EVALUATION OF POTENTIAL RUN-OF RIVER HYDROPOWER PLANT SITES USING MULTI-CRITERIA DECISION MAKING IN TERMS OF ENVIRONMENTAL AND SOCIAL ASPECTS

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ABSTRACT

EVALUATION OF POTENTIAL RUN-OF RIVER HYDROPOWER PLANT SITES USING MULTI-CRITERIA DECISION MAKING IN TERMS OF ENVIRONMENTAL AND SOCIAL ASPECTS

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Electrical energy is an indispensable need of continuity of life in today's world. Therefore energy generation sources are one of the most important topics of countries, so that every country develops a strategy to use them efficiently. At this point, necessity of involving sustainability of energy sources in strategies makes hydropower energy become prominent. On the other hand, rapid increase in number of hydropower projects causes losing control of environmental effects of them. In this sense, a decision making methodology including environmental and social evaluation of run-of river hydropower plants is developed in the content of this study. In the scope of the study multi-criteria decision making (MCDM) analysis is used as decision making tool. For the MCDM analysis, ten environmental and social criteria are determined; for the aggregation of these criteria "and", "or", "Ordered Weighted Averaging" (OWA) and "Linear Weighted Averaging" (LWA) methods are used. Developed methodology is applied on five hydropower plants in Artvin/ Şavşat. Case study showed that "and" and "or" aggregation methods do not give chance to compare results and make no contribution to decision making process while OWA and LWA methods give useful results. Also, according to the case study implementation Gana is the most acceptable hydropower plant among five selected projects while Armutlu is the least acceptable one. Acceptability results of the case study implementation areas change between 0.17 and 0.72.

Keyword: Multi-criteria decision making, fuzzy logic, run-of river hydropower plant and environment, sustainability.

ÖZ

POTANSİYEL NEHİR TİPİ HİDROELEKTRİK SANTRAL ALANLARININ ÇOK KRİTERLİ KARAR VERME YAKLAŞIMI İLE ÇEVRESEL VE SOSYAL AÇIDAN DEĞERLENDİRİLMESİ

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Günümüz dünyasında elektrik enerjisi hayatın devamlılığı için vazgeçilmez ihtiyaç haline gelmiştir. Bu nedenle, enerji üretim kaynakları ülkeler için en önemli konulardan biridir, öyle ki her ülke enerji kaynaklarını verimli kullanmak için bir strateji geliştirmektedir. Bu noktada, enerji kaynaklarının sürdürülebilirliğinin de göz önünde bulundurulması gerekliliği hidroelektrik santrallerin öne çıkmasına neden olmaktadır. Diğer yandan hidroelektrik santrallerin sayısındaki hızlı artış, onların çevreye ve topluma olan etkilerinin kontrolünün kaybedilmesine yol açmıştır. Bu bağlamda, bu çalışmada nehir tipi hidroelektrik santraller için çevresel ve sosyal kriterler içeren bir karar verme metodolojisi geliştirilmiştir. Çalışma kapsamında karar verme yöntemi olarak çok kriterli karar verme analizi kullanılmıştır. Çok kriterli karar verme analizini uygulamak için çevresel ve sosyal değerlendirmeler içeren on kriter belirlenmiş, bu kriterler "ve", "veya", "Sıralı Ağırlıklı Ortalama" ve "Doğrusal Ağırlıklı Ortalama" yöntemleri kullanılmıştır. Geliştirilen yöntem Artvin / Şavşat bölgesinde beş nehir tipi hidroelektrik santral üzerinde uygulanmıştır. Örnek uygulama sonuçlar "ve" ve "veya" yöntemlerinin sonuçları kıyaslama imkânı vermediği, karar verme aşamasına katkı sağlamadığı, "Sıralı Ağırlıklı Ortalama" ve

"Doğrusal Ağırlıklı Ortalama" yöntemlerinin ise faydalı sonuçlar verdiğini ortaya koymuştur. Ayrıca örnek uygulama sonuçlarına göre Gana en kabul edilebilir, Armutlu ise en kabul edilemez proje olmuştur. Örnek uygulamanın yapıldığı projelerin kabul edilebilirlik değerleri 0.17 ile 0.72 arasında değişmektedir.

Anahtar kelimeler: Çok kriterli karar verme, bulanık mantık, nehir tipi hidroelektrik santral ve çevre, sürdürülebilirlik

to my parents…

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LIST OF ABBREVIATIONS

HPP Hydropower Plant

ESA Environmentally Sensitive Area

DSHA Deterministic Seismic Hazard Analysis

PGA Peak Ground Acceleration

PP Public Perception

OLR Organism Living in the River

FR Flow rate

ESA Distance from the Nearest Environmentally Sensitive Area

DFS Destructed Forest Size

MCDM Multi-criteria Decision Making

LWA Linear Weighted Average

LFR Low Flow Requirement

CHAPTER 1

INTRODUCTION

Together with unpredictable population growth and industrial developments, energy need in whole world has become an important issue. At the beginning stage of industrial developments, fossil fuel was used as the main energy generation source. However, as environmental concerns have became an issue and sustainability of energy sources have been considered as preference reason, renewable energy sources have became popular. In energy preferability list, hydropower is the fourth in world and it is the first among renewable sources (Guisandez, 2013). Especially in developing countries, use of hydropower has increased greatly after 1980s (Xiaochenget al., 2008). Share of hydropower in this production portion was 17% by year 2008, but still fossil fuel had the biggest share with 81% (Uzlu et al., 2008). However, beside its sustainability, no carbon emission advantage and economic contribution in constructed regions, hydropower plants have vital negative ecologic and social effects on surrounded areas. That is why many countries developed policies and rules that are had to be obeyed during the operation in order to minimize negative effects of the hydropower plants (Guisandez et al., 2013).

At 1970s energy sector's first priority was meeting the energy demand of the society that is why the sector focused on efficiencies of energy generation options which consist of energy-economy relationship. Because of that economy-oriented approach, low cost energy generation techniques became prominent in that time period. However in 1980s, growing environmental awareness modified the decision maker criteria. Environmental and social concerns were included in energy planning strategies (Pohekar and Ramachandran, 2004). Yet economy based decision making mechanism is still valid in so many regions; especially in developing countries.

Today, there are 411 hydropower plants in operation. Total hydropower potential of these plants is 35310 MW and production capacity is 125328 GWh/year [2]. When run-of river potential is considered; by year 2007, there were 142 run-of river hydropower plants in operation. Total installed capacity of these plants is 12788 MW and annual production capacity is 45930 GWh. This production number provides about 35% of total electricity demand and corresponds to 35.5 % of procurable hydropower potential in Turkey. Also, there are 41 hydropower plants that are on construction and correspond to 11.1% of total potential. Total planned production capacity of these power plants is 14351 GWh/year. In addition, in future, 69173 GWh/year hydropower potential is planned to be evaluated by 589 hydropower plants and they will constitute 53.4% of economically procurable potential (Akpınar and Kömürcü, 2009). However energy strategy plans are prepared by prioritizing economic contributions of the projects in Turkey. Environmental and social evaluations are carried out in the content of Environmental Impact Assessment Report; but hydropower projects whose energy generation capacities are less than 10MW are excluded Environmental Impact Assessment Report preparation obligation according to Turkish Environmental Impact Assessment Regulation that is published in gazette at 25.11.2014.

On the other hand, economic analyses of the project areas are done by the investors strictly. In economic feasibility studies, net benefit and annual energy income values are compared with annual investment cost. Since net benefit and annual investment costs are not directly proportional to annual investment cost for all energy generation capacities, optimum energy generation has to be selected with economic analysis (Ak,2011), (Çetinkaya, 2013).

As mentioned, it is a common practice to evaluate the feasibility of the possible hydroelectric power plant construction sites in a watershed-scale based on the economic and technical criteria. On the other hand, social and environmental criteria are often omitted in these evaluations because of the high cost and time to generate data to develop evaluation procedure. In addition, evaluation of the hydroelectric power plant site alternatives based on social and environmental criteria may bring high degree of uncertainties. Starting point of the study is to develop a tool to be used in feasibility studies of run-of river hydropower plants and make decision makers to think environmental and social aspects of the projects.

The aim of this study is to develop an approach to carry out an evaluation for site selection based on environmental and social acceptability criteria for run-of river hydropower plants.

Working Mechanism of Run-of River Hydropower Plants

Hydropower plants convert water pressure into mechanical shaft power that is used to drive an electric generator through the hydro turbines (Mishra et al., 2011). Design of run-of river hydropower plants need multi-disciplinary engineering or multi-specialist team work. The working group generally consists of hydraulic, hydrological structures, electric, mechanical, geologic and environmental experts. Essential components of the run-of river hydropower plants are; penstock, power house, tailrace, generating plant and allied equipments (Balat, 2007). Major components of run-of river hydropower plants and their arrangement are given in Figure 1.1.

In electric generation process in hydropower plants; a portion of river's water is taken from intake at a weir. The weir is a man-made structure that is constructed across the river and provides continuous flow through the intake. The taken water passes through the settling basin to clean out large particles and then it goes to surge tank by passing through the headrace. In the surge tank, water is slowed down sufficiently in order to enable suspended particles to settle out. The aim of settling out suspended particles, such as; stones, timber etc., is to prevent damaging of turbines. After surge tank, water is sent to power house by penstock or pipeline, and the rotating turbine, which is in power houses, generates electricity by the help of water pressure. After electricity generation, the spent water from the turbine is carried back to the river by a tailrace or a canal (Balat, 2007), (Rojanamon et al., 2009), (Paish, 2002).

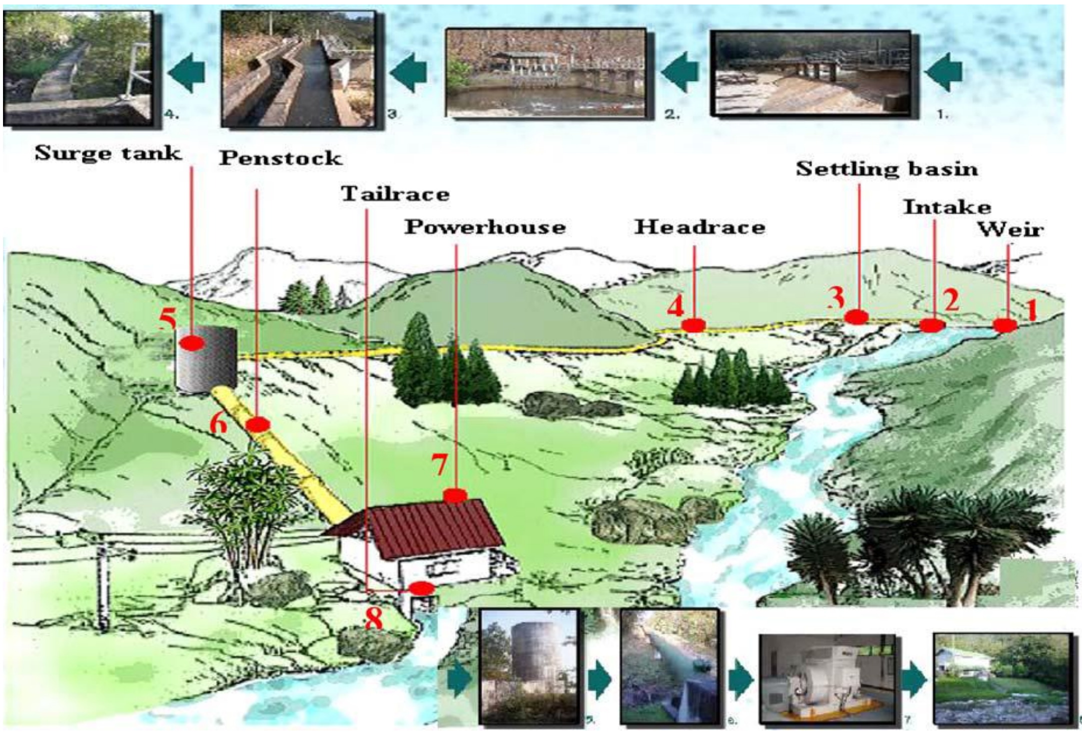

Figure 1.1 Components of Run-of River Hydropower Plants (Rojanamon et al., 2009)

The methodology is applied on Şavşat, Artvin where high hydroelectric power potential is already evaluated based on the technical and economic criteria by the State Hydraulic Works. The reason of selecting Şavşat region is popularity of the region among hydropower plant investors. According to State Hydraulic Work data there are 2 hydropower plants in operation and 19 plants are planned to operate in Şavşat region which is a great number for such a small town. Five different run-of river hydropower plant projects are selected as specific case study of this thesis study which are Cüneyt, Gana, Meydancık, Armutlu and Şavşat hydropower plants. In order to apply the MCDM methodology detailed environmental and geological data is needed, Cüneyt, Gana, Meydancık, Armutlu and Şavşat hydropower plants are the ones whose environmental impact assessment reports are obtained from the Ministry of Environment and Urbanization Artvin Provincial Directorate. That is why only these five projects are evaluated in this study, if there would be data about other hydropower projects, it would be possible to make more broad range analyses for Şavşat district.

In the proposed methodology, Multi Criteria Decision Making (MCDM) which is based on several environmental and social criteria is used as decision making tool in fuzzy environment. Bellman and Zadeh (1965) are first users of fuzzy set theory as an effective methodology in multi criteria decision making processes. After their study, in several studies fuzzy set has been used in MCDM analysis in order to deal with problem of imprecision and subjectiveness (Chang et al., 2013).

In the scope of MCDM analysis of run-of river hydropower plants, ten criteria are determined after doing literature research as first step, these criteria are: Landslide, Earthquake, Flow Rate Alteration, Public Perception, Destructed Forest Size, Distance from Environmentally Sensitive Areas, Distance from the Nearest Residential Area, Population Density, Number of Downriver Tributaries and Terrorism.

In the second step, actual conditions of the case study region regarding to each criterion are evaluated and finally these conditions are assessed with multi-criteria decision making to find out "acceptability" of the region. Also the study is parallel with Hydropower Sustainability Assessment Protocol which is developed in the content of a project named "Hydro4life" and founded by European Commission. The aim of the protocol is also developing an evaluation tool for hydropower projects.

In Chapter 2 literature research is given. In the chapter, usage of multi-criteria decision making, previous similar studies and criteria selecting step of this study are explained. In Chapter 3 methodology of multi-criteria decision making is explained and in Chapter 4 application of the MCDM methodology on Şavşat is shown. In Chapter 5 the results of Şavşat case study are discussed and finally in Chapter 6 the study is concluded.

CHAPTER 2

LITERATURE REVIEW

2.1 Multi Criteria Decision Making (MCDM) Analysis

Decision making is an everyday activity that is made by groups or individual decision makers. During selecting a locate to live or choosing land development strategy or picking up the most suitable clothes for the day, people use rules of decision making analysis (Jankowski et al., 2001).

Decision making can be defined as a technique of choosing or selecting "sufficiently good" alternative from a set of alternatives in order to succeed a goal or goals. Most of the decision making processes include uncertainties, so one of the most important issue to make right decision is handling imprecise information, such as 'large price', 'small length' (Riberio, 1996). In order to deal with imprecise information, fuzzy logic is used in this study; detailed explanation of the methodology will be given in following sections.

In general there are two types of problems that MCDM analysis is needed to solve;

- Problems that consequences cannot be determined by using single criterion. This kind of problems need analysis of models including economic as well as natural indices which means alternatives cannot be reduced to comparable form.

- Problems that uncertainty of information does not permit to get unique solutions with single criterion and multi criteria approach is needed to reduce uncertainty (Ekel et al., 2008).

This thesis study can be included in first category, because, in the study there are ten basic criteria that each of them are needed to define environmental and social problems related with hydropower plants. In this point of view MCDM analysis is the one of the best choice to make site selection study for hydropower plants.

In addition, information that is used to evaluate criteria includes some uncertainty in them, and in order to minimize this uncertainty MCDM analysis is implemented in fuzzy environment. In order to do that fuzzy sets that define the term of “acceptability” are developed for each criterion. These fuzzy sets and developed methodology is in a form that, it can be used in any area where hydropower plant is planned to construct.

In this study, Multi-criteria Decision Making (MCDM) analysis is conducted to be used in site selection procedure for run-of river type hydropower plants. The aim of MCDM analysis is to find solutions to decision problems that are determined by multiple choice alternatives, and evaluated by means of performance characteristics called decision criteria (Jankowski et al., 2001). The analysis provides a step by step procedure to make a decision in the presence of multiple criteria. This well-defined method minimizes arguments and conflicts, and plays an important role to solve complicated problems (Abdullah and Adawiyah, 2014).

In literature, using MCDM analysis in environmental decisions is a common application, since environmental problems need multidisciplinary studies and group decision process that includes natural, physical and social sciences, medicine, politics and ethics (Kiker et al., 2005). Common application areas that MCDM is used are; renewable energy planning, energy resource allocation, building energy management, transportation energy management, planning for energy projects and electric utility planning (Pohekar and Ramachandran, 2004).

Advantages of MCDM analysis is listed as below in Multi-criteria Analysis Manual that is prepared by Department for Communities and Local Government, London;

- The method is open and explicit
- It can be modified by users for different kind of objectives and criteria since the method is open to develop and change
- Calculations in the method can also be changed according to changing score and weight sources
- The procedure is well-defined so the results do not change even if it is implemented by different users, which minimizes subjectivity
- Applying this method for the project initiate communication between stakeholders and it provides audit trial for the project.

In this study, MCDM analysis is used together with fuzzy logic approach which is a common application. Fuzzy logic application in decision making studies is defined by Zadeh, who is the inventor of fuzzy logic. In fuzzy logic application in MDCM, the goals and/or the criteria of the study are determined but classes whose boundaries are not strictly defined (Ribeiro, 1996).

In general MCDM analysis in fuzzy environment application has a single goal that is selected from set of alternatives. The alternatives are produced by assessing the criteria and their degrees of importance. Therefore, goal definition and criteria selection are the first and main steps of this method. For example; goal could be selecting a certain automobile and selected criteria could be price and maximum speed. After determining the goal and the criteria, fuzzy sets of the criteria are prepared. Also, another variable which is weight of the criteria could be specified, for example; ‘price of the automobile is much more important than maximum speed of it’, therefore weight of the price can be 0.9 where weight of the maximum speed is 0.1 (Ribeiro, 1996).

In this study, MCDM analysis was conducted using 10 criteria that represent environmental and social effects of run-of river type hydroelectric power plans.

Also weight of each criterion is specified with different methods for different aggregation techniques. Applied procedures and the results of the study will be explained following parts of the thesis.

2.2 Previous Studies in the Literature

In literature there are several application examples of MCDM in energy projects. Aydın et al. (2009), Lee et al. (2009), Heidarzade et al. (2014) and Borah et al. (2013) are all include MCDM application for site selection problem of wind power plants. In the studies, environmental criteria are included in order to make evaluations more objective. Aydın et al. (2009) consist of six criteria and all of them represent different environmental effects of the wind power plants. The study includes a case study application which evaluates western part of Turkey to determine best sites for wind power plant construction. Similarly, Lee et al. (2009), Heidarzade et al. (2014) and Borah et al.(2013) aims to develop tools to be used for site selection studies for wind power stations. For this purpose, the studies include environmental, economic and social criteria. Also there are case study implementations in the studies; in Lee et al. (2009) 5 different points in Chine are evaluated with the MCDM analysis, while in Heidarzade et al. (2014) 68 different cities in Iran and in Borah et al. (2013) over 100 cities in Gujarat State India are evaluated.

