of the scenarios are taken into consideration, Sinop-Abalı site is proposed as the preferred site for the construction of the nuclear power plant.

In NPP siting study, all attributes are assumed to be independent. For future research, dependencies among the attributes can be considered and analyses are constructed based on conditional probabilities. Additionally, construction of single-attribute utility functions requires the assessment of subjective probabilities. These probabilities used in the utility functions can be revised after expert opinions are taken into consideration for future research. Another issue to be explored for future research is using additional attributes. For instance, proximity to cooling water sources, initial construction costs, socioeconomic impacts of NPP construction could be assessed for multi-criteria decision making.

REFERENCES

[1] "The History of Nuclear Energy," tech. rep., U.S. Department of Energy Office of Nuclear Energy, Science and Technology.

[2] "Outline History of Nuclear Energy." Available at http://www.world-nuclear.org/information-library/current-and-future-generation/outline-history-of-nuclear-energy.aspx, August 2018.

[3] C. J. Cleveland, *Concise Encylopedia of History of Energy*. Elsevier, first ed., 2009.

[4] International Atomic Energy Agency, "Atoms for Peace." Available at https://www.iaea.org/about/history/atoms-for-peace-speech.

[5] N. Char and B. Csik, "Nuclear power development: History and outlook," tech. rep., International Atomic Energy Agency, 1987.

[6] "Country Nuclear Power Profiles." Available at https://cnpp.iaea.org/countryprofiles/Russia/Russia.htm. updated 2018.

[7] "Chernobyl Accident 1986." Available at http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx. Updated April 2018.

[8] Wikipedia, "Build-operate-transfer." Available at https://en.wikipedia.org/wiki/Buildoperatetransfer.

[9] M. Rouse, "Build-own-operate model." Available at https://whatis.techtarget.com/definition/BOO-project-build-own-operate-project.

[10] "Country Nuclear Power Profiles." Available at https://cnpp.iaea.org/countryprofiles/Turkey/Turkey.htm. updated 2018.

[11] International Atomic Energy Agency, "Site Survey and Site Selection for Nuclear Installations." Available at https://www-pub.iaea.org/MTCD/publications/PDF/Pub1690Web-41934783.pdf, July 2015.

[12] R. L. Keeney and K. Nair, "Selecting Nuclear Power Plant Sites in the Pacific Northwest Using Decision Analysis," in *Conflicting Objectives in Decisions* (D. Bell, R. Keeney, and H. Raiffa, eds.), ch. 14, pp. 298–322, Wiley, 1977.

[13] C. W. Kirkwood, "A Case History of Nuclear Power Plant Site Selection," *The Journal of the Operational Research Society*, vol. 33, pp. 353–363, April 1982. Retrieved from http://www.theorsociety.com/Pages/Publications/JORS.aspx.

[14] O. Omitaomu, B. Blevins, W. Jochem, G. Mays, R. Belles, and S. Hadley, "Adapting a GIS-based multicriteria decision analysis approach for evaluating new power generating sites," *Applied Energy*, December 2011. doi: 10.1016/j.apenergy.2011.11.087.

[15] H. Pwani, F. Kamanja, and Z. Zolkaffly, "NPP Site Selection: A Systems Engineering Approach," *Journal of the Korea Society of Systems Engineering*, vol. 9, pp. 55–63, June 2013. Retrieved from https://www.researchgate.net/publication/264178351_NPP_Site_Selection_A_Systems_Engineering_Approach.

[16] M. Kassim and D. Kessel, "Selection Methodology Approach to Preferable and Alternative Sites for the First NPP Project in Yemen," May 2015.

[17] N. Basri, S. Hashim, A. Ramli, and K. Hamzah, "Regulatory requirements for nuclear power plant site selection in Malaysia-a review," *Journal of Radiological Protection*, September 2016. doi:10.1088/0952-4746/36/4/R96.

[18] C. Wang, C. Su, and V. Nguyen, "Nuclear Power Plant Location Selection in Vietnam under Fuzzy Environment Conditions," *Symmetry*, October 2018. doi:10.3390/sym10110548.