Demirtas (2013), Yazdani-Chamzini et al. (2013), Polatidis et al. (2006), Keeney et al. (1987) and Cristóbal (2011) are other studies that aim to select the best renewable energy production technique by using MCDM analysis. In the studies, geothermal, solar, wind, hydropower and biomass energy production techniques are evaluated with environmental, economic and social criteria. By developing an evaluation tool, all of the studies aim to contribute Renewable Energy Plans of their own countries.

Also, Georgopoulou et al. (1997) and Beccali et al. (1998) discuss different MCDM techniques on renewable energy problems. Similarly, both studies aim to contribute development of renewable energy diffusion strategic plans of the contraries.

In the following paragraphs, the literature that was used to determine criteria for environmentally and socially evaluation of run-of river hydropower plants is explained. As mentioned before, Hydropower Sustainability Protocol is a tool to evaluate environmentally, socially and economically suitability of hydropower projects. It is supported by European Union and it is applied by countries all over the world; from Australia to South America. In the content of the protocol 19 criteria are evaluated whose 5 of them are technical, 5 of them are environmental, 5 of them are social, 4 of them are economic and 5 of them are integrative. All of these criteria are assessed in Level 1 to 5 score range by project team. Implementation of the protocol is divided into 4 basic parts, early stage, preparation, implementation and operation. For all stages, there are some evaluation topics and for all topics, implementers give scores from 1 to 5. The assessment is carried out by making site visits to see physical conditions of the projects, making interview with local residents and meeting other stakeholders (investors, NGOs etc.) of the hydropower projects. The results of the assessment are shown by listing scores of each criterion and achieving Level 3 out of 5 for all criteria is considered as “basic good practice” which should be the minimum target of the hydropower projects. On the other hand achieving Level 5 for all criteria is called as “proven best practice” which is very difficult to success but it is the most desired condition for all hydropower projects.

Evaluation topics of the protocol are; communications and consultation, governance, environmental and social issues management, hydrological resource, asset reliability, infrastructure safety, financial viability, project benefits, project-affected communities and livelihoods, resettlement, indigenous people, labor and working conditions, cultural heritage, public health, biodiversity, erosion and sedimentation, water quality, reservoir management and downstream flows.

Beside the protocol, there are similar studies with this thesis study in the literature; Rojanamon et al. (2009), Tanutpongpalin and Chaisomphob (2004), Yi et al. (2004), Zelenakova et al., (2013) and Küçükali (2011) carried out the studies that aims to aid decision makers.

Rojaman et al. (2009) conducted a site selection study for small run-of river hydropower plants in Thailand. Criteria are divided into four basic titles which are engineering, economic, environmental and social impact. Environmental analysis includes six criteria that are watershed class area, location of national park and wildlife sanctuary, land use type, population density, mean annual sediment yield and heritage site. Social impact is evaluated by using results of the survey conducted in the study region.

Tanutpongpalin and Chaisomphob (2004) and Yi et al. (2010) are also site selection studies for small run-of river hydropower plants which include only environmental parameters. In Tanutpongpalin and Chaisomphob (2004) there are six criteria; watershed class, wildlife sanctuary, land use type, suspended sediment, population density and heritage which are the same with Rojaman et al. (2009). In Yi et al. (2010) there are three criteria; distance to national parks, land use and water supply source protection.

In Zelenakova et al., (2013), a risk assessment methodology is developed in order to include environmental impact assessment process of hydropower projects. In the methodology multi-criteria decision making approach is used. There are 16 criteria in the study which are; reservoir surface area, water retention time in reservoir, biomass flooded, length of river impounded, number of downriver tributaries, likelihood of reservoir stratification, useful reservoir life, access roads through forests, people requiring resettlement, critical natural habitats affected, fish species diversity and endemism, cultural property affected, the distance of the proposed activity from the nearest residential area zone, health affects, estimated time of the construction and the rate of the utilization of construction machinery. Among these criteria useful reservoir life and the rate of utilization of construction machinery are economic criteria, but the all other criteria are assess the environmental and social impacts of the projects.

Another similar site selection study is Küçükali (2011). In the study there are 11 criteria whose two of them are economic, two of them are social, six of them are environmental and one of them is legal. Environmental criteria are; access to infrastructure, natural hazards, grid connection, environmental issues, land use and site geology, and the social criteria are social acceptance and terrorism.

2.3 Criteria Used in the MCDM Analysis

As explained in the previous sections, in thus study, a methodology is developed in order to assess the environmental and social acceptability of run-of river hydropower plants. By using the methodology, regions that hydropower plants are planning to construct can be evaluated to find out if the region is suitable for such projects or not. The aim of the study is to make investors or responsible stakeholders see the projects in environmental and social point of view.

Within the scope of the study 10 criteria are determined which are; Landslide, Earthquake, Flow Rate Alteration, Distance from the Environmentally Sensitive Areas, Destructed Forest Size, Terrorism, Distance to the Nearest Residential Area, Population Density, Number of Downriver Tributaries and Public Perception. These 10 criteria are selected by making literature research about similar studies.

Public Perception, Distance to the Nearest Residential Area and Population Density represent the social impacts of hydropower plants. On the other hand, environmental effects of hydropower plants are represented by Flow Rate Alteration, Distance from the Environmentally Sensitive Areas, Number of Downriver Tributaries and Destructed Forest Size criteria. Also Landslide, Earthquake and Terrorism criteria are used to evaluate effects of geologic and social characteristic of the region and natural disasters that may occur on the project area.

2.3.1 Social Criteria

Public Perception

In Hydropower Sustainability Protocol social aspects of the projects are evaluated under "social issues management" and "indigenous people" titles. In the content of these titles, protocol implementers make interviews with local residents and evaluate their opinion about the projects. Similarly, in Rojaman et al. (2009) and Küçükali (2011) surveys are conducted to assess the reactions of local residents according to the hydropower projects. By inspiring those projects public perception criterion is included in this study.

In this study, a survey which includes opinion of 93 residents of Şavşat region is used to understand the social effects of hydropower projects. Since conducting survey is the simplest and the most common method to measure the reaction of the society, it is applied in this study as in previous studies in the literature. In Turkey most of the hydropower projects cause public indignation since local residents have concerns about losing their social and ecological environment. For this reason big portion of hydropower projects end up with opening a case against investors of the projects by local residents or NGOs, and that is the reason including opinion of residents in the study.

Distance from the Nearest Residential Area

As the distance between the project area and the residential area get closer, influence degree of the project on society gets greater as well, because physical effects which cause environmental harms in the region is directly proportional to distance. In Zelenakova et al., (2013), distance from the nearest residential area is evaluated and in this study similar evaluation has done by referencing Zelenakova et al., (2013).

Population Density

Population density criterion is included to measure social influence degree of the projects and magnitude of the impacts. Accordingly as population density gets bigger, number of people affected and magnitude of impacts get bigger. In Rojaman et al. (2009), Tanutpongpalin and Chaisomphob (2004) and Yi et al. (2010) are also used population density criterion to measure influence degree of the projects and magnitude of the impacts.

2.3.2 Environmental Criteria

Flow Rate Alteration

Flow rate alteration is the most problematic issue of run-of river hydropower plants, since in most of the projects, remained water amounts are not sufficient for organisms, plants and local residents to maintain their life. In Turkey, common application is remaining 10% of the flow in order to maintain ecosystem rate in river body, however sufficiency of 10% remained water is controversial. In the content of this study, remained water amounts in study areas are compared with needed water amounts according to studies in the literature. Ideally needed remained water amount should be calculated according to specific needs of the study areas, because generalization of needed flow rate amount for all regions may not be right. Yet, it was not possible to make that kind of detailed biological analysis in the content of this study. Instead of making analysis to specify needs project area, data obtained from literature research are used for this criterion.

Similar evaluations about flow rate alteration were carried out in Küçükali (2011), Rojaman et al. (2009), Yi et al. (2010) and Hydropower Sustainability Protocol.

Destructed Forest Size

Destructed forest size criterion is selected to represent deforestation impact of the projects. In the content of destructed forest size criterion, distances of water transfer channels through forests are evaluated. As constructed roads and water transfer channels get long, deforestation rate of the project gets bigger. Similar assessment about constructed road through in forests is carried out in Zelenakova et al., (2013).

Number of Downriver Tributaries

Number of downriver tributaries is correlated with flow rate alteration criterion since in both criteria pollution load of the river is considered. When flow rate remained is so small, pollution dilution capacity of the river decreases dramatically beside its insufficiency for living creatures and humans. If there are many downriver tributary in project area, those tributaries can tolerate low dilution capacity of project region and downriver regions are not affected so much from the project area. Therefore it is important to include number of downriver tributaries in the acceptability study. In Yi et al. (2010) and Zelenakova et al., (2013) are used as guidance for evaluation of number of downriver tributaries.

Distance from the Nearest Environmentally Sensitive Area

Environmentally sensitive areas are thought as areas that are protected by national or international conventions such as; natural reserve areas, national parks etc. In Turkish regulations, construction studies in environmentally sensitive areas are forbidden however there is no defined buffer zone to prevent negative effects of construction studies around the sensitive areas. In this study, distances between project area and the nearest environmentally sensitive area are evaluated by defining buffer zone. Buffer zone identification procedure is carried out by making research about model buffer zone application in Turkey and world. In model buffer zone applications, buffer zone distances are defined by considering site specific needs of the regions. However, it was not possible to make that kind of site specific studies in the content of this thesis study, so buffer zone fuzzy set identification was carried out by depending on previous similar studies in the literature such as; Zelenakova et al., (2013), Tanutpongpalin and Chaisomphob (2004), Yi et al. (2010), Küçükali (2011) and Rojaman et al. (2009).

2.3.3 Technical Criteria

Landslide and Earthquake

Both landslide and earthquake are the most common and destructive natural disasters, however there is no legal restriction to prevent construction of power plants on risky regions with regard to landslide or earthquake. If one of these natural disasters occurs in project region, there would be greater environmental and social results of the projects. For this reason these two criteria are included in the study. In landslide evaluation landslide inventory map is used to represent landslide occurrence risk in the region. In Turkish legislation there is no restriction to build any kind of structure on risky zones by means of landslide and the earthquake. However it is important to consider landslide and earthquake vulnerability of the projects areas, especially in regions like Turkey, where these kind of natural disasters happen frequently. Acceptability levels of the regions are evaluated with Deterministic Seismic Hazard Analysis (DSHA) Method for earthquake and projects that are in first degree earthquake zone are considered as "not acceptable". For landslide criterion, buffer zone identification is made as in environmentally sensitive areas, and projects that are in these buffer zones are considered as "not acceptable". Hydropower Sustainability Protocol and Küçükali (2011) are the main references that are used to decide and apply landslide and earthquake criteria.

Terrorism

The other technical criterion in the study is terrorism, but aim of including terrorism in the study is similar with landslide and earthquake; if there is a terrorist attack in project area, it causes destruction in projects area which increases the effects of the project on environment, society and economy. Terrorism attacks have become one of the most important social problems of human being for decades. Especially remarkable spots are chosen by terrorist in order to take attention of the society and hydropower plants can be thought as a good target for them, particularly in small towns. Consequently, by considering current social structure of the world terrorism criterion is needed to include in the study. Main reference of terrorism criterion for this study is Küçükali (2011).

Almost all of the criteria in Hydropower Sustainability Protocol and previous similar studies are included in the study by selecting these 10 criteria. Only thing that is not included in the study is economic evaluation of the projects which is not considered as aim of the study. Also water quality and biodiversity researches were not handled in detail since these researches need multidisciplinary and long term studies in the project sites. On the contrary, lack of site studies and time limitation are the main problems of the study. Hence, lack of site specific data is compensated with detailed literature research for some criteria.

CHAPTER 3

METHODOLOGY

In this chapter Multi-criteria Decision Making (MCDM) analysis is explained step-by-step. As it is seen in Figure 3.1, steps of MCDM analysis can be listed as follows;

- MCDM is started with goal definition, objective and criteria identification, which are carried out by making literature research in this study,

- It continues with criteria scoring which includes scoring all criteria according to their own fuzzy sets. The score is called as “membership grade”, however in this study the membership grade is called as “acceptability”, since the score represents the acceptability of the hydropower project in terms of that specific criterion,

- Next step is weight defining; weights can be defined by decision makers or expert people. In this study, in ordered weighted averaging operators, weights defined by the method itself are used while in linear weighted averaging method weights defined by experts are used.

- Last steps of MCDM are aggregation of acceptability values and discussion of the results. Aggregation can be applied by several different methods. In this study there are four different aggregation methods whose details are given in following sections. Also final step of the MCDM, discussion of the results, is given in last chapter of this study. Comparison and evaluation of the results are included in the study, but final decision of site selection is not part of the study, since it has to be done by decision makers.

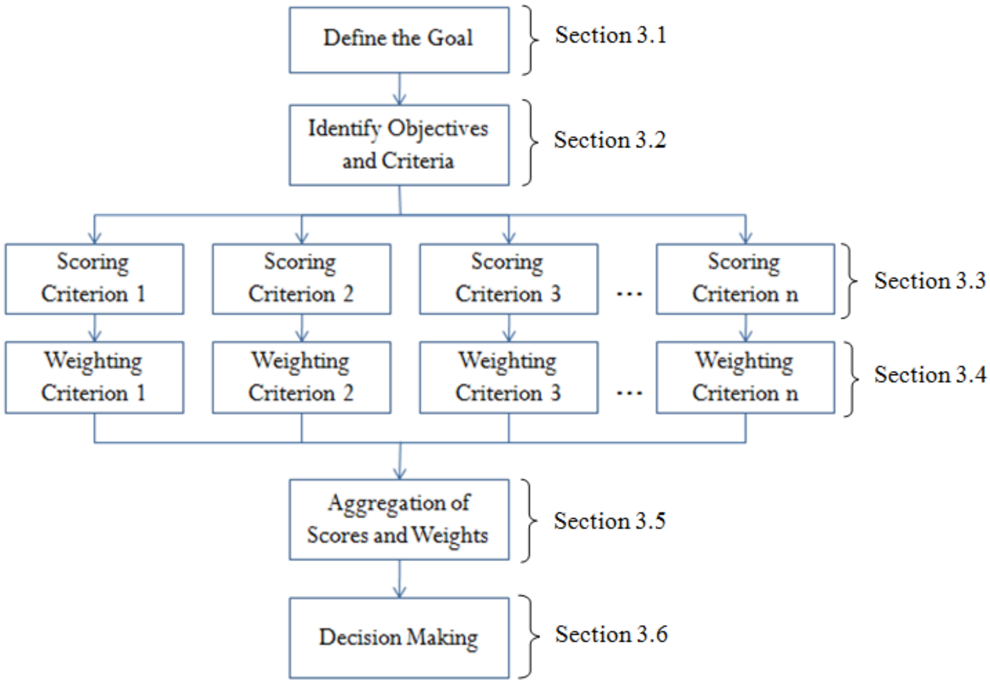

Figure 3.1 MCDM Analysis Flow Chart

3.1 Goal Definition

First stage of MCDM analysis is to represent goal of the study with clear explanations. The goal definition process should contain root cause identification, limiting assumptions, system and organizational boundaries and any stakeholder issues. The important thing is to explain the goal with a short and clear expression, preferably with a single sentence if it is possible (Department for Communities and Local Government, 2009).

The key to developing adequate goal definition is to ask enough and related questions about the problem in order to be sure that final report is able to find solution to the problem and meet the requirement of the stakeholders (Baker et al., 2001).

Goal of the Artvin/Şavşat case study is to compare the acceptability of the possible HPP locations in terms of several social and environmental criteria. Artvin region is a popular study area among hydropower plant investors, however local residents of the region are not actually happy to be a part of those projects. Also Artvin region is one of the most naturally preserved area of Turkey, therefore local residents and the scientists are worried about sustainability of this naturalness. All these concerns initiate us to develop a multi-criteria decision making methodology in order to use in site selection studies for hydropower plant. Within this scope the goal of the study is defined as "selection of appropriate sites for hydropower plant construction".

3.2 Objectives and Criteria Identification

In order to reach desired goal, discriminating criteria which based on the goal should be defined. It is necessary to measure how well the alternatives which are produced by combining the criteria achieve the goal. Every goal must have at least one criterion but complex goal may be represented by several criteria (Department for Communities and Local Government, 2009).

According to Baker et al. (2001), each criterion should measure something important and not depend on another criterion. Also they should be;

- able to discriminate among the alternatives,
- complete; include all goals,
- operational; meaningful to the decision maker's understanding of the implications of the alternatives,
- non-redundant; avoid double counting,
- few in number to keep the problem dimension manageable.

Criteria identification stage of Şavşat case study was carried out by making literature research on environmental and social effects of hydropower plants. As a result of this literature research given in Chapter 2, 10 criteria were identified which are; distance from the nearest environmentally sensitive area, earthquake, flow rate alteration, terrorism, destructed forest size, public perception, landslide, distance from the nearest residential area, population density and number of downriver tributaries.

3.3 Criteria Scoring

At scoring step of the study, the most important thing is to specify decision making tool. Pros and Cons Analysis, Kepner-Tregoe Decision Analysis (K-T), Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory Analysis (MAUT) and Cost Benefit Analysis (CBA) are some of the well known tools that are used widely (Baker et al., 2001). However in the content of this study Fuzzy Logic is used as decision making tool. Fuzzy logic is an effective MCDM method especially for environmental projects (Velasquez and Hester, 2013).

Fuzzy logic is a widely used term that is used for “fuzzy set analysis” and “possibility theory”. It is an efficient tool to determine uncertainties and imprecision in the applications that have no sharp boundaries (Markowski et al., 2009).

Lotfali A. Zadeh, who introduced fuzzy approach, define fuzzy sets as; “a class of objects with continuum of grades of membership. Such a set is characterized by a membership function which assigns to each object a grade of membership ranging between zero and one” (Zadeh, 1965).

In implementation of fuzzy logic in risk assessment studies, physical conditions are classified by using linguistic terms such as; “low”, “medium”, “high” etc. However, in order to determine strict boundaries of classes, detailed data are needed because if there is not sufficient data, assessment may give deceptive results. Therefore fuzzy logic approach is developed to deal with conditions that it is so difficult to define sharp boundaries for classes (Zadeh, 1965). In other words fuzzy logic is a series of mathematical principles that is used to represent knowledge based on degrees of membership (Abul-Haggag and Barakat, 2013).

In the methodology, natural language expressions are used to describe linguistic variables. Each word ‘x’ can be thought as summarized description of a fuzzy set A(x) of a universe of U. In the expression, A(x) stands for the meaning of x (Kangari and Riggs, 1989).

Fuzzy set’s mathematical expression is given in Equation 3.1:

$$A = \{X|\mu A(x)\} \tag{3.1}$$

Where; A= fuzzy set; $\mu A(x)$ = membership grade between 0 and 1; and x = a scale element (Kangari and Riggs, 1989).