[19] G. Bezedi, M. Sorour, S. Tewfik, A. Abulnour, and M. El-Sayed, "Multi-criteria decision making for small/medium nuclear desalination site selection: Egypt

case study," *ARPN Journal of Engineering and Applied Sciences*, vol. 13, February 2018. Retrieved from http://www.arpnjournals.org/jeas/research_papers/rp_2018/jeas_0218_6762.pdf.

[20] Türkiye Elektrik Kurumu Nükleer Enerji Dairesi, "Türkiye'de kurulması öngörülen nükleer santral için yaplması gerekli yersel araştırmalar," February 1975.

[21] A. Gürpınar, P. Gülkan, c. Soydemir, S. Gençoğlu, O. Yener, and M. Çelebi, "Aksaz ve Marmara Ereğlisi'nde Yaplması Öngörülen Nükleer Enerji Santralları İçin Yerel Deprem Değerlendirmesi," July 1975.

[22] I. Erol, S. Sencer, A. Özmen, and C. Searcy, "Fuzzy MCDM framework for locating a nuclear power plant in Turkey," *Energy Policy*, December 2013. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421513011865.

[23] R. L. Keeney and H. Raiffa, *Decisions with Multiple Objectives*. Cambridge University Press, 1993.

[24] R. L. Keeney, *Siting Energy Facilities*. 111 Fifth Avenue,New York, New York 10003: Academic Press, 1980.

[25] International Atomic Energy Agency, "Basic safety principles for nuclear power plants 75-insag-3 rev.1." Available at http://www.pub.iaea.org/MTCD/publications/PDF/P082scr.pdf, 1999.

[26] R. L. Winkler, *An Introduction to Bayesian Inference and Decision*. Holt,Rinehart and Winston, Inc., 1972.

[27] J. W. Baker, "An introduction to probabilistic seismic hazard analysis." Available at https://web.stanford.edu/~bakerjw/Publications/Baker_(2008)_Intro_to_PSHA_v1_3.pdf, 2008.

[28] M. S. Yücemen and P. Gülkan, "Seismic Risk Analysis for Nuclear Power Plants," tech. rep., Middle East Technical University, Department of Applied Statistics, 1976.

[29] USGS, “The Modified Mercalli Intensity Scale.” Available at https://earthquake.usgs.gov/learn/topics/mercalli.php.

[30] USGS, “Magnitude/ intensity comparison.” Available at https://earthquake.usgs.gov/learn/topics/mag_vs_int.php.

[31] O. Emre, T. Duman, S. Özalp, H. Elmacı, Ş. Olgun, and F. Şaroğlu, “Turkey live fault map 1/1.250.000.” General Directorate of Mineral Research and Exploration special publications series, Ankara, Turkey, 2013.

[32] O. Emre, T. Duman, S. Özalp, H. Elmacı, Ş. Olgun, F. Şaroğlu, and T. Çan, “Active fault database of Turkey,” *Bulletin of Earthquake Engineering*, 2016. doi:10.1007/s10518-016-0041-2.

[33] Disaster and Emergency Management Authority Presidental of Earthquake Department, “Earthquake Catalog.” Available at https://deprem.afad.gov.tr/depremkatalogu?lang=en.

[34] A. Deniz and M. Yucemen, “Magnitude conversion problem for the turkish earthquake data,” *Natural Hazards*, vol. 55, pp. 333–352, 11 2010.

[35] EZ-FRISK, “Ez-frisk software fro earthquake ground motion estimation (7.52).” Available at https://www.ez-frisk.com, 2019.

[36] Atomic Energy Regulatory Board, “Seismic studies and design basis ground motion for nuclear power plants.” Available at https://aerb.gov.in/storage/uploads/documents/regdocWndoQ.PDF, 3 1990.

[37] Government of India, “Monograph on siting of nuclear power plants.” Available at https://aerb.gov.in/images/PDF/Siting.pdf, 2014.

[38] O. Glöckler, “Effects of extreme weather on nuclear power plants.” Available at http://indico.ictp.it/event/a09141/session/34/contribution/24/material/0/0.pdf, 2010.