3.3.1 Fuzzy Set Identification

If A is characterized by B and C, fuzzy set definition, which is linguistic representation of variables, has to be done for both B and C (Mure et al., 2006). In classical mathematic approach if a variable is in a certain range, it takes value of 1 otherwise it takes value of 0. Yet, in fuzzy sets a variable that is in a certain range can take any value between 0 and 1 which is called “membership grade” (Kıyak and Kahveciaoğlu, 2003).

Basically fuzzy sets are defined by membership functions (Kissi et al., 2003). If membership grade of an object in a set is ’1’, it means that the object is definitely in that set. If membership grade of an object in a set is ‘0’, it means that the object is definitely not in that set. However, in fuzzy set applications generally membership takes a value between 0 and 1 which means the object is in more than one set (Ma and Zhou, 2000).

Representation of variable function of classic mathematic and membership function of fuzyy logic approach is given in Equation 3.2 and Equation 3.3 respectively.

$$U(x) = \begin{cases} 0\ when x = Vi \\ 1\ when x \neq Vi \end{cases} \quad (3.2)$$

where i = 1,2,3,.., m

$$\mu(x) = \mu(x;a,b,c) = \begin{cases} \frac{x-a}{x-b}\ when\ a \leq x < b \\ 1 \qquad when x = b \\ \frac{c-x}{c-b}\ when\ b \leq x < c \\ 0\ \ when\ x > c\ or\ x > a \end{cases} \quad (3.3)$$

where x is fuzzy function variable and a,b,c are fuzzy set values.

In the scope of this thesis study, fuzzy sets are determined for all criteria. For each criterion there is a single fuzzy set and score of the criterion is equal to the membership grade of the criterion. All the fuzzy sets of all criteria are given below.

3.3.1.1 Distance from the Nearest Environmentally Sensitive Area

Environmentally Sensitive Area (ESA) is defined in Turkish Environmental Impact Assessment Regulation as; “Areas whose biological, physical, economic, social or cultural features are sensitive to environmental impacts or whose pollution load is already in a range that have negative effects on environment and public health. Also areas that are decided to be protected by national or international conventions are called Sensitive Areas.” In content of the Environmental Impact Assessment Regulation there is no restriction about distance between hydropower plants and environmentally sensitive areas. However, within the scope of the Environmental Impact Assessment Report, environmental impacts of hydropower plants are asked to evaluate.

In the content of this study, evaluation of distance from the nearest environmentally sensitive area is carried out by specifying buffer zone. Buffer zones aim to minimize the impacts of human being on wildlife (Rodgers and Smith, 1997). During buffer zone fuzzy set determination, national and international applications are searched; in Table 3.1 model buffer zone implementations are given.

Table 3.1 Model Buffer Zone Applications

Protected Area Name	Buffer Zone Width (km)	Reference
Küre Mountains National Park	9.7	http://www.kdmp.gov.tr/
Cape Floral Region	23.5	Martin& Piatti, World Heritage and Buffer Zones, 2009
Le Parc National Park	2.7	Martin& Piatti, World Heritage and Buffer Zones, 2009
Mount Huangshan	5.5	Martin& Piatti, World Heritage and Buffer Zones, 2009
Royal Chitwan National Park	9.0	Martin& Piatti, World Heritage and Buffer Zones, 2009
Butrint National Park	1.7	Martin& Piatti, World Heritage and Buffer Zones, 2009
Vu Quang Nature Reserve	1.7	Ebregt & De Greve, 2000
Alejandro de Humboldt National Park	3.3	World Heritage Committee, 2013
Desembarco del Granma National Park	4.7	World Heritage Committee, 2013

By inspiring implementations given in Table 3.1, fuzzy set of this criterion is prepared but among model applications, marginal data are excluded by using box whisker tool of excel. Prepared fuzzy set for environmentally sensitive area criterion is given in Table 3.2 and Figure 3.2.

Table 3.2 Fuzzy Set of Distance from the Environmentally Sensitive Area Criterion

Distance between ESA and the Study Site (km)	**Acceptability**
$x \geq 9$	Acceptable
$1.5 < x < 9$	Partially Acceptable
$x \leq 1.5$	Not Acceptable

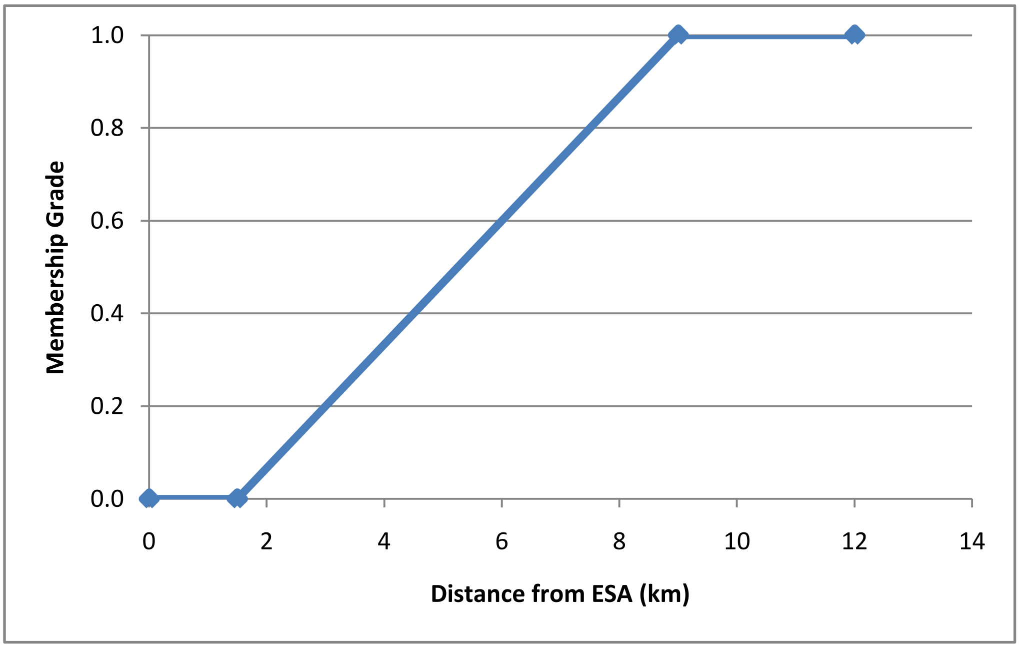

Figure 3.2 Fuzzy Set Representation of Distance from the Nearest Environmentally Sensitive Area Criterion

3.3.1.2 Earthquake

Before starting any kind of construction study, ground analysis should be done in order to see the earthquake risk of the study site. Otherwise an unpredictable earthquake may cause important results on human life, environment and economy. In environmental point of view, if the region that hydropower plant is constructed is in risky zone, a severe earthquake may cause destruction of hydropower plant units and water that is taken by hydropower plant cannot be given back to river. During all reconstruction period, ecosystem of the river body is affected irreversibly.

In order to evaluate earthquake risk, Deterministic Seismic Hazard Analysis (DSHA) Method is used. The method involves the development of a particular seismic scenario upon which a ground motion hazard evaluation is based. The scenario comprise of admitted occurrence of an earthquake of a specified size occurring at a specified location. In DSHA method there are 4 major steps which are explained below:

i. All earthquake sources that are capable of producing significant ground motion are identified and characterized. Also definition of each source's geometry (the source zone) and earthquake potential are defined in source characterization.
ii. Distance parameter of source and site are selected for each source zone. Generally, the shortest distance between the source and zone and the site of interest is selected.
iii. "Controlling Earthquake" is selected which is generally expressed in terms of some ground motion parameter at the site. For example; controlling earthquake can be selected as earthquake that is expected to produce the strongest level of shaking, and it is described in terms of its size and distance from the site.
iv. The hazard at the site is determined in terms of the ground motions produced by controlling earthquake. Also the characteristics of the hazard is expressed by one or more ground motion parameters, such

as; peak acceleration, peak velocity, response spectrum ordinates etc.(Kramer, 2007)

In this study peak acceleration is used to express characteristic of the hazard. While applying Seismic Hazard Analysis Method, two equations are used in order to find out magnitude of fault and Peak Ground Acceleration (PGA). Magnitude of the fault is calculated by using Equation 3.4 (Coppersmith and Wells, 1994).

$$Mchar = 1.02logA + 3.98 \pm 0.24 \tag{3.4}$$

Where M_{char} is the magnitude of the characteristic earthquake and A is the area of the fault which is found by multiplying width (W) and depth (d) of the fault.

After calculation of M_{char} value, Peak Ground Acceleration calculations are carried out by using Ground Motion Prediction Equation in excel work sheet (Boore and Atkinson, 2008).

After calculation of magnitude of characteristic earthquake and peak ground acceleration, earthquake risk evaluation is carried out by depending on Peak Ground Acceleration classification in Turkish Earthquake Regulations. In Table 3.3, classification in Turkish Earthquake Regulation is shown. Also in Table 3.3 and Figure 3.3 fuzzy set representations are given which are obtained by making fuzzification on values that are given in Turkish Earthquake Regulation. During fuzzy set preparation of earthquake, “first degree earthquake zones” are considered as “not acceptable”. According to the regulation the regions whose PGA values are greater than 0.3 are in “first degree earthquake zones”, so the regions whose PGA values are greater than 0.3 are considered as “non acceptable”.

Table 3.3 Earthquake Risk Level Classification (Turkish Earthquake Regulations, 2007, item 2.4.1)

PGA Value	**Earthquake Zone**
0.40	1
0.30	2
0.20	3
0.10	4

Table 3.4 Fuzzy Set of Earthquake Criterion

PGA Value	**Acceptability**
$x \geq 0.3$	Not Acceptable
$0.1 < x < 0.3$	Partially Acceptable
$x \leq 0.1$	Acceptable

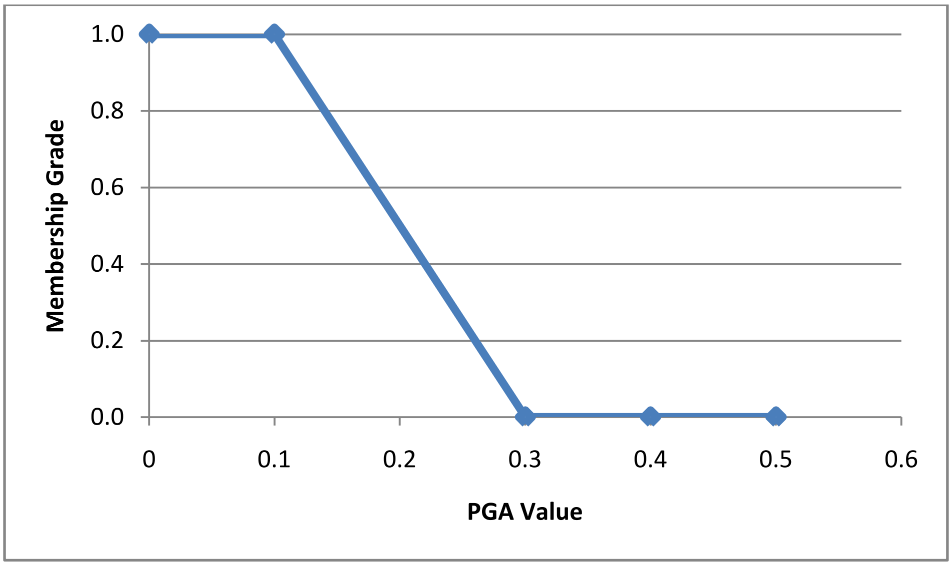

Figure 3.3 Fuzzy Set Representation of Earthquake Criterion

3.3.1.3 Flow Rate Alteration

Flow regime alteration is asserted as the most serious and continuing threat to ecological sustainability of rivers and their associated floodplain wetlands (Bunn and Arthington, 2002). Therefore, natural hazards are evaluated by considering flow rate alteration in the rivers in this thesis study. In order to do that, data of average flow rates of all river segments that regulators are planned to construct and planned residual water amounts are used. Flow rate data of the study site are taken from Environmental Impact Assessment Report of the project which is supplied by Ministry of Environment and Urbanization.

Poff and Zimmerman, (2010) is an important study that shows the effects of flow rate change on riparian, microinvertebrates and the fishes. In the study 165 papers, that are about flow rate alterations of rivers, are analyzed and ecological responses to flow rate change is tried to be find out. Authors of the paper define the aims of the study as;

- Understand the relationship between natural flow alteration and ecological responses to that alteration by analyzing publications, primarily in the last 10 years, and
- Create statistically supported patterns between define defined types of flow alteration and ecological response metrics by using quantitative relationships published in previous studies.

After analyzing 165 papers, determined common responses of aquatic and riparian organisms to alteration of flow magnitude, frequency, duration timing and rate of change are determined. Also responses of macroinvertebrates, riparian and fishes to flow rate alteration are given in Figure 3.4. In order to get quantitative results, rate of change of ecology, according to rate of change of flow rate has to be known. In this thesis study, residual water amount in Şavşat region is evaluated to decide risk level of this factor. Fuzzy set boundaries of this risk factor depend on Tennant methodology.

Tenant Method, which is also known as Montana Method, was developed by Donald Leroy Tennant in Montana, USA in 1976. The method is used by 16 states in USA and it is the second most widely used in USA (Caissie et al., 2007).

The method claims that some percentage of mean flow is needed to maintain healthy ecosystem in river bodies. In order to reach this idea Tennant examined 58 streams in Montana, Wyoming, Nebraska and many sites in eastern and western USA. By depending on the results of those field works, Tennant assumed that stream width, water velocity and depth all increase rapidly from zero to 10% of mean flow, and that increase are not observed at flows higher than 10%. He observed that flows that are less than 10% provide “short-term” survival for aquatic life. By depending on the same data, he assumed that 30% of average flow provides “satisfactory” stream width, depth and velocity for base flow regime, and as an overall idea he claims that environmental quality of different levels of flow is based on the quality of the physical habitat that they provided (Jowett, 997), (Allain and El-Jabi, 2002). In Table 3.5 recommended flows and the conditions that they represent are given.

Table 3.5 Recommended Residual Water Rates by Tennant Method (Tennant,1976)

Flow Conditions	**October-March**	**April-September**
Flood Situation	100 %	200 %
Optimal Situation	60 %	100 %
Superior Situation	40 %	60 %
Excellent Situation	30 %	50 %
Good Situation	20 %	40 %
Acceptable Situation	10 %	30 %
Minimum Situation	10 %	10 %
Degraded Situation	0 %	10 %

If the method is adapted to this study; 10% and lower residual water amount can be assumed as not acceptable and 60% and greater residual water amount can be assumed as acceptable. By inspiring the methodology, fuzzy set of flow rate alteration risk factor are determined and given in Table 3.6 and Figure 3.5. In the content of flow rate alteration criterion, microinvertebrates, riparian and fishes are evaluated separately, as it was done in Poff and Zimmerman, (2010), however for all them, one fuzzy set is used since Tennant methodology involves all of these organisms.

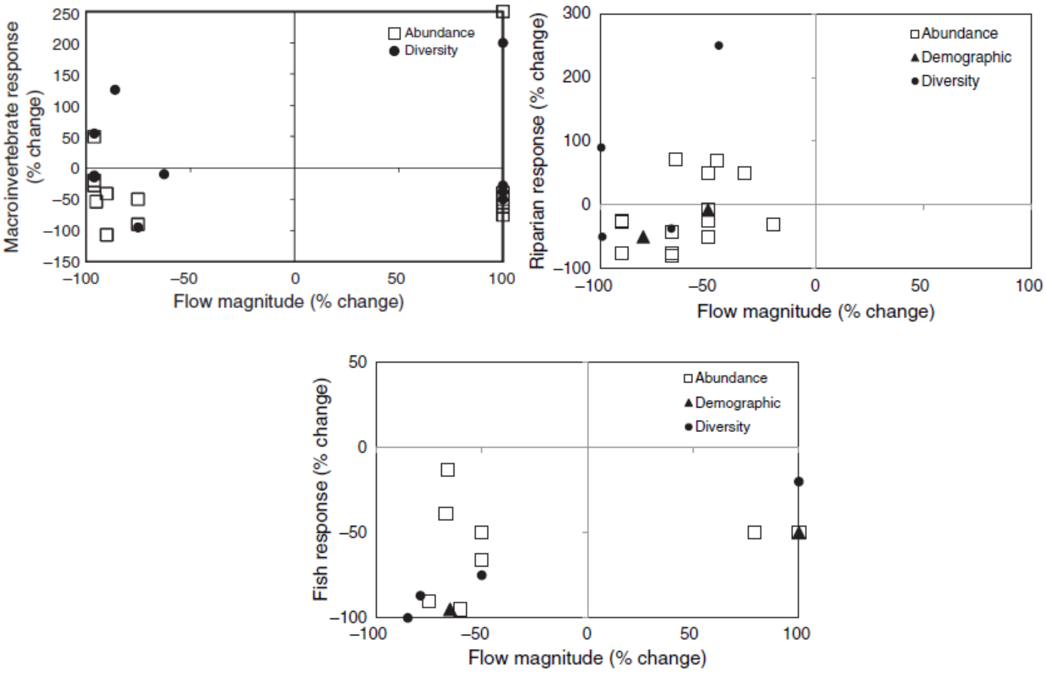

Figure 3.4 Responses of Macroinvertebrates, Riparian and Fishes to Flow Rate Alteration

Table 3.6 Fuzzy Set of Flow Rate Alteration Criterion

Residual Water Amount (%)	**Acceptability**
$x \leq 10$	Not Acceptable
$10 < x < 60$	Partially Acceptable
$x \geq 60$	Acceptable

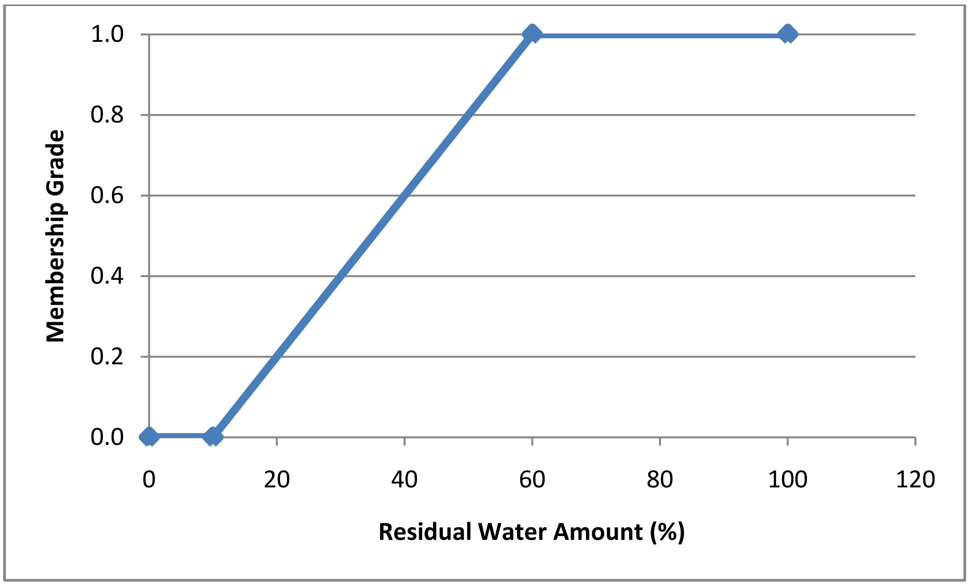

Figure 3.5 Fuzzy Set Representation of Flow Rate Alteration Criterion

3.3.1.4 Destructed Forest Size

Although land use is considered as a local issue, it has been gaining a global role. Huge portion of the planet's land surface have been transformed by land use activities. In order to get suitable areas for agricultural activities, farmlands productions, urban centers or other human activities, considerable large forest areas have been destroyed. Moreover as the population of the planet increases, problems caused by land transformation get bigger correspondingly (Foley et al., 2005).

Hydropower plants have been used for centuries to meet electricity demand, for irrigational purposes, flood control and water supply. Beside these benefits of hydropower plants, they are responsible for loss of forests (Tefera and Sterk, 2008).

Land requirement of the human activity is very important in point of land use or land transformation issue. Land requirement of hydropower plants significantly depend on site-specific conditions and capacities of hydropower plants. However according to some studies land transformation rate of run-of river hydropower plants is 3 m^2/GWh (Fthenakis and Kim, 2009).

Assessment of destructed forest size criterion is carried out by evaluating distance of water transfer channels through forest, since as all construction studies cause loss of habitat and biota, not only in vicinity of the projects site but also in wide ranges (Findlay and Bourdages, 1999). Yet, in both national and international regulations there is no forest logging limitation during any kind of construction works. In Turkey, during construction studies, investors are free to cut trees as long as they pay the price which is regulated in The Forest Law. However it should be considered in environmental acceptability or suitability studies so as to make discrimination between good and bad applications. For this purpose deforestation of project areas are included in this study.

Fuzzy set identification is made by depending on risk class boundary values in Zelenakova et al., (2013) that is an ecological risk assessment study about hydropower plants. In the study if distance of constructed access roads through forest is greater than 3 km, the risk level of the region is “unacceptable” and if the distance is smaller than 1 km, the risk level is “acceptable” with regard to deforestation criterion. Fuzzy set of this criterion is prepared with similar approach; if the total length of water transfer channels through the forest is greater than 3 km, the region is considered as “unacceptable in terms of destructed forest size”, on the other hand if the length is less than 1 km the region is considered as “acceptable in terms of destructed forest size”. Prepared fuzzy set is given in Table 3.7 and Figure 3.6.

Table 3.7 Fuzzy Set of Destructed Forest Size Criterion

Total Length of Water Transfer Channels (km)	**Acceptability**
$x \leq 1$	Acceptable
$1 < x < 3$	Partially Acceptable
$x \geq 3$	Not Acceptable

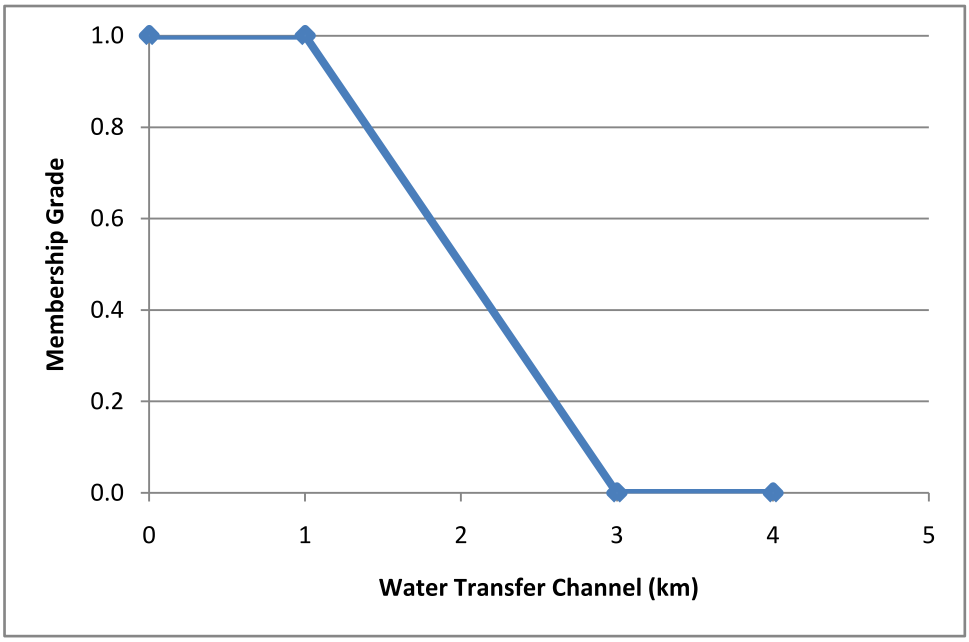

Figure 3.6 Fuzzy Set Representation of Destructed Forest Size

3.3.1.5 Terrorism

Terrorism is a willful act of violence that is directed against society. Terrorism activities include antigovernment activities, organized crime events, common criminals, rioting mobs, militant protests and individual psychotic attacks (Hoffman, 2006).

There are some vital effects of terrorist attacks on economy. Beside property loses, increased security taxes is another loss with regard to economy. Studies show that investors avoid investing regions that have terrorism risk because of 3 major reasons;

- Even absence of direct terrorist attacks, protecting facilities against possible attacks increase operational cost,
- Terrorist attacks may destroy infrastructure such as; plant buildings, roads, accommodations of workers etc.,
- It is difficult to find employee since people do not feel secure in risky regions (Enders et al., 2006).

For all these reasons terrorism criterion is included in this study in order to make investors consider possible, unexpected economic, environmental and lives losses in the projects.

Terrorism criterion is discussed by considering destruction of hydropower plant as consequence of terrorist attack. In the event of that kind of attack, all the pressure pipe lines and regulators may be destroyed and all carried water may spill. Consequently taken water cannot be given back to the stream bed and environmental effects of hydropower plant reach critical level. Even if hydropower plant is reconstructed, elapsed time during reconstruction may cause irreversible result. Therefore, terrorism is as an important factor that should be considered before construct a hydropower plant in a region.

Terrorism criterion evaluation based on comparison between numbers of terror attacks happened in project district last 20 years and number of terror attacks happened in the country in recent years.

For the case study implementation, average terrorist attack number of Şavşat district and average terrorist attack number per district in Turkey are compared. For more accurate results total number of terror attacks happened in Turkey in last 20 years are asked from General Directorate of Security Affairs, but it is rejected because of confidentiality reasons. However, according to terrorism reports of

Turkish Grand National Assembly; (Annual Terrorism Report, 2011) and (Annual Terrorism Report, 2012), 281 and 229 terror attacks were happened in Turkey in 2011 and 2012, respectively. Therefore we can conclude that average terror attack number in Turkey is about 255/year, if the number is divided into number of district in Turkey, which is 957, average terrorism attack number per district in Turkey, which is 0.27/year, can be found.

Fuzzy set preparation of terrorism risk factor was made by referencing average terrorism attacks number per district of Turkey per year. In the fuzzy set average terrorist attack number is considered as boundary of "not acceptable" region and fuzzy set is prepared according to that idea. Fuzzy set and their graphical representation are given in Table 3.8 and Figure 3.7.

Table 3.8 Fuzzy Set of Terrorism Criterion

Annual Terrorism Attacks Number	**Acceptability**
$x = 0$	Acceptable
$x \leq 0.27$	Partially Acceptable
$x > 0.27$	Not Acceptable

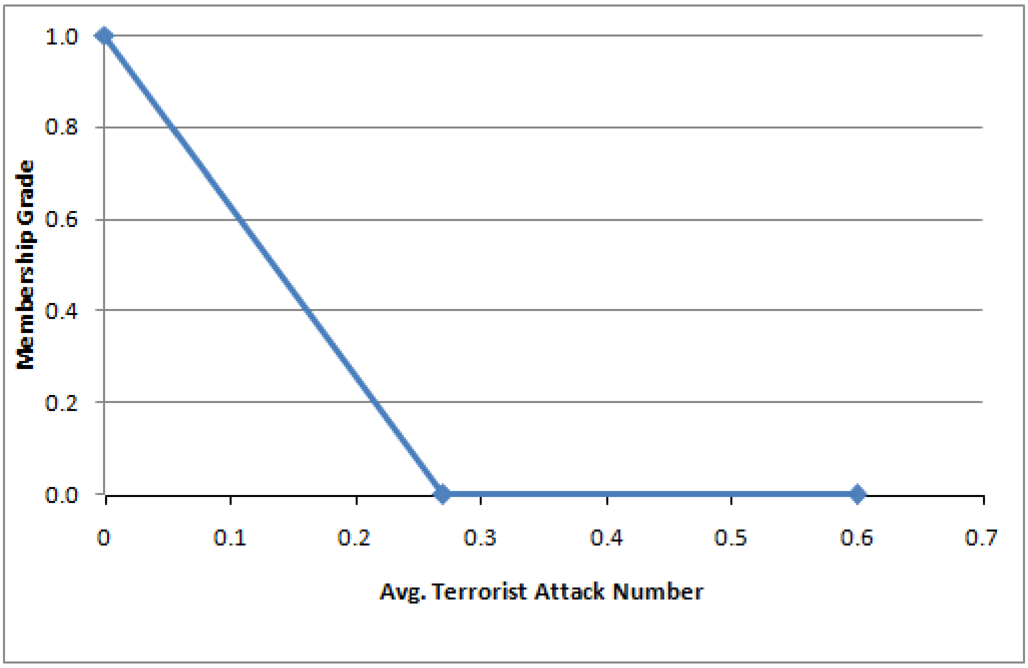

Figure 3.7 Fuzzy Set Representation of Terrorism Criterion

3.3.1.6 Public Perception

Over 50 years ago, society started to count environmental issues as major important social problem. However these problems received attention of only some professionals and public health officials up to mid-sixties, after that society, media and policy makers began to show interest to environmental issues. So that after seventies, in developed countries, parallelism between public opinion and actions of governments seemed as inevitable necessity of democracy. Under the favor of these evolvements concept of "public participation" terms was arisen (Lester, 1997).

Public participation refers to involvement of society in the decision making procedure. Involvement of public opinion in decision making process increase the quality of decisions, so policy makers, and industrial investors started to pay attention to public opinion (Harding, 1998).

In order to find out public perception about an issue there are some techniques such as; public perception surveys, citizens' jury/panel, consensus conference, referenda etc. These techniques are used in decision making studies beside evaluations features of the projects (Rowe and Frewer, 2000). In the scope of this thesis study, a survey study was carried out in case study region in order to evaluate the public perception.

Fuzzy set preparation for public perception criterion was carried out by applying statistical approach. In the determination process rules of standard normal distribution are applied. Standard normal distribution is a normally shaped distribution with a mean of zero and standard deviation 1. The characteristics of standard normal distribution, it is possible to compare scores from different samples and compare different scores from the same samples (Dancey and Reidy, 2002).

Standard normal distribution is known as probability distribution since the area under the curve between any specified points represents the probability of obtaining scores within the specified points. For example, the probability of obtaining scores between -1 and +1 from the distribution is 68%, which means that 68% of the total area under the standard normal curve falls between the -1 and +1 standard deviations from the mean. Similarly, the probability of obtaining a score between -1.96 and +1.96 from the distribution is 95% (Dancey and Reidy, 2002).

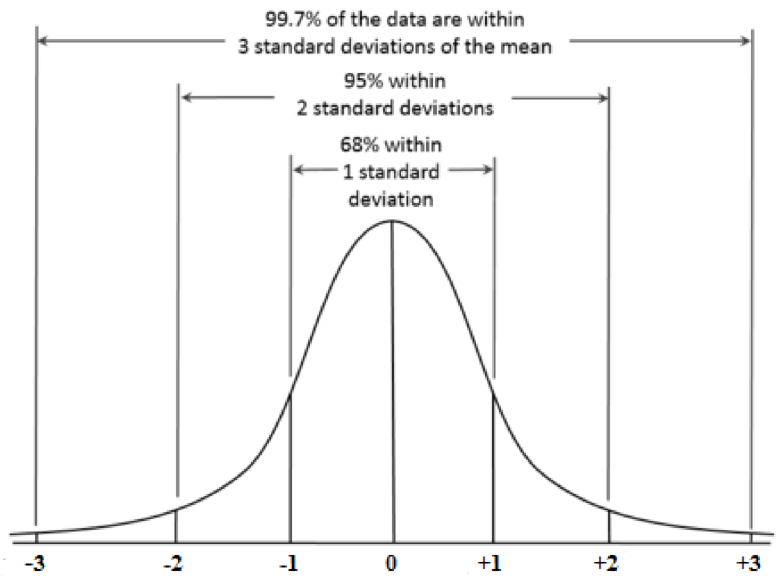

Figure 3.8 Standard Normal Distribution with Percentages of Standard Deviations

According to expert opinion of Assoc. Prof. Dr. Türker ÖZKAN (Middle East Technical University, Psychology Department), that was taken by personal communication percentage between -1 and +1 standard deviations is used to evaluate public perception criterion, because it is believed that 68% of agreement on an idea can be considered as "accepted" by the society. Fuzzy set of the criterion is prepared by assuming 68% as boundary of "acceptance" and remained 32% as boundary of "not acceptance". Prepared fuzzy set is given in Table 3.9 and Figure 3.9.

Table 3.9 Public Perception Fuzzy Set

Public Perception Percent	**Acceptability**
$x \geq 68$	Acceptable
$32 < x < 68$	Partially Acceptable
$x \leq 32$	Not Acceptable

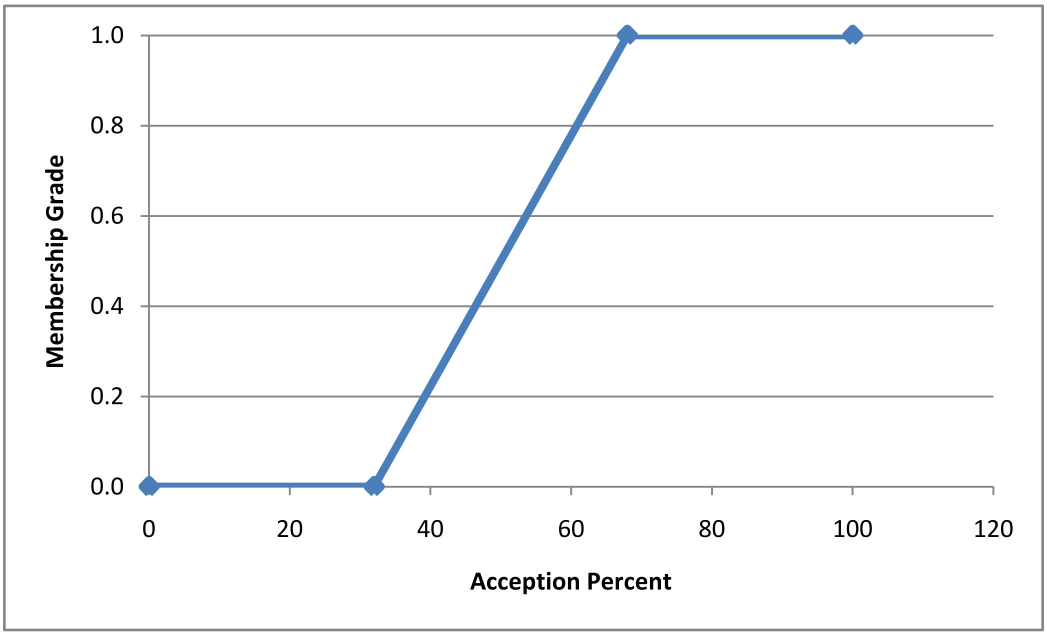

Figure 3.9 Fuzzy Set Representation of Public Perception Criterion

3.3.1.7 Landslide

Landslide is defined as; down slope movement of mass of rocks, debris or earth under gravitational influence of soil and mass rock (Cruden, 1991). There are certain external stimuli that trigger occurrence of landslides such as earthquake shaking, storm waves, water level change, intense rainfalls or stream erosion that cause a rapid increase in shear stress or decrease in shear strength of slope-forming materials. In 21^{st} century, occurrences of landslide events have been increasing because of following reasons;

- Increased urbanization and development in landslide-prone areas,
- Continued deforestation of landslide-prone areas, and
- Increased regional precipitation caused by climate changing (Dai et al., 2002).

Especially at mountainous areas, landslides have been causing huge economic losses and loss of lives. Such that, in United States, landslides cause an estimated

US$ 1-2 billion economic loses and 20-25 deaths annually. These numbers are greater than average losses caused by earthquakes (Dai et al., 2002).

In recent years, regional and medium scale landslide researches have become an important topic for engineering, geology, planning and local administration disciplines, since landslide occurrence have been increasing recently. Therefore, making landslide risk assessment studies at early stages has crucial importance for safe and economic planning, such as urbanization activities and engineering structures (Ercanoglu and Gokceoglu, 2004).

When number of landslide occurrence and the structures that are affected by landslides are considered, importance of landslide studies can be understood (Eker et al., 2012). Eastern Black Sea region is the most mountainous and the rainiest part of Turkey, so it is important to consider landslide occurrence potential instudy sites before starting urbanization and engineering projects. Because of these reasons, landslide topic has taken as a criterion in this study.

In order to evaluate landslide criteria, 1/25000 scaled Landslide Inventory Map of the study region has obtained from Mineral Research and Exploration Institute. Landslide acceptability evaluation is handled by measuring the distance between the study region and the closest landslide area. In fuzzy set preparation buffer zone determination technique is used as in Environmentally Sensitive Area criterion. However in any of national and international regulation, there is no determined buffer zone in order to prevent construction near the landslide zones. Therefore buffer zone determination is handled by consulting an expert about landslides. According to expert opinion of Asst. Prof. Dr. Nejan HUVAJ SARIHAN who is a faculty member at Civil Engineering Department, Middle East Technical University, technical studies that include site visits have to be done to determine buffer zone for landslide zones, because characteristics of landslide zones and geology of the regions are important factors that determine the size of the area affected by landslides. However, 10% of the greatest width of landslide zones can be considered as buffer zone area in order to be on the safe side and any kind of construction should not be permitted on those areas.

By considering expert opinion of Asst. Prof. Dr. Nejan HUVAJ SARIHAN, fuzzy set of landslide criterion is prepared. Fuzzy sets and their graphical representation are given in Table 3.10 and Figure 3.10.