[39] Foro Nuclear, “How do nuclear power plants withstand hurricanes.” Available at https://www.foronuclear.org/en/ask-the-expert/120060-how-do-nuclear-power-plants-withstand-hurricanes-.

[40] "Nuclear Power Plant Akkuyu," Tech. Rep. 1, Akkuyu Npp Power Generation Joint Stock Company, May 2013.

[41] "Sinop nükleer güç sanrali projesi," tech. rep., Elektrik Üretim A.Ş., 2017.

[42] Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and Natural Parks, "Resmi İstatistikler." Available at http://www.milliparklar.gov.tr/resmiistatistikler, 2017.

[43] Biodiversity a-z, "Endemic species." Available at https://www.biodiversitya-z.org/content/endemic-species, 2014.

[44] Republic of Turkey Ministry of Agriculture and Forestry, "Biyoçeşitlilik Verileri." Available at http://www.nuhungemisi.gov.tr/istatistik/, 2017.

[45] M. Khattak, A. Umairah, M. Amirudin Mohamad Rosli, S. Sabri, M. Akmal Saad, M. Solehan Abd. Hamid, S. Badshah, and S. Kazi, "Siting consideration for nuclear power plant: A review," *Open Science Journal*, vol. 2, 07 2017.

[46] Republic of Turkey the Ministry of Culture and Tourism, "İllere Göre Korunması Gerekli Taşnmaz Kültür Varlığı İstatistikleri ." Available at https://kvmgm.ktb.gov.tr/TR-44799/illere-gore-korunmasi-gerekli-tasinmaz-kultur-varligi-i-.html, 2018.

[47] Google, "GoogleEarth Pro application (7.3.2.5776)." Available at https://www.google.com.tr/intl/tr/earth/, 2019.

[48] General Directorate of Mapping, "İl ve İlçe Yüz Ölçümleri ." Available at https://www.harita.gov.tr/images/urun/il_ilce_alanlari.pdf, 2014.

[49] Turkish Statistical Institute, "Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları ." Available at https://biruni.tuik.gov.tr/medas/?kn=95&locale=tr, 2018.

[50] M. Erdoğan and I. Kaya, “A combined fuzzy approach to determine the best region for a nuclear power plant in Turkey,” *Applied Soft Computing*, November 2015. Retrieved from https://www.sciencedirect.com/science/article/pii/S1568494615007279.

[51] E. Cunningham and G. Bagchi, “Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America,” tech. rep., United States Nuclear Regulatory Commission, 2009.

[52] Wikipedia, “Peak ground acceleration.” Available at https://en.wikipedia.org/wiki/Peak_ground_acceleration.

APPENDIX A

PSHA OUTPUT FOR MERSİN-AKKUYU SITE

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Probabilistic Spectra results for EZ-FRISK 7.52 Build 003