Table 3.10 Landslide Criterion Evaluation

Distance Between HPP and Landslide Area (% of Width of the Landslide Zone)	**Acceptability**
$x \geq 10$	Acceptable
$0 < x < 10$	Partially Acceptable
Inside the landslide zone	Not Acceptable

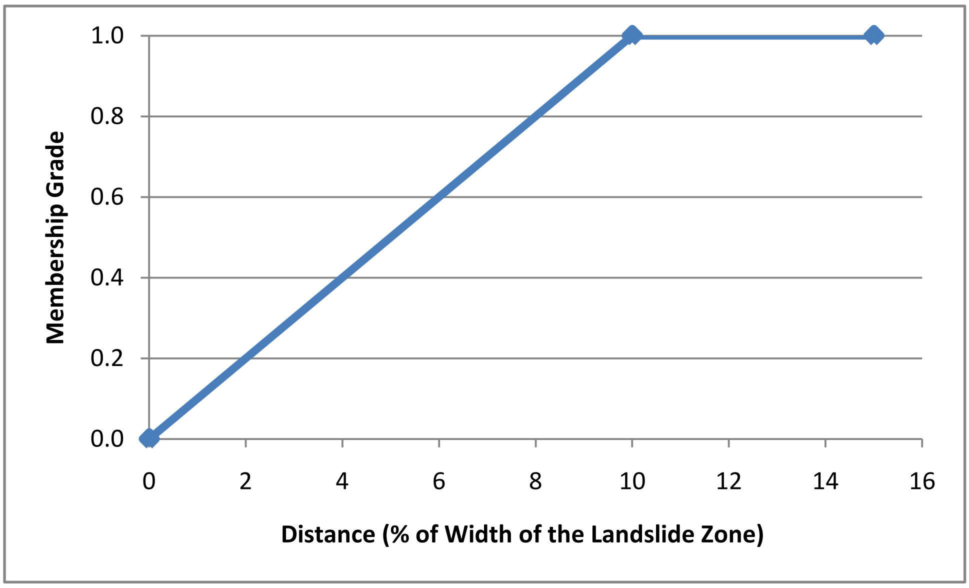

Figure 3.10 Fuzzy Set Representation of Landslide Criterion

3.3.1.8 Distance from the Nearest Residential Area

Distances between residential area and hydropower plants are not regulated by national or international legislation. However, during both construction and operation phases of power plants, people face with the impacts of them in their daily lives. Beside physical (noise, air pollution etc.) and environmental effects of the power plants, in case of any unusual situation, such as natural disasters and catastrophic occupational accident, people living around the power plants are affected directly. Therefore, because of these impacts of power plants, distance between the hydropower plant and the nearest residential area is included in this study as a criterion.

Fuzzy set of this criterion is based on Zelenakova et al., (2013) which is a risk assessment study including 16 criteria and a case study implementation. In the study, each criterion is evaluated with a scoring system from 1-4. In the scoring system, there boundaries of each risk group which are decided by depending on literature research and scientific experiences. In the scoring system of 'distance to the nearest residential area' criterion; distances less then meter is considered as, "unacceptable risk level" (Level 4), distances between 10.1-100 meters are considered as "undesirable risk level" (Level 3), distances between 100.1-1000 meters are considered as "moderate risk level" (Level 2) and distances greater than 1000.1 km are considered as "acceptable risk level" (Level 1).

While determining fuzzy set of distance between the hydropower plant and the nearest residential area criterion, Turkish regulations are researched and it is realized that only legal regulation about the distance from the residential area is Turkish Mining Regulation which limits the distance between the residential areas and mining areas and the determined maximum distance is 60 meters. However there is no restriction in regulations about the distance between the residential areas and the hydropower projects. After further researches, "acceptable risk level" and "unacceptable risk level" of Zelenakova et al., (2013) are considered as the boundary of the fuzzy set. Fuzzy set representation of the criterion is given in Table 3.11 and Figure 3.11.

Table 3.11 Fuzzy Set of Distance Between the Hydropower Plant and the Nearest Residential Area

Distance (km)	Acceptability
≤ 10	Not Acceptable
10-1000	Partially Acceptable
≥ 1000	Acceptable

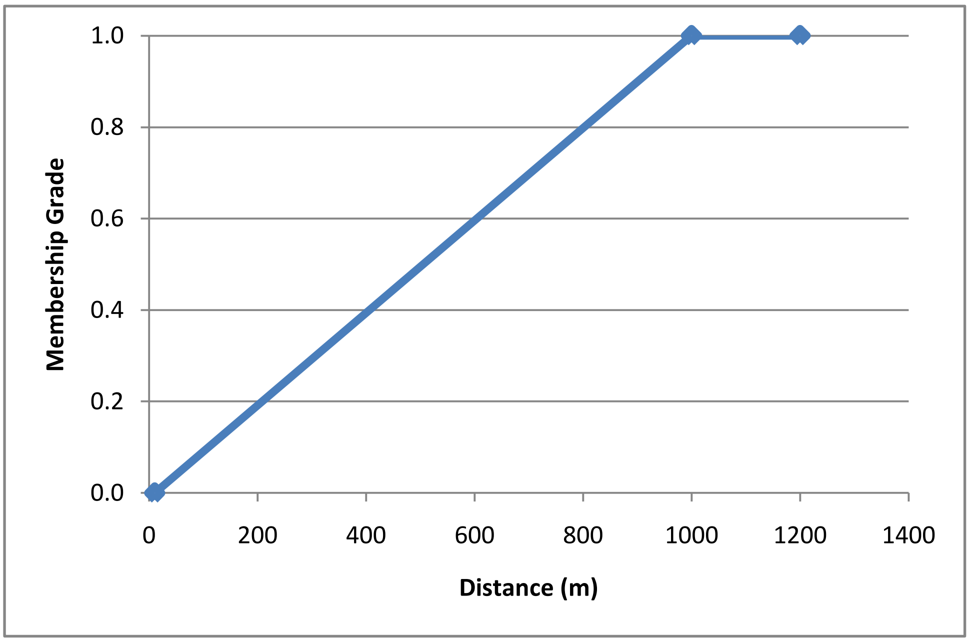

Figure 3.11 Fuzzy Set Representation of Distance between the Hydropower Plant and the Nearest Residential Area

3.3.1.9 Population Density

As mentioned in previous parts of the study in detail, there are certain impacts of hydropower projects on society. As number of affected people increase, sizes of these impacts increase either. Therefore it is important to take into account number of people living around the hydropower projects.

In order to express the size of the social impacts, fuzzy set given in Table 3.12 and Figure 3.12 was prepared. Boundaries of the fuzzy set were defined according to information gathered from the literature. Especially Rojanamon et al., (2009) and Tanutpongpalin and Chaisomphob (2004), which are similar studies focusing on "suitability" of selected areas for hydropower plant construction, are used as references of fuzzy set definition.

Table 3.12 Population Density Fuzzy Set

Population Density (people/km^2)	**Acceptability**
≤ 10	Acceptable
10-30	Partially Acceptable
≥ 30	Not Acceptable

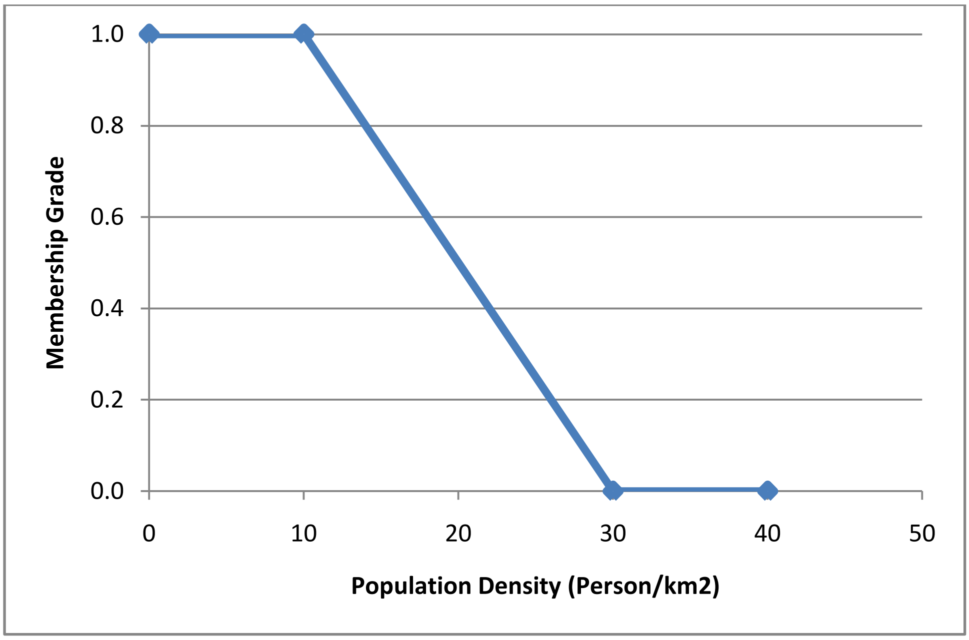

Figure 3.12 Fuzzy Set Representation of Population Density Criterion

3.3.1.10 Number of Downriver Tributaries

Pollution load caused by hydropower plant contrition and taking big portion of water from river bodies for energy generation is one of the most important problems regarding to hydropower plants. Number of tributaries is a major factor that determines the exposure magnitude of the downriver parts of the watershed. Increase in number of downriver tributaries is better for maintaining accessible habitat for migratory fish, the natural flooding regime for riverine ecosystems, and nutrients inputs needed for the high biological productivity of estuaries (Zelenakova et al., 2013). Fuzzy set identification depends on risk class determination boundaries of number of downriver tributaries criteria in Zelenakova et al., (2013); boundaries of “unacceptable risk level” and “acceptable risk level” are used to specify fuzzy set boundaries of this criterion. Prepared fuzzy set is given in Table 3.13 and Figure 3.13.

Table 3.13 Fuzzy Set of Number of Downriver Tributaries Criterion

Number of Downriver Tributaries	**Acceptability**
> 2	Acceptable
0-2	Partially Acceptable
0	Not Acceptable

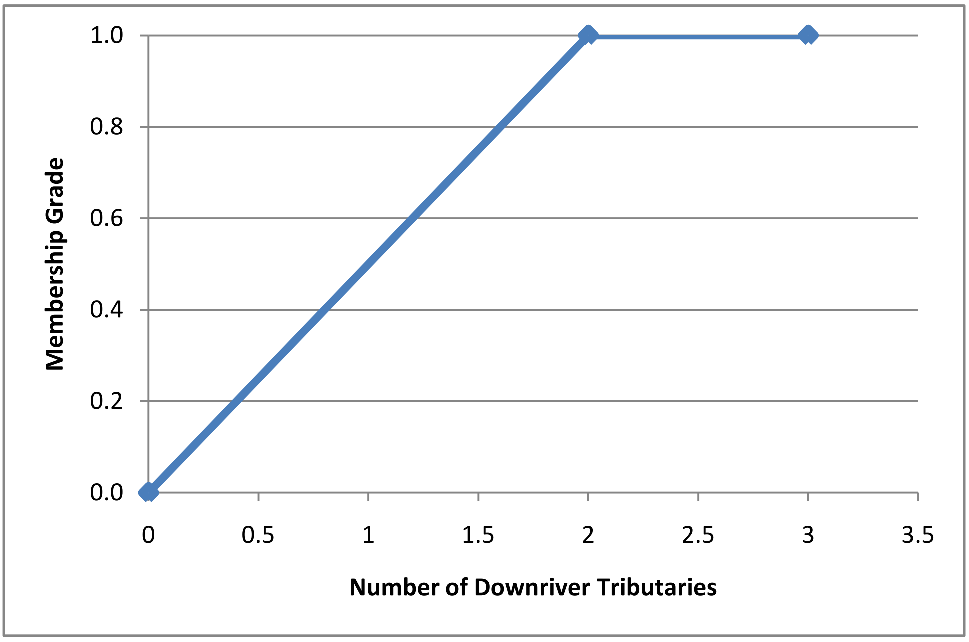

Figure 3.13 Fuzzy Set Representation of Number of Downriver Tributaries Criterion

After fuzzy set identification, memberships of all criteria have to be calculated. Membership calculation process is carried out by using fuzzy sets; an example of membership calculation is given in Figure 3.14. In the example, distance between the nearest residential area and the hydropower plant is assumed as 6 km and membership grade is determined by making correlation between assumed distance and the fuzzy set boundaries.

In Şavşat case, input values of Şavşat are evaluated in identified fuzzy sets for all f the criteria. All of the determined membership grades are given in Chapter 4.

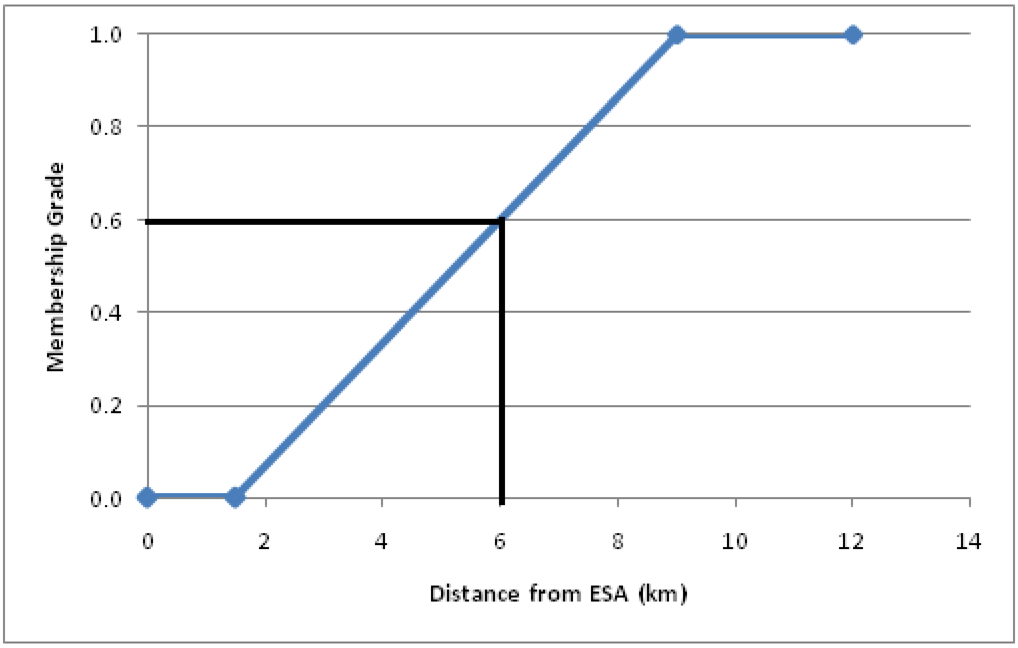

Figure 3.14 Graphical Representation of Membership Grade Determination

3.4 Criteria Weighting

Weight of all the criteria can be taken as equal at aggregation stage. However, by this way, low scores on one criterion can be compensated by higher scores on other criterion. If decision maker wants to put emphasis on a criterion or some of the criteria, relative weighing system has to be applied (Velasquez and Hester, 2013).

In this study, there are two aggregation methods that weights of the criteria are evaluated. These aggregation methods are Ordered Weight Averaging (OWA) and Linear Weighted Averaging (LWA). In OWA method, weights are determined by the method itself while in LWA method decision makers are needed to determine the weights of each criterion. In this study, in order to define relative weight of the criteria, a survey was conducted among 39 competent people about hydropower plants. They are asked to assign weight value for all criteria in 1-4 scale. After survey results are gained, assigned weight values of each risk factor are summed in itself, and results are fitted in 0-1 scale in order to keep all weight values in 0-1 range. Detailed explanation about aggregation methods are given below.

3.5 Aggregation of the Scores and the Weights

The problem of aggregation of criteria functions in order to obtain overall decision function is the most important stage in many disciplines (Yager, 1988). General formula of aggregation is given in Equation 3.5.

$$D(A_i) = (R_{i1} \ o \ R_{i2} \ o \ \dots \ o \ R_{in}) \qquad (3.5)$$

Where; "o" represent operation and R_{ij} is the numerical rating of alternative A_i for criteria C_j (Ribeiro, 1996).

In this study 4 different aggregation method are used which are; "and", "or", "Ordered Weighted Averaging (OWA)" and "Linear Weighted Average (LWA)" operators.

3.5.1 "And" Operator

"And" operator is called t-norms operator which means satisfaction conditions are met by "all" the criteria. Therefore "anding" aggregation allows for no compensation for one bad satisfaction. Mathematical expression of "anding" operation is given in Equation 3.6 (Yager, 1998).

$$T(a_1, a_2, \dots, a_n) \leq Min \ (a_1, a_2, \dots, a_n) \qquad (3.6)$$

T-norms operator enables to implement of fuzzy set aggregation (Aydın, 2009). Fuzzy set "anding" aggregation operation in the content of this thesis study can be shown as follows;

$$D= F_1 \cap F_2 \ ... \ \cap F_n = \text{Min}(F_i)$$

Where F_i values represent score of the criteria in other words membership grade of the criteria that are obtained from fuzzy sets of the criteria.

3.5.2 "Or" Operator

"Oring" operator is called co-t-norm operator which is the opposite of "anding" operator. In "oring" aggregation satisfaction conditions are met by "any" of the criteria. Mathematical expression of "oring" operation is given in Equation 3.7.

$$T(a_1, a_2, \dots, a_n) \leq Max\ (a_1, a_2, \dots, a_n) \tag{3.7}$$

"Oring" aggregation operation allows for no distraction from one good satisfaction (Yager, 1988). Fuzzy set "oring" aggregation operation in the content of this thesis study can be shown as follows;

$$D = F_1 \cup F_2 \ ... \cup F_n = \text{Max}(F_i)$$

Where F_i values represent score of the criteria in other words membership grade of the criteria that are obtained from fuzzy sets of the criteria.

3.5.3 Ordered Weighted Averaging (OWA) Operator

OWA operator is developed by Ronald Yager in 1988. "anding" and "oring" aggregation operators are represent two extreme cases which are; "aggregation satisfaction conditions are met by all of the criteria" and "aggregation satisfaction conditions are met by any of the criteria". In Yager (1988), a new approach was suggested which is between these two extreme cases.

The main aim of developing OWA operator is avoiding extreme applications. In literature there are some aggregation method to achieve that; one of them OWA and the other one is LWA Method, which is one of the aggregation method used in this study. However, in OWA application each criterion has a weight and these weights are not decided by decision makers. In the method, the weights are assigned to the ordered values (i.e. the worst value, the second worst value and so on) rather than the specific criteria. Moreover, the decided weight values are called as "position" since they mean the order of the criterion rather than its importance, that is why OWA is known as "equal importance method" (Ogryczak and Sliwinski, 2003), (Makropoulos and Butler, 2006).

Assignment of weights by the method itself rather than the decision makers is the most advantageous feature of the OWA method, because it increases the practicability of the method. If the determined weight values by decision makers are close to each other and if it is important to evaluate distribution of the values of the criteria, other aggregation methods may not give correct results. Similarly, other aggregation methods are not preferred by some decision makers since they violate the requirement of impartiality, as they assign the weights to the specific criteria (Grabisch, 1995), (Chiclana et al., 2007). Because of its mentioned advantageous feature, OWA aggregation method is used in many fields such as neural networks, database systems, fuzzy logic controller and group decision making under uncertainty to model the anticipated utility (Fodor et al., 1995). Mathematical representation of OWA operator is given in Equation 3.8.

$$f\left(\mu_{S,1}, \mu_{S,2}, \dots, \mu_{S,n}\right) = W_1 b_1 + W_2 b_2 + \dots + W_n b_n \qquad (3.8)$$

Where;

- $W_i \in (0,1)$,
- $\sum Wi = 1$,
- b_i is the *i*th largest element of $\mu_{S,1}, \mu_{S,2}, \dots, \mu_{S,n}$,

- W is the weight of the criteria, and
- The aggregation operation is represented by f, and individual satisfaction of each alternative, S for fuzyy objective F_i is represented by $\mu_{S,i}$ (Aydın et al., 2010).

3.5.3.1 Quantifier Guided OWA

As mentioned before, previous aggregation operators are based on satisfaction either "all" (anding) or "any" (oring) of the criteria. However, in many cases decision maker claims the condition that is between these two applications. For example a decision maker may require the "most" of the criteria be satisfied or "few" or "many" of the criteria be satisfied. Therefore fuzzy logic proposes that the class of quantifiers; such that if Q is a linguistic quantifier, such as "most", then Q can be denoted as a fuzzy subset Q of I; where for each $r \in I$, Q(r) indicates the degree to which the proportion *r* satisfies the concept denoted by Q (Yager, 1996).

In Yager (1996a) relative quantifiers are divided into three sub-categories;

- Regular Increasing Monotone (RIM) quantifier such as "all", "most", "at least α",
- Regular Decreasing Monotone (RDM) such as " at least one", "few" and "at most α", and
- Regular UniModal (RUM) such as "about α" (Aydın et al., 2009).

In the content of this thesis study "most" of the criteria are aimed to be satisfied. Therefore Q quantifier is a RIM quantifier in this study and weights of the criteria is defined by Equation 3.9.

$$W_i = Q\left(\frac{i}{n}\right) - Q\left(\frac{i-1}{n}\right) \tag{3.9}$$

For i = 1,2,..,n and where guided quantifier "most" is defined as $Q(r) = r^2$ and W is the weight of the criteria(Aydın et al.,2009).

In brief, in Quantifier Guided OWA application, the criteria are listed in descending order according to their value and for the greatest criterion; *i* value in the Equation 3.9 takes 1. Then other criteria takes 2, 3.., n values in Equation 3.9 according to their place in the descending value order.

3.5.4 Linear Weighted Average (LWA) Operator

Linear Weighted Average aggregation tool is another prominent method. The method is applied by using normalized weight values and normalized scores of the criteria (Steele et al., 2009). In order to use Linear Weighted Average method, all criteria have to be mutually preference independent of each other. In LWA aggregation method, each criterion takes weights according to their importance and these weights are determined by decision makers. Since criteria are not equally important, the method is classified as “heterogenic” (Chiclana et al., 2007). However, LWA is the most commonly used aggregation method, because its application is simple and in some cases importance of the criteria is an important issue (Makropoulos and Butler, 2006). Mathematical representation of Linear Weighted Average Method is given in Equation 3.10.

$$D(A_i) = \sum_{j=1}^{n} W_i * C_{ij} \qquad (3.10)$$

3.6 Decision Making

Decision making is the final step of the MCDM analysis. At this step, decision maker(s) evaluates the result of the analysis and decide which alternative should be applied. In order to make evaluation easier and meaningful, MCDM analysis is applied at more than one spots or study area so as to give chance of comparison. In Şavşat case there are five hydropower projects to compare and make decision.

In order to make easier the decision making three set of criteria are prepared; set of all criteria, set of reduced criteria and set of environmental criteria. In set of all criteria, all of the criteria are included in the calculations while in set of reduced criteria six selected criteria and in set of environmental criteria four criteria are included in the calculations. The aim of preparing set of reduced criteria is representing the acceptability results with less number of criteria. In some cases obtaining the data of all ten criteria may be difficult or sometimes impossible. Therefore reducing the numbers of criteria makes the methodology more applicable. On the other hand main aim of preparing set of environmental criteria is to show the environmental acceptability of the projects. In decision making step, results set of environmental criteria may not make sense by itself but they can be used to check or support the results. In Şavşat case results of all sets are calculated but it is decision maker(s) decision to use results of set of reduced criteria or set of environmental criteria.

CHAPTER 4

APPLICATION OF MULTI-CRITERIA DECISION MAKING PROCEDURE IN ŞAVŞAT, ARTVİN

In this chapter, implementation of the methodology is shown through a case study. For the case study area Artvin/ Şavşat region is selected. The consideration behind the idea choosing Şavşat is its hydropower potential which makes the region popular among investors. Another decision criterion is resistance of local residents against hydropower projects by social media, law cases and protests. In Artvin, 15 dams and 116 run-of river hydropower plants are planned to construct (Özalp et al, 2010). In today's condition there are 4 dams in operation and 1 dam is under construction according to State Hydraulic Works' data. According to the same data only in Şavşat there are 21 hydropower projects that are in operation, under construction or in feasibility phase.

In the implementation part fuzzy sets and results of case study are given. The fuzzy sets are prepared for general usage, not only for Şavşat region. However in order to make the thesis easy to follow fuzzy sets are given in the part of case study implementation.

4.1 Artvin/ Şavşat Study Site

Şavşat is located in north-east region of Turkey and it is surrounded by Ardahan and Hanak from east, Posof in from north-east, Ardanuç from south, Artvin and Borçka from west and Georgia from north. Coordinates of the town is 41^0 14' 42" North and 42^0, 21' 52" East. Population is 17600 according to Turkey Statistical Institute research carried out in 2012.

Total surface area of the town is 1317 km^2 which is mainly mountainous and rough. The town is surrounded by mountains whose highest one is Karçal Mountain with 3537 meter height. Minimum and maximum altitudes of the region are 950 meter and 1800 meter respectively.

The town is in transition region between continental climate and Black sea climate. Also the town has diversity by means of vegetation. At high parts of the region, earth is covered by coniferous trees while lowlands are covered by broad-leaved trees.

Although the land is rough and agricultural area is limited in the town, main economic source of living is agriculture. Since it is not an industrial area and other economic sectors are not developed, there is an employment problem in the town. Also animal breeding sector is getting worse day by day in the town. In order to provide economic opportunities, tourism investments are supported these days. Plus, green housing and beekeeping are other economic areas that are supported by economic inducements [1].

Since the result MCDM analysis is needed to compare with multiple data, 5 hydropower plants are also evaluated with the methodology. The results cannot give an overall idea for whole Şavşat region, but hydropower suitability for certain points is obtained as output of the study. All fuzzy sets and results of all hydropower projects are given below.

Specific case study areas of the study are project areas of Cüneyt HPP, Gana HPP, Meydancık HPP, Armutlu HPP and Şavşat HPP. Cüneyt HPP projects which is planned to construct on Gökner River is the biggest hydropower projects in Şavşat with 247.246 GWh/year. Total area of the project is 375950 m^2 and it includes six regulators, total length of water transfer channels of those regulators is 16945 meters. The nearest residential area to the project area is Taşköprü neighborhood and the distance between the project area and the neighborhood is 500 meters. Gana HPP project is planned to construct on Gana River and electric generation capacity of the project is planned as 33.799 GWh/year. Total project area is 40800

m^2 and total length of water transfer channel is 500 meters. The nearest residential area is Gürsoy neighborhood which is 150 meters away from the the project area. Meydancık HPP project which is planned to construct on Meydancık River will have 61.20 GWh/year installed capacity and total length of the water transfer channel in the project is 6258 meters. The total project area is 116226 m^2 and the nearest residential area is Dereiçi Village which is 270 meters away from the project area. Armutlu HPP project which is planned to construct on Nanep River will have 34.87 GWh/year energy generation capacities and total length of the water transfer channel will be 6849 meters. Total project area will be 75327 m^2 and the nearest residential area is İspiroğlu neighborhood which is 400 meters away from the project area. Şavşat HPP project is going to construct on Şavşat River. Total installed capacity of the project will be 57.76 GWh/year and total length of water transfer channel is 2870 meters. Total project area of the project is 339033 m^2 and it is 200 meters away from the Şavşat district.

Table 4.1 Summary Information about Hydropower Plants

HPP	**Project Area (m^2)**	**Capacity (GWh/year)**	**Water Transfer Channel Length (meters)**	**Distance from Nearest Residential Area (meters)**
Cüneyt	395950	247.246	16945	500
Gana	40800	33.799	500	150
Meydancık	116226	61.20	6258	270
Armutlu	75327	34.87	6849	400
Şavşat	339033	57.76	2870	200

Figure 4.1 Locations of Hydropower Plants

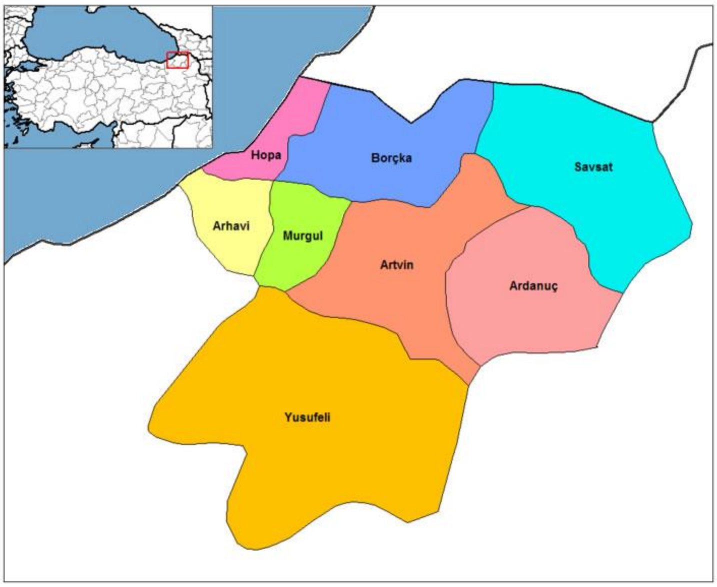

Figure 4.2 Geographical Location of Şavşat/Artvin

4.2 Evaluation of Savşat Case Study Area

4.2.1 Distance from the Environmentally Sensitive Areas

Within the boundaries of Artvin, there are 3 national parks, 2 natural reserve areas and 1 natural park that are classified as sensitive areas. 2 national parks among these environmentally sensitive areas are in Şavşat.

As mentioned before, environmentally sensitive area criterion is evaluated by considering width of buffer zone and distance between hydropower plant and the nearest environmentally sensitive area.

In the Figure 4.3, surrounding sensitive areas of Cüneyt hydropower plant are given. In the figure; pink lines represents study area of Cüneyt Regulators, red areas represent natural reserved areas, green areas represent national parks and purple area represent a wildlife protection area.

As it can be seen in Figure 4.3 nearest environmentally sensitive area to the study site is a natural reserve area which is within the boundary of Borçka. The distance between the natural reserve area and study area the study area is 14.6 km.

If the buffer zone width and distance between the nearest environmentally sensitive area and the hydropower plant are evaluated according to fuzzy set of this criterion, which is given in Table 3.2 and Figure 3.2, it can be said that the study region is in “acceptable” in terms of ecological effects on environmentally sensitive areas, and membership grade is “1”.

Also, locations of Gana, Meydancık, Armutlu, Şavşat HPP and environmentally sensitive areas are given in Figure 4.4.

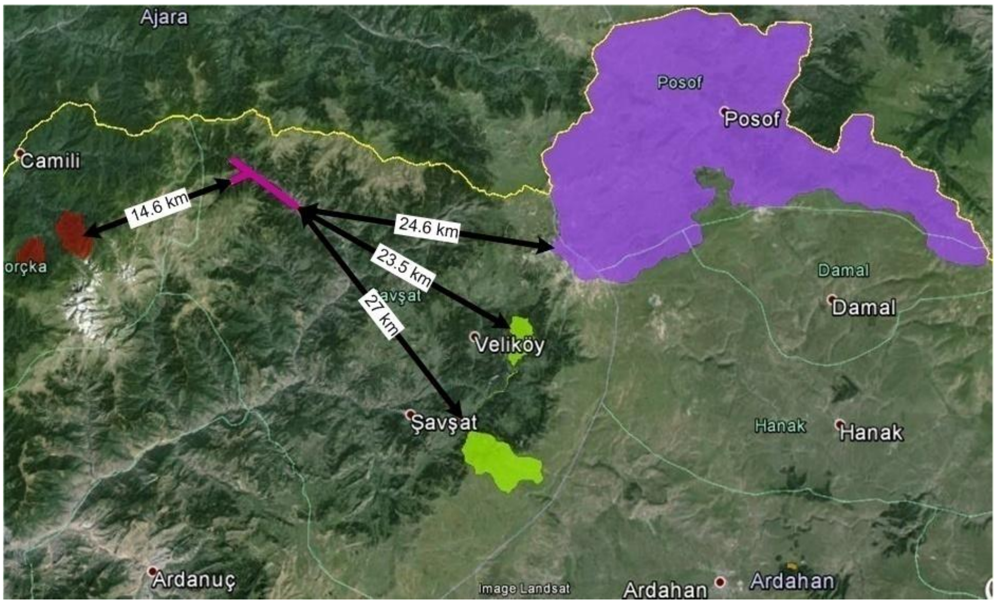

Figure 4.3 Distance between Study Area and Surrounding Environmentally Sensitive Areas

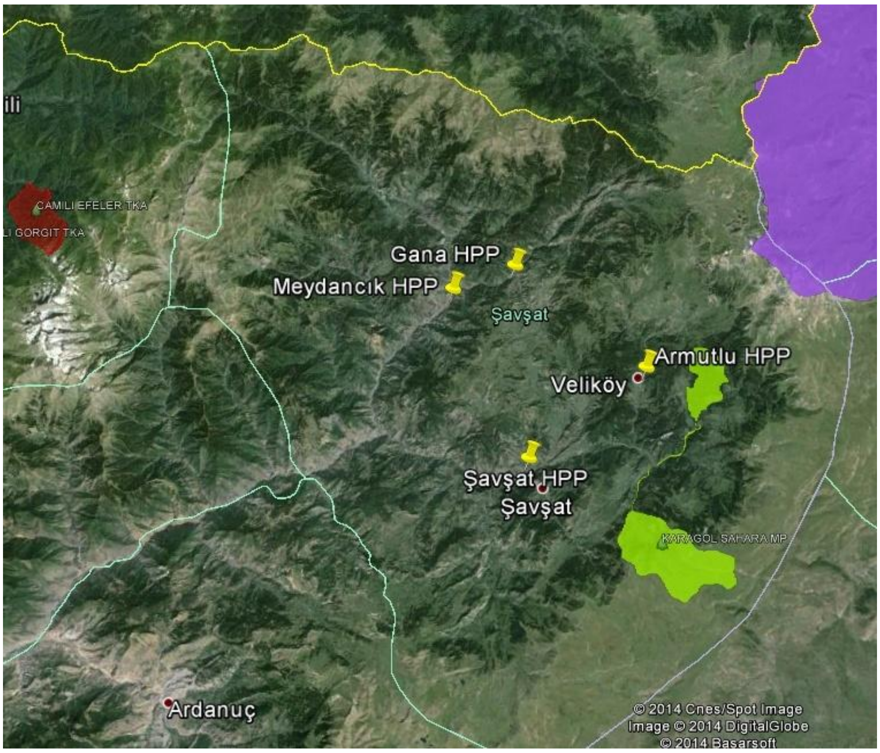

Figure 4.4 Locations of Environmentally Sensitive Areas and Selected Regions

As it is seen in Figure 4.4, the nearest environmentally sensitive area to all regions is Sahara/Karagöl National Park. The distances between Gana, Meydancık, Şavşat and Armutlu HPP and Sahara/ Karagöl National Park are 12.8 km, 16.2 km, 7.3 km and 2.9 km, respectively. According to fuzzy set of ESA criterion Gana and Meydancık HPPs are in "acceptable" region and their membership grades are "1", while Şavşat and Armutlu HPPs are in "partially acceptable" region and their membership grades are "0.77" and "0.17".

Table 4.2 Distances from Sensitive Areas and HPPs and Membership Grades

	Cüneyt HPP	**Gana HPP**	**Meydancık HPP**	**Armutlu HPP**	**Şavşat HPP**
Distance (km)	14.6	12.8	16.2	7.3	2.9
Membership Grade	1	1	1	0.77	0.17

4.2.2 Earthquake

In the Şavşat case study earthquake risk calculation is carried out by using Equation 3.4. In order to make calculations, active fault map of the region, which is given in Figure 4.5, was obtained from Mineral Research and Exploration Institute.

According to Probabilistic Seismic Hazard Analysis Method which is used in earthquke calculations, faults that are at maximum 150 km distance are included in the calculations. As it can be seen in Figure 4.5, there are 4 active faults around the study site, their distances and calculated M_{char} values are given in Table 4.3. Since fault depts are unknown, depths of all the faults are taken as 12 km which is general acceptance in Probabilistic Seismic Hazard Analysis Method.

Figure 4.5 Active Fault Map of the North Eastern Region of Turkey

Table 4.3 Active Faults and Their M_{char} Calculations

Fault No	Length (L)	Width(W)	Area (A)	M_{char}	M_{max}	M_{min}
1	5 km	12 km	60 km^2	5.79	6.03	5.55
2	7.5 km	12 km	90 km^2	5.97	6.21	5.73
3	11.25 km	12 km	135 km^2	6.15	6.39	5.91
4	8.75 km	12 km	105 km^2	6.04	6.24	5.80

Areas of the faults are calculated by simple multiplication of length and width of the faults. After that M_{char} values are calculated by using Equation 3.4. M_{min}value is founded by subtracting 0.24 from M_{char} value, and similarly M_{max} value is founded by adding 0.24 to M_{char} value, as it is asked in the formula. However earthquake risk calculations are continued by using M_{max} values since the most risky scenario is wanted to find out in this study.

In Table 4.4 $M_{max,}$ distance of the fault to the study area and resultant PGA values are given. PGA values are calculated by excel worksheet that is mentioned before and who is designed for Probabilistic Seismic Hazard Analysis Method.

Table 4.4 PGA Calculations of the Faults

Fault No	**M_{max}**	**Distance (d)**	**PGA**
1	6.03	71.25 km	0.026
2	6.21	75.00 km	0.029
3	6.39	76.25 km	0.035
4	6.24	80.00 km	0.028

As it is seen in Table 4.4, all calculated PGA values are lower than 0.1, so according to fuzzy set given in Table 3.4 and Figure 3.3 earthquake risk of the study site is in “acceptable region” and takes the membership grade “1”.

In Figure 4.6, locations of Gana, Meydancık, Armutlu, Şavşat HPPs and the faults are given. Also distances between the faults and the hydropower plants are given in Table 4.5. If the PGA value calculations are applied to the Gana, Meydancık, Armutlu, Şavşat HPPs, it can be seen that all the values of each hydropower plant regarding to each fault are smaller than 0.1. Calculated PGA values are given in Table 4.6. Therefore we can say that all the selected hydropower plants are in “acceptable region” with regard to earthquake criterion and membership values of all of them are “1”.

Figure 4.6 Locations of Selected HPPs and Faults

Table 4.5 Distances between Selected HPPs and the Faults

	Distance from Fault 1 (km)	**Distance from Fault 2 (km)**	**Distance from Fault 3 (km)**	**Distance from Fault 4 (km)**
Gana HPP	60.0	64.2	65.7	70.3
Meydancık HPP	62.3	66.1	67.1	71.0
Şavşat HPP	51.9	55.4	55.6	58.9
Armutlu HPP	49.5	53.6	55.3	61.1

Table 4.6 PGA Values of All HPP Regarding to All the Faults

	PGA Value Fault 1	**PGA Value Fault 2**	**PGA Value Fault 3**	**PGA Value Fault 4**	**Membership Grade**
Gana HPP	0.031	0.035	0.040	0.032	1
Meydancık HPP	0.030	0.033	0.040	0.032	1
Şavşat HPP	0.036	0.040	0.048	0.039	1
Armutlu HPP	0.038	0.042	0.048	0.038	1

4.2.3 Flow Rate Alteration

In this study, percentage of residual water in Cüneyt HPP project was taken from the Environmental Impact Assessment report of the project. The project consist of 6 regulators and in the report, monthly average flow rate data of all 6 regulators are given. Average flow rate data includes monthly average flow rate amounts between years of 1982-2004. Beside average flow rate data, planned residual water percentages are also given in the report and these values are given in Table 4.7 and in Appendix A monthly flow rate data of all selected hydropower plants are given. All of these data are taken from the Environmental Impact Assessment reports of the hydropower projects that obtained from Ministry of Environment and Urbanization Artvin Provincial Directorate. According to the Environmental Impact Assessment Reports these data are the actual flow rates of the places of the hydropower projects.