ANNUAL FREQUENCY OF EXCEEDANCE: 4.041e-004
RETURN PERIOD: 2474.9
PROBABILITY OF EXCEEDENCE: 2.0% IN 50.0 YEARS
  Column 1: Spectral Period
  Column 2: Acceleration (g) for: Mean
  Column 3: Acceleration (g) for: Abrahamson-Silva (2008) NGA
  Column 4: Acceleration (g) for: Boore-Joyner-Fumal (1997)
  Column 5: Acceleration (g) for: Gülerce et. al. (2015)
```

1	2	3	4	5
PGA	1.872e-001	1.791e-001	2.024e-001	1.746e-001
5.e-002	2.507e-001	2.364e-001	2.751e-001	2.365e-001
0.1	3.587e-001	3.745e-001	3.250e-001	3.747e-001
0.2	4.413e-001	4.479e-001	4.276e-001	4.481e-001
0.3	3.797e-001	3.804e-001	3.773e-001	3.813e-001
0.4	3.026e-001	3.002e-001	3.061e-001	3.018e-001
0.5	2.342e-001	2.275e-001	2.461e-001	2.297e-001
0.75	1.368e-001	1.294e-001	1.514e-001	1.294e-001
1.	9.224e-002	8.398e-002	1.076e-001	8.396e-002
2.	4.273e-002	2.469e-002	6.170e-002	2.470e-002
3.	2.757e-002	1.187e-002	4.082e-002	1.187e-002
4.	2.069e-002	6.134e-003	3.042e-002	6.135e-003

ANNUAL FREQUENCY OF EXCEEDANCE: 1.026e-003
RETURN PERIOD: 974.8
PROBABILITY OF EXCEEDENCE: 5.0% IN 50.0 YEARS
Column 1: Spectral Period
Column 2: Acceleration (g) for: Mean
Column 3: Acceleration (g) for: Abrahamson-Silva (2008) NGA
Column 4: Acceleration (g) for: Boore-Joyner-Fumal (1997)
Column 5: Acceleration (g) for: Gülerce et. al. (2015)

1	2	3	4	5
PGA	1.372e-001	1.285e-001	1.516e-001	1.260e-001
5.e-002	1.785e-001	1.663e-001	1.988e-001	1.665e-001
0.1	2.508e-001	2.611e-001	2.289e-001	2.613e-001
0.2	3.149e-001	3.191e-001	3.061e-001	3.195e-001
0.3	2.730e-001	2.745e-001	2.684e-001	2.760e-001
0.4	2.182e-001	2.177e-001	2.167e-001	2.201e-001
0.5	1.691e-001	1.650e-001	1.738e-001	1.685e-001
0.75	1.006e-001	9.724e-002	1.073e-001	9.724e-002
1.	6.719e-002	6.243e-002	7.615e-002	6.242e-002
2.	3.021e-002	1.861e-002	4.368e-002	1.861e-002
3.	1.959e-002	8.431e-003	2.893e-002	8.430e-003
4.	1.443e-002	4.242e-003	2.186e-002	4.242e-003

ANNUAL FREQUENCY OF EXCEEDANCE: 2.107e-003
RETURN PERIOD: 474.6
PROBABILITY OF EXCEEDENCE: 10.0% IN 50.0 YEARS
Column 1: Spectral Period
Column 2: Acceleration (g) for: Mean
Column 3: Acceleration (g) for: Abrahamson-Silva (2008) NGA
Column 4: Acceleration (g) for: Boore-Joyner-Fumal (1997)
Column 5: Acceleration (g) for: Gülerce et. al. (2015)

1	2	3	4	5
PGA	1.079e-001	9.927e-002	1.210e-001	9.758e-002
5.e-002	1.343e-001	1.244e-001	1.504e-001	1.247e-001
0.1	1.867e-001	1.943e-001	1.714e-001	1.945e-001
0.2	2.368e-001	2.393e-001	2.312e-001	2.399e-001
0.3	2.080e-001	2.092e-001	2.037e-001	2.110e-001
0.4	1.655e-001	1.647e-001	1.635e-001	1.681e-001
0.5	1.295e-001	1.265e-001	1.314e-001	1.305e-001
0.75	7.755e-002	7.571e-002	8.141e-002	7.571e-002
1.	5.195e-002	4.876e-002	5.782e-002	4.874e-002
2.	2.311e-002	1.436e-002	3.301e-002	1.436e-002
3.	1.468e-002	5.953e-003	2.217e-002	5.952e-003
4.	1.090e-002	3.191e-003	1.662e-002	3.190e-003

APPENDIX B

PSHA OUTPUT FOR SİNOP-ABALI SITE