In this thesis study average residual water percentage is used to find out natural hazard. By using values given in Table 4.7, average residual water of whole project is calculated and ecological responses are determined according to those number.

Table 4.7 Residual Water Percentages of Regulators

Regulator Number	**Average Residual Water Percentage**
Regulator 1A	13.5
Regulator 1B	9.6
Regulator 2A	15.6
Regulator 2B	20.3
Regulator 3	17.3
Regulator 4	21.8
Average	16.35

As it can be seen in Table 4.7, average residual water amount is 16.35% in Cüneyt HPP project. If fuzzy set values that are given in Table 3.6 and Figure 3.5 are considered, acceptability of flow rate alteration criterion is in "partially acceptable" region and the membership grade is "0.13".

Data of water amount that are taken from Gana, Meydancık, Armutlu and Şavşat hydropower plants are also taken from environmental impact assessment reports of the hydropower plants which are provided by Ministry of Environment and Urban Planning. According to environmental impact assessment reports percents of residual water are 25%, 20.3%, 26.7% and 18% for Armutlu HPP, Meydancık HPP, Gana HPP and Şavşat HPP, respectively. Membership grades of selected regions are given in Table 4.8.

Table 4.8 Residual Water Percents and Membership Grades of Selected Regions

	Armutlu HPP	Meydancık HPP	Gana HPP	Şavşat HPP
Residual Water Percent	25	20.3	26.7	18
Membership Grade	0.30	0.21	0.33	0.16

4.2.4 Destructed Forest Size

Data of length of water transfer channels through the forest is taken from Environmental Impact Assessment Report of Cüneyt Hydropower Plants project. The lengths are given in Table 4.9.

Table 4.9 Distances of Water Transmission Channels through Forest in Cüneyt HPP Project

Regulator Number	Water Transfer Channel Lengths (km)
1A + 1B	6.49
2A + 2B	3.76
3	3.58
4	1.44
Total	**15.27**

According to Table 3.7 and Figure 3.6 acceptability of Cüneyt HPP project with regard to land use is “not acceptable” and membership grade is “0”.

Also in Table 4.10, water transfer channel lengths of Gana, Meydancık, Armutlu and Şavşat HPPs are given. These data are also taken from their Environmental

Impact Assessment Reports that are obtained by Ministry of Environment and Urban Planning. According to the table, Gana hydropower plant is in “acceptable” region and its membership value is “1”, however all other hydropower plants are in “not acceptable” region and their membership values are “0”.

Table 4.10 Lengths of Water Transfer Channel of the HPPS

Hydropower Plant	Length of the Water Transfer Channel (meter)
Gana	500
Meydancık	6258
Armutlu	6849
Şavşat	2870

4.2.5 Terrorism

In order to evaluate terrorism risk factor, number of terror attacks in Şavşat in last 20 years was obtained from Artvin Provincial Directorate of Security. According to official answer of Artvin Provincial Directorate of Security, which is given in Appendix B, there have been 3 terror attacks occurred in Şavşat in last 20 years, so yearly average is 0.15. Hence, if fuzzy set of terrorism risk factor are considered, the terrorism criteria is in “partially acceptable” region and the membership grade is “0.56” for all hydropower plants in Şavşat.

4.2.6 Public Perception

In order to measure reaction of the public to hydropower plant construction, a survey was conducted in the case study region. A survey was conducted on 93 randomly selected people live in Village of Meydancık and City of Şavşat on November 2012. The answers the question of “Do you think that HPP projects should be supported by government?" is used to evaluate public perception, distribution of the answers are given in Table 4.21, and those answers are evaluated according to Table 3.9 and Figure 3.9.

There is a hydropower plant in operation and one more hydropower plant is planned to construct in Village of Meydancık, so the village was selected as study survey area. Also in order to get opinion of working class of the region, survey was applied in City of Şavşat. The survey, given in Appendix C, consists of 2 sections and 23 questions. In first section there are 10 questions that aim to get personal profile and in second section there are 13 questions that aim to find out problems of the region and people's environmental concerns and opinions about hydropower plants. Average answering duration is about 20 minutes.

The survey was applied by three people whose one of them lives in Şavşat, one of them is a college student and the other one is the author of this thesis. The most difficult part of the survey study was convincing people that the survey is prepared for a thesis study and people applying the survey are not workers of the companies which will construct hydropower plants in Şavşat region. Distribution of the participants is given in Table 4.11.

Table 4.11 Distribution of Participants

	Frequency	Percent
Meydancık	43	46.2
Şavşat	50	53.8
Total	93	100.0

Information about participants' gender, marital status, occupation and educational status are given in Table 4.12, Table 4.13, Table 4.14 and Table 4.15 respectively. As it is seen in the tables, most of the participants are male and most of them are married. Occupational distribution of the participants is almost homogeneous. Beside, mean of the age of participants is 43 and mean monthly income of participants is 3012 TL.

Table 4.12 Gender Distribution of the Participants

	Frequency	Percent
Female	35	37,6
Male	58	62,4
Total	93	100,0

Table 4.13 Marital Status Distribution of the Participants

	Frequency	**Percent**
Single	31	33,3
Married	62	66,7
Total	93	100.0

Table 4.14 Occupation Information of the Participants

	Frequency	**Percent**
Farmer	19	20.4
Shopkeeper	22	23.7
Public Servant	17	18.3
Other	35	37.6
Total	93	100.0

Table 4.15 Educational Information of the Participants

	Frequency	**Percent**
Never Go to School	5	5.4
Primary Education	15	16.1
High School Graduate	42	45.2
University Graduate	30	32.3
Have MS Degree	1	1.1
Total	93	100.0

In the survey, people are asked to mention the most important environmental and social problem of their region. Among environmental problems, pollution of water resources was selected by participants as the most important environmental problem of the region. In addition, participants think that unemployment is the biggest social problem of the region and construction of hydropower plants is follows it as the second biggest social problem of the region. Percent distributions of the answers about environmental and social problems of the region are given in Table 4.16 and Table 4.17. In literature the only positive social effect of the hydropower plants is thought as their contribution to local economy. However, the biggest portion of the Şavşat residents (41%) think that the most important social problem is unemployment (Table 4.17) and operating hydropower plants have no contribution to the local economy (55.9%) (Table 4.18). Therefore we can conclude that the survey results support literature by means of environmental effects of hydropower plants, plus they do not feel the only positive effect of the hydropower plants which is economic contribution.

Table 4.16 Answer of the Question of "What is the Biggest Environmental Problem of the Region?"

	Frequency	**Percent**
Pollution of the Forests	34	36.6
Air Pollution	8	8.6
Noise Pollution	4	4.3
Pollution of Water Resources	36	38.7
Other	11	11.8
Total	93	100.0

Table 4.17 Answer of the Question of "What is the Biggest Social Problem of the Region?"

	Frequency	Percent
HPP	25	26.9
Unemployment	41	44.1
Transportation	14	15.1
Education	11	11.8
Other	2	2.2
Total	93	100.0

In the content of the survey study, there were some questions that are aimed to understand the reactions of the people against hydropower plant constructions. For example; "Do hydropower plants contribute the economy of the region?" and "Do you think HPPs will be beneficial for the next generations?", answers of participants to these are given in Table 4.18 and Table 4.19, as it is seen below half of the people think that HPP do not contribute to the economy and they will not be beneficial for the next generations.

Table 4.18 Answer of the Question of "Do hydropower Plants Contribute the Economy of the Region?"

	Frequency	Percent
No	52	55.9
Yes	22	23.7
No Idea	19	20.4
Total	93	100.0

Table 4.19 Answer of the Question of "Do you think HPPs Will Be Beneficial for the Next Generations?"

	Frequency	Percent
No	58	62.4
Yes	19	20.4
No Idea	16	17.2
Total	93	100.0

In literature the biggest environmental effect of hydropower plants is mentioned as negative effects on water resources. Likewise results of the survey shows that (Table 4.16) the biggest portion of Şavşat residents also think that the most important environmental problem that is caused by hydropower plants is pollution of water resources and 65.6% of the people think that hydropower plants will be harmful for the ecology (Table 4.20). Also 58% of them think that hydropower plants are not beneficial for next generations (Table 4.19) since they do not think that the plants are not beneficial for society and the ecology.

Table 4.20 Answer of the Question of "Will the HPP Be Harmful for the Ecology of the Region?"

	Frequency	Percent
No	20	21.5
Yes	61	65.6
No Idea	12	12.9
Total	93	100.0

Lastly, people were asked "Do you think that HPP projects should be supported by government?". As the results can be seen in Table 4.21, 51.2% of the people living in Meydancık and 62% of the people living in Şavşat think that government should not support HPP projects, while 39.5% of the people living in Meydancık and 26% of the people living in Şavşat appreciate the support of government.

Table 4.21 Answer of the Question of "Do You Think That HPP Projects Should Be Supported By Government?"

	Meydancık		**Şavşat**	
	Frequency	**Percent**	**Frequency**	**Percent**
No	22	51.2	31	62.0
Yes	17	39.5	13	26.0
No Idea	4	9.3	6	12.0
Total	43	100.0	50	100.0

Public perception evaluation of Şavşat region is carried out by using the answer of the question "Do you think that hpp projects should be supported by government?". The question represents the overall opinion of people about hydropower plants. According to the results given in Table 4.21, both Meydancık and Şavşat region is in "partially accepted" with regard to public perception criterion and the membership grades are "0.58" and "0.38" for Meydancık and Şavşat, respectively. Cüneyt, Gana and Meydancık HPPs are closer to Meydancık village, so membership grades of them are taken as "0.58", while membership grades of Şavşat and Armutlu HPPs are taken as "0.38" since they are closer to Şavşat.

At the end of the survey there is a question to assess willingness to pay to prevent HPP constructions. There is no evolution about willingness to pay in this study but survey results show that 39% of the people willing to pay more for electricity to prevent hydropower construction.

4.2.7 Landslide

In the landslide evaluation method, every landslide zone has different buffer zone width according to its greatest width. In the content of this study landslide criterion evaluation is carried out by measuring the distance between the study region and landslide area. The distance between the study area of this thesis study and the nearest active landslide area was measured on the 1/25000 scaled landslide inventory map of the study region. The map was obtained from Mineral Research and Exploration Institute.

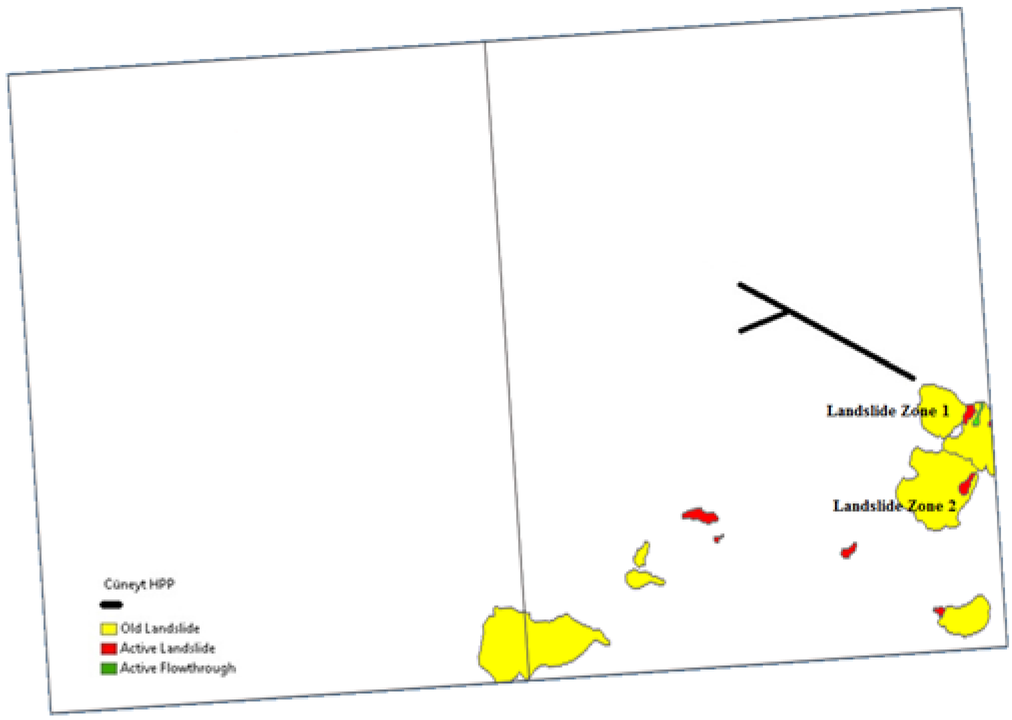

Figure 4.7 Landslide Inventory Map of the Study Region

As it can be seen in Figure 4.7, which shows 1/25000 scaled landslide inventory map, there are two big old landslide zones near the project area of Cüneyt HPP.. The greatest width of Landslide Zone 1 and Landslide Zone 2 are 1230 meters and

1980 meters, respectively. Thus, buffer zone widths of the landslide zones are 123 meters and 198 meters, respectively. However, distances between Cüneyt HPP project area and Landslide Zone 1and Landslide Zone 2 are 60 meters and 1350 meters, respectively.

Distance between Cüneyt HPP project area and Landslide Zone 2 is acceptable since the project area is out of buffer zone of the landslide zone. However, if the distance between Cüneyt HPP project area and the Landslide Zone 1 is evaluated in fuzzy set of the landslide zone, which is given in Table 4.22 and Figure 4.8, it can be seen that the project area is in "partially acceptable" region and the membership grade is "0.49".

Table 4.22 Fuzzy Set of Landslide Zone 1

Distance Between Cüneyt HPP and Landslide Zone 1 (meter)	**Acceptability**
$x \geq 123$	Acceptable
$0 < x < 123$	Partially Acceptable
Inside the landslide zone	Not Acceptable

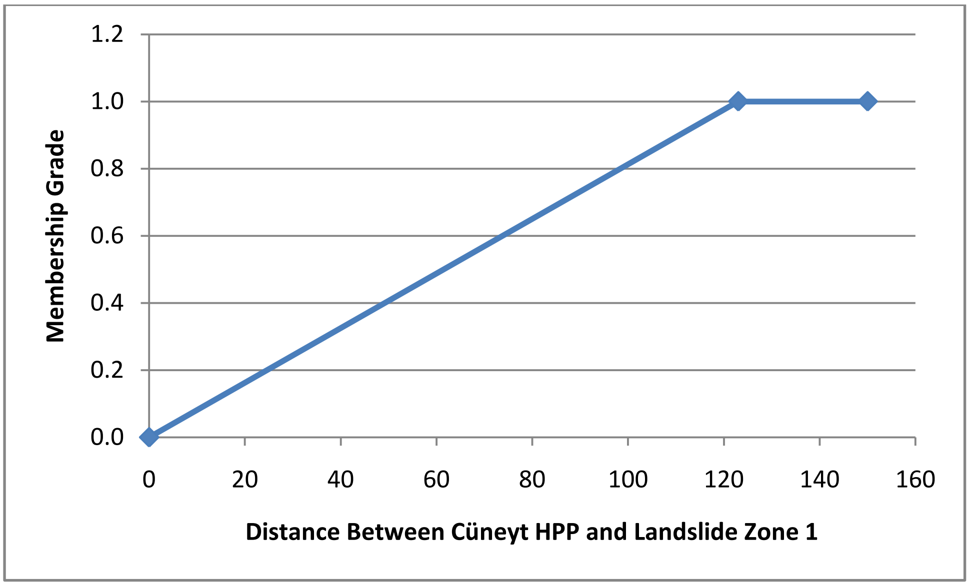

Figure 4.8 Landslide Zone 1 Fuzzy Set Representation

Locations of landslide zones and Gana, Meydancık, Armutlu and Şavşat hydropower plants are given in Figure 4.9. Also, nearest landslide zones widths, buffer zones widths, distances between the hydropower plants and calculated membership grades according to those data are given in Table 4.23.

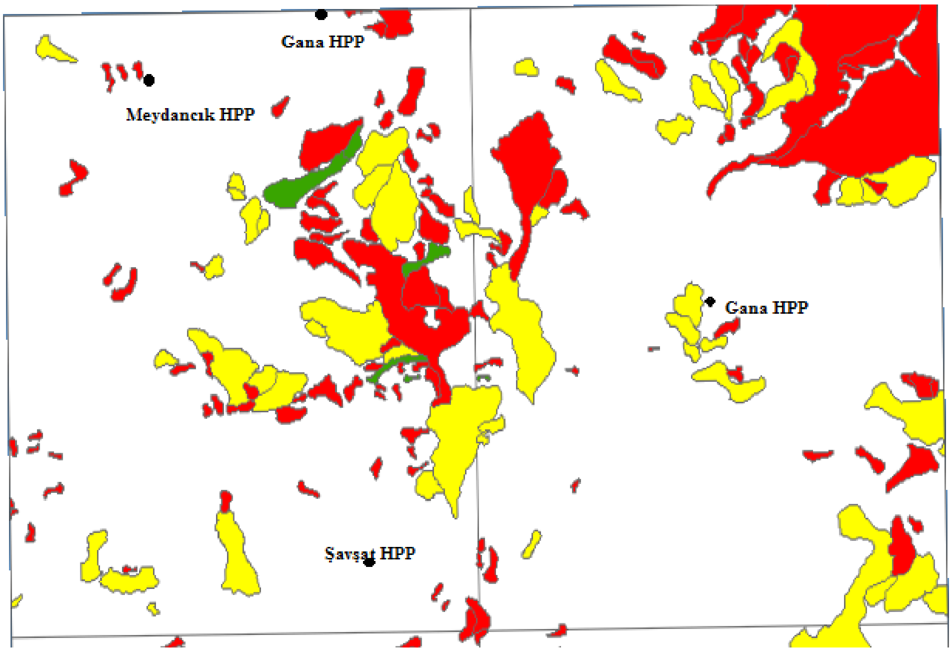

Figure 4.9 Locations of HPPs and Landslide Zone

Table 4.23 Landslide Data and Membership Grades of the HPPs

Hydropower Plant	**The Nearest Landslide Zone Width**	**Buffer Zone Width**	**Distance between the Landslide Zone and the HPP**	**Membership Grade**
Cüneyt	**1230**	**123**	**60**	**0,49**
Gana	1071	107.1	535	1
Meydancık	380	38	90	1
Armutlu	996	99.6	0	0
Şavşat	2440	244	1930	1

4.2.8 Distance from the Nearest Residential Area

According to the data in Environmental Impact Assessment Report of Cüneyt HPP project, the nearest residential area to the Cüneyt HPP project area is Taşköprü neighborhood and the distance is 500 meters. Thus, Cüneyt HPP is in "partially acceptable" region with regard to distance between the HPP and the nearest residential area criterion and the membership grade is "0.50". Also, distances between Gana, Meydancık, Armutlu, Şavşat hydropower plants and the nearest residential areas are 150 meters, 270 meters, 400 meters and 200 meters, respectively. Consequently, membership grades of Gana, Meydancık, Armutlu and Şavşat HPPs are "0.15", "0.27", "0.40" and "0.20", respectively.