Probabilistic Spectra results for EZ-FRISK 7.52 Build 003

ANNUAL FREQUENCY OF EXCEEDANCE: 4.041e-004
RETURN PERIOD: 2474.9
PROBABILITY OF EXCEEDENCE: 2.0% IN 50.0 YEARS
Column 1: Spectral Period
Column 2: Acceleration (g) for: Mean
Column 3: Acceleration (g) for: Boore-Joyner-Fumal (1997)
Column 4: Acceleration (g) for: Abrahamson-Silva (2008) NGA
Column 5: Acceleration (g) for: Gülerce et. al. (2015)

1	2	3	4	5
PGA	1.687e-001	1.921e-001	1.514e-001	1.454e-001
5.e-002	2.198e-001	2.168e-001	2.214e-001	2.214e-001
0.1	3.336e-001	2.407e-001	3.720e-001	3.722e-001
0.2	3.593e-001	3.239e-001	3.776e-001	3.776e-001
0.3	2.740e-001	2.839e-001	2.682e-001	2.685e-001
0.4	2.061e-001	2.276e-001	1.920e-001	1.927e-001
0.5	1.531e-001	1.811e-001	1.348e-001	1.357e-001
0.75	8.616e-002	1.082e-001	7.041e-002	7.041e-002
1.	5.617e-002	7.402e-002	4.182e-002	4.181e-002
2.	2.584e-002	3.808e-002	1.113e-002	1.111e-002
3.	1.709e-002	2.535e-002	4.395e-003	4.387e-003
4.	1.275e-002	1.925e-002	2.456e-003	2.451e-003

ANNUAL FREQUENCY OF EXCEEDANCE: 1.026e-003
RETURN PERIOD: 974.8
PROBABILITY OF EXCEEDENCE: 5.0% IN 50.0 YEARS
Column 1: Spectral Period
Column 2: Acceleration (g) for: Mean
Column 3: Acceleration (g) for: Boore-Joyner-Fumal (1997)
Column 4: Acceleration (g) for: Abrahamson-Silva (2008) NGA
Column 5: Acceleration (g) for: Gülerce et. al. (2015)

1	2	3	4	5
PGA	1.250e-001	1.465e-001	1.066e-001	1.033e-001
5.e-002	1.528e-001	1.571e-001	1.498e-001	1.499e-001
0.1	2.261e-001	1.703e-001	2.508e-001	2.510e-001
0.2	2.499e-001	2.330e-001	2.589e-001	2.589e-001
0.3	1.938e-001	2.048e-001	1.868e-001	1.872e-001
0.4	1.443e-001	1.625e-001	1.328e-001	1.337e-001
0.5	1.093e-001	1.289e-001	9.580e-002	9.693e-002
0.75	6.095e-002	7.709e-002	4.970e-002	4.970e-002
1.	3.917e-002	5.244e-002	2.924e-002	2.923e-002
2.	1.819e-002	2.695e-002	7.322e-003	7.308e-003
3.	1.188e-002	1.814e-002	3.007e-003	3.001e-003
4.	8.723e-003	1.355e-002	1.763e-003	1.759e-003

ANNUAL FREQUENCY OF EXCEEDANCE: 2.107e-003
RETURN PERIOD: 474.6
PROBABILITY OF EXCEEDENCE: 10.0% IN 50.0 YEARS
Column 1: Spectral Period
Column 2: Acceleration (g) for: Mean
Column 3: Acceleration (g) for: Boore-Joyner-Fumal (1997)
Column 4: Acceleration (g) for: Abrahamson-Silva (2008) NGA
Column 5: Acceleration (g) for: Gülerce et. al. (2015)

1	2	3	4	5
PGA	9.897e-002	1.189e-001	7.872e-002	7.640e-002
5.e-002	1.142e-001	1.213e-001	1.094e-001	1.094e-001
0.1	1.626e-001	1.278e-001	1.799e-001	1.801e-001
0.2	1.848e-001	1.771e-001	1.890e-001	1.892e-001
0.3	1.435e-001	1.545e-001	1.364e-001	1.370e-001
0.4	1.092e-001	1.237e-001	9.983e-002	1.008e-001
0.5	8.245e-002	9.900e-002	7.118e-002	7.254e-002
0.75	4.570e-002	5.834e-002	3.642e-002	3.642e-002
1.	2.936e-002	3.926e-002	2.217e-002	2.217e-002
2.	1.354e-002	2.064e-002	5.104e-003	5.093e-003
3.	8.703e-003	1.368e-002	2.243e-003	2.238e-003
4.	6.193e-003	1.033e-002	1.364e-003	1.361e-003