Table 4.24 Distances between Hydropower Plants and Residential Areas

	Cüneyt	**Gana**	**Meydancık**	**Armutlu**	**Şavşat**
Distance from the Nearest Residential Area	500	150	270	400	200
Membership Grade	0.50	0.15	0.27	0.40	0.20

4.2.9 Population Density

According to the information taken from Environmental Impact Assessment Report of Cüneyt HPP project, in Turkey 43,140,431 people live in cities and districts while 24,668,617 people live in villages. Also in cities, average number of people in each family is 4.18 while it is 5.19 in villages. According to the same data 210.032 people live in Artvin, whose 80887 live in city centre or districts and 129,145 live in villages.

In the content of this study, population density is evaluated according to the data of number of people live for per kilometer square of the district. In this regard, population density of Şavşat district is calculated by using the data of population and surface area which are also taken from Environmental Impact Assessment report of Cüneyt HPP project. According to the data; surface area of Şavşat is 7513 km^2 and according to 2013 population census results of Turkish Statistical Institute population of Şavşat is 17507; as a result population density of Şavşat district is 2.33. If the population density is evaluated in fuzzy set of the criterion, it can be said that Şavşat district is in "acceptable" region with regard to "population density" criterion and its membership value is "1" for all hydropower plants.

4.2.10 Number of Downriver Tributary

In order to determine number of downriver tributaries in study areas, hydraulic map of the Şavşat district is obtained by General Command of Mapping and it is given in Figure 4.10.

Number of tributaries between the regulator (spot where water is taken from the river) and the power house (location of turbines are evaluated). For the specific case of Cüneyt HPP project, there are 6 turbines in the project and all of them are at the black line that is given in Figure 4.10, thus for the evaluation of Cüneyt HPP project, total number of tributaries that have connection with the project site are evaluated. According to the map, Cüneyt HPP project is on two main rivers tributary and total number of tributaries that have connection with the project site is 24. As a result, Cüneyt HPP project area is in "acceptable region" regarding to "number of downriver tributaries" criterion and its membership grade is "1".

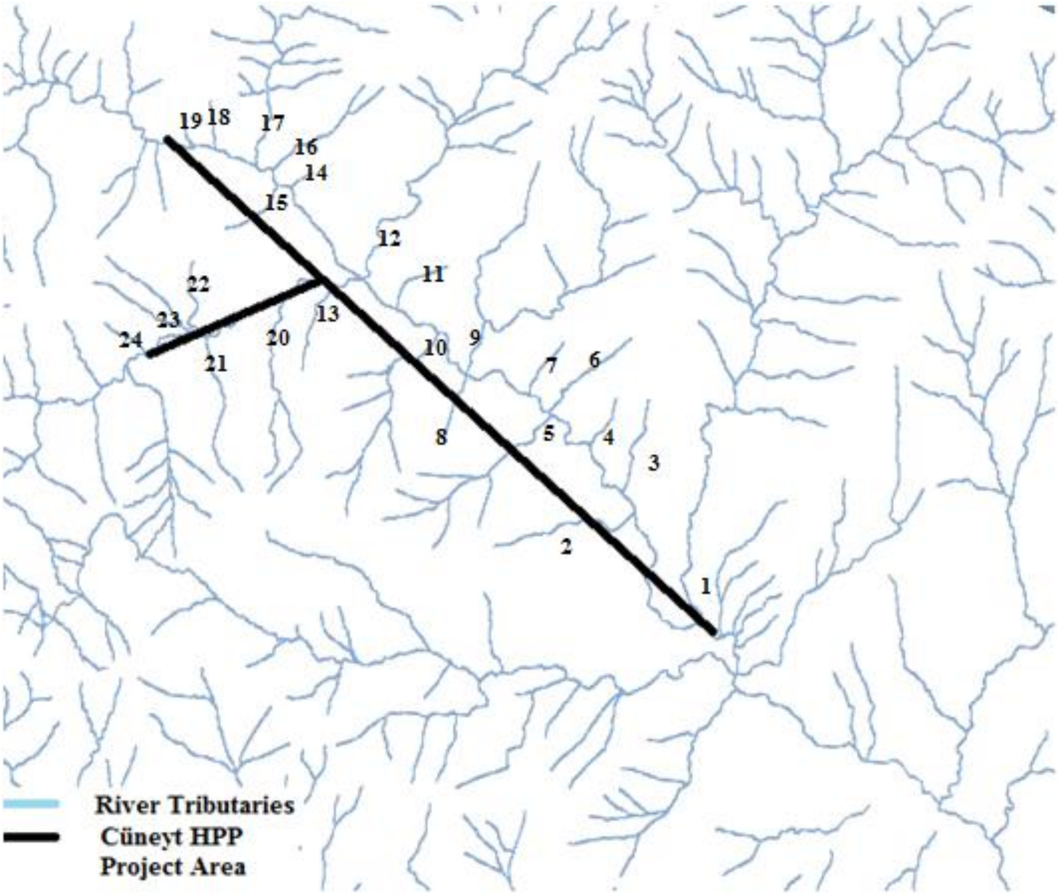

Figure 4.10 Hydraulic Map of Cüneyt HPP Project Region

Number of downriver tributaries criterion evaluation of Gana, Meydancık, Armutlu and Şavşat hydropower plants were carried out by counting tributaries between regulators and the locations of the power houses. All the locations are shown in Figure 4.11. In the figure, G1, M1, A1 and Ş1 are locations of regulators of Gana, Meydancık, Armutlu and Şavşat hydropower plants, respectively. Similarly, G2, M2, A2 and Ş2 points are the power houses' locations of Gana, Meydancık, Armutlu and Şavşat hydropower plants, respectively. According to the figure, there are 12, 11, 6 and 3 tributaries between the water intake points and the regulators of Gana, Meydancık, Armutlu and Şavşat, respectively. Therefore all of the hydropower plants are in "acceptable" region and their membership grades are "1".

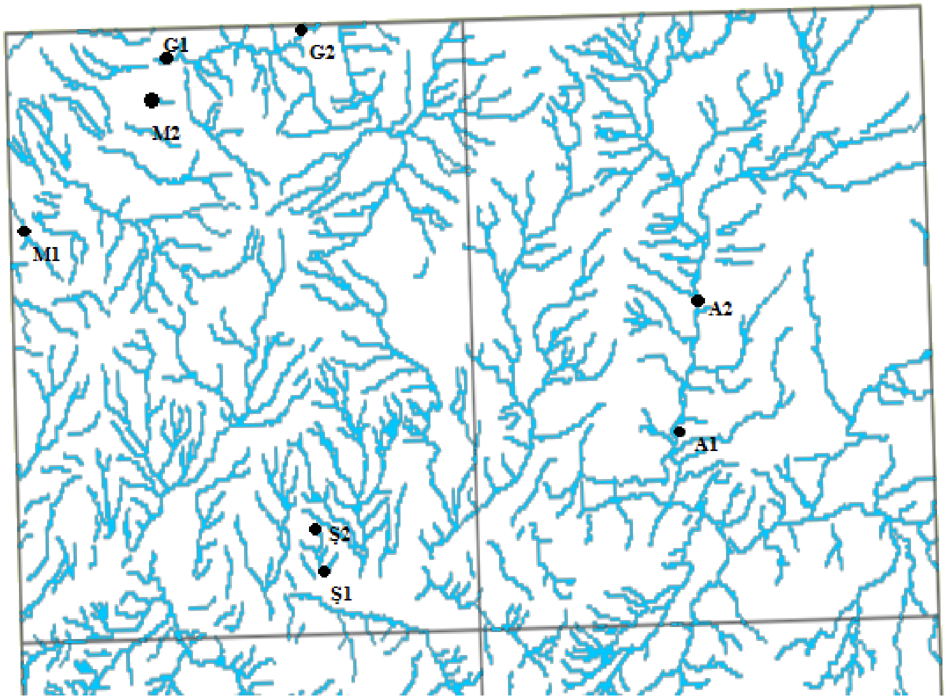

Figure 4.11 Locations of Water Intake Points and Regulators of HPPs

Table 4.25 Number of Downriver Tributaries and Membership Grades

	Cüneyt	**Gana**	**Meydancık**	**Armutlu**	**Şavşat**
Number of Downriver Tributaries	24	12	11	6	3
Membership Grade	1	1	1	1	1

CHAPTER 5

RESULTS AND DISCUSSIONS

In this section, acceptability results of all selected hydropower plants will be calculated. Acceptability results are obtained by aggregation of membership grades of each criterion. As mentioned before, there are four different aggregation techniques to calculate acceptability values of each hydropower plant in this study and calculations of all aggregation methods are given in following parts of this chapter. Also results are recalculated with changed flow rate alterations and public perception rates in order to see the changes in acceptability values. In flow rate alteration changes, Tennant, Q_{90} and Q_{50} methods are used; details of the calculations are given in following sections.

In Table 5.1 all input values of all criteria for all selected hydropower projects are included. Membership grades that are calculated according to the input values are also given. In all the result calculations given in following sections, these membership grades will be used to determine acceptability values of the projects.

Table 5.1 Summary Table of All Membership Grades

	Criteria Value					Membership Grade				
	Cüneyt	Gana	Meydancık	Armutlu	Şavşat	Cüneyt	Gana	Meydancık	Armutlu	Şavşat
Distance from the Nearest Sensitive Area (km)	14.6	12.8	16.2	7.3	2.9	1.00	1.00	1.00	0.77	0.17
Earthquake (PGA Value)	0.035	0.040	0.040	0.048	0.048	1.00	1.00	1.00	1.00	1.00
Flow Rate Alteration (%)	16.4	26.7	20.3	25.0	18.0	0.13	0.33	0.21	0.30	0.16
Destructed Forest Size (km)	15.3	0.5	6.3	6.8	2.9	0	1.00	0	0	0
Terrorism (terror attack/year)	0.15	0.15	0.15	0.15	0.15	0.56	0.56	0.56	0.56	0.56
Public Perception (%)	39.5	39.5	39.5	26.0	26.0	0.21	0.21	0.21	0	0
Landslide (m)	1230	1071	380	996	2240	0.50	1.00	1.00	0	1.00
Dist. from the Nearest Residential Area(m)	500	150	270	400	200	0.49	0.14	0.26	0.39	0.19
Population Density	2.33	2.33	2.33	2.33	2.33	1.00	1.00	1.00	1.00	1.00
Number of Downriver Tributaries	24	12	11	6	3	1.00	1.00	1.00	1.00	1.00

All the given membership grades aggregated with different operators for three different cases. In the first case, all the criteria are included in calculations while in second case six reduced criteria and in the last case four environmental criteria are included in calculations. The aim of making calculations with different criteria combinations is to find out the effects of specific criteria on results. Cases and included criteria in the cases are given in Table 5.2.

Table 5.2 Criteria Sets

Criteria Sets	**Names of the Criteria Included in a Given Set**
Set of All Criteria	All criteria
Set of Reduced Criteria	Dist. from the nearest sens. area, earthquake, flow rate alteration, destructed forest size, terrorism, public perception and landslide
Set of Environmental Criteria	Dist. from the nearest sens. area, flow rate alteration, destructed forest size and number of downriver tributaries

5.1 Results of Acceptability Scores Using Set of All Criteria

In this section acceptability results of all selected hydropower projects calculated by “and”, “or” and “ordered weighted averaging” operators by including all criteria are given. Summary table and comments on results of this section is given in Section 5.2. Calculation details of Cüneyt hydropower plant are given below as example, but calculations of other hydropower plants are given in Appendix E, in order to decrease the complexity of the thesis.

Calculations of Set of All Criteria of Cüneyt HPP

Table 5.3 Membership Summary of Cüneyt HPP

Criteria	Membership Grade of Cüneyt HPP
Distance from the Nearest Sensitive Area	1.00
Earthquake	1.00
Flow Rate Alteration	0.13
Destructed Forest Size	0
Terrorism	0.56
Public Perception	0.21
Landslide	0.50
Dist. from the Nearest Residential Area	0.49
Population Density	1.00
Number of Downriver Tributaries	1.00

"And" Operator

In "and" operator implementation weight of the criteria are not included in the calculations, and minimum of the membership grades gives the result. In the light of this information, "and" operator implementation is given below;

Acceptability

$= 1.00 \cap 1.00 \cap 0.13 \cap 0 \cap 0.56 \cap 0.21 \cap 0.50 \cap 0.49 \cap 1.00 \cap 1.00$

⇨ Acceptability= 0

“Or” Operator

As in “and” operator implementation, in “or” operator implementation weights of the criteria are not considered during calculations of the result. “Or” operator implementation is given below;

Acceptability=
$1.00 \cup 1.00 \cup 0.13 \cup 0 \cup 0.56 \cup 0.21 \cup 0.50 \cup 0.49 \cup 1.00 \cup 1.00$

Acceptability= 1

Ordered Weighted Average (OWA) Operator

“Ordered Weighted Average” operator used its own weights rather than the weights that are determined by the survey which is given Appendix D and explained in 5.3 in detail. Weight calculation formula is given in Equation 5.1.

$$W_i = Q\left(\frac{i}{n}\right) - Q\left(\frac{i-1}{n}\right) \qquad \text{where i= 1, 2, …10, n=10 and Q= } (r^2) \qquad (5.1)$$

According to quantifier guided ordered weighted averaging method, for the greatest membership value “*i*” variable takes the value 1, while for the lowest membership grade “*i*” variable takes the value 10. Ordered weight values are given below;

$W_1 = (1/10)^2 - (0/10)^2 = 0.01$ $W_2 = (2/10)^2 - (1/10)^2 = 0.03$

$W_3 = (3/10)^2 - (2/10)^2 = 0.05$ $W_4 = (4/10)^2 - (3/10)^2 = 0.07$

$W_5 = (5/10)^2 - (4/10)^2 = 0.09$ $W_6 = (6/10)^2 - (5/10)^2 = 0.11$

$W_7 = (7/10)^2 - (6/10)^2 = 0.13$ $W_8 = (8/10)^2 - (7/10)^2 = 0.15$

$W_9 = (9/10)^2 - (8/10)^2 = 0.17$ $W_{10} = (10/10)^2 - (9/10)^2 = 0.19$

After calculating weight values aggregation of the scores and weight values can be done by applying Equation 5.2.

$$Acceptability = \sum W_i * b_i \text{ ;where } W_i \text{ is weight and } b_i \text{ is the score of criteria} \quad (5.2)$$

- ⇨ Acceptability= (1x0.01) + (1x0.03) + (1x0.05) + (1x0.07) + (0.56x0.09) + (0.50x0.11) + (0.49x0.13) + (0.21x0.15) + (0.13x0.17) + (0x0.19)
- ⇨ Acceptability = 0.38

5.2 Summary and Discussion of the Set of All Criteria

Case study implementation results show that Gana HPP project is the most feasible one, if all of the criteria are included in the calculations. Due to "extreme" approach of the "and" and "or" operators, results of those operator are the same or very close to each other. Therefore, making a choice by depending on those evaluations may not give proper results. As it is given in Table 5.4, results of "or" operators are the same for all HPPs, and results of "and" operators show that Gana is the most preferable project among all others. Also according to the results of OWA operator, Gana HPP is the most preferable project.

Table 5.4 Summary of the Acceptability Results Using Set of All Criteria

	"and"	**"or"**	**OWA**
Cüneyt HPP	0	1	0.38
Gana HPP	0.14	1	0.49
Meydancık HPP	0	1	0.41
Armutlu HPP	0	1	0.28
Şavşat HPP	0	1	0.28

5.3 Results of Acceptability Scores Using the Set of Reduced Criteria

In the previous section, there are 10 criteria that are believed to represent environmental and social effects of hydropower plants. For these 10 criteria difficult and time consuming data collection procedure is needed. Almost all of the data are obtained from governmental institutions and some data are obtained by making site visit. For some specific regions, data collection may be more difficult or it can be impossible to reach them. That is why data elimination is needed.

Reducing number of criteria make the study more applicable and simpler. However elimination of criteria is important in order not to destroy representability of remained criteria. In selection process there are two important parameters are considered; easiness of data to reach and importance of the criteria. Consequently, after elimination 6 criteria left which are; distance from the nearest environmentally sensitive area, earthquake, flow rate alteration, terrorism, public perception and landslide. Results of all hydropower plants with eliminated criteria are given below.

For the eliminated criteria a survey was conducted in order to determine weights of the criteria to be used in Linear Weighted Average aggregation operator. The survey was applied through e-mail at March 2014. Participants of the survey consist of private sector employees and public employees who are experts in HPPs and their environmental effects. There are 39 participants of the survey; 23 of them are academicians, 7 of them public employees and 6 of them are private sector employees. The survey and the results of the survey are given in Appendix D.

In the survey, participants were asked to assign an importance value out of 1 to 4 for each criterion which are; Distance from the Nearest Environmentally Sensitive Area, Earthquake, Flow Rate Alteration, Terrorism, Public Perception and Landslide. Importance values are classified as “very high” (for value 4), “high” (for value 3), “moderate” (for value 2) and “low” (for value 1). In Appendix D, grades that participants gave to the criteria and related weights of the each criterion are given.

As it is seen in Table D-1 in Appendix D, landslide is voted as the most important criterion for hydropower construction. Landslide, earthquake and public perception are voted as the other important parameters while terrorism and access to infrastructure are the least important criteria.

Amount of remained water in the rivers are much-debated issue in our country, such that most of the legal cases are originated from that issue. Other much-debated issue is quality of environmental impact assessment report. These two topics constitute main reasons that local residents or NGOs open cases against investors. That is why; it is not a surprise that expert people select the water flow alteration as the most important criterion. On the other hand, landslide and earthquake are the most common natural disasters that happen in our country, therefore they are included in the study and they are selected as important criteria. However terror attacks to hydropower plants are not common events in Turkey, so it can be the reason of terrorism is selected as the least important criterion by the experts.

After weight determination, acceptability results of each hydropower plant are calculated according to the formula given in Equation 5.3.

$$D = \sum(W_i * b_i) \text{ where } W_i \text{ is weight and } b_i \text{ is the score of criteria} \quad (5.3)$$

Result calculation of Cüneyt hydropower plant is given in below and calculations of other hydropower plants are given in Appendix E. Summary table and discussions on results are given in Section 5.4.

Calculations of Set of Reduced Criteria of Cüneyt HPP

“And” Operator

Acceptability= $1.00 \cap 1.00 \cap 0.13 \cap 0.56 \cap 0.21 \cap 0.49$

⇨ Acceptability= 0.13

“Or” Operator

Acceptability= $1.00 \cup 1.00 \cup 0.13 \cup 0.56 \cup 0.21 \cup 0.49$

⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Also, since the number of criteria has change, weights of the criteria are calculated again according to the formula given in Equation 5.4.

$$W_i = Q\left(\frac{i}{n}\right) - Q\left(\frac{i-1}{n}\right) \quad \text{where i= 1,2,…6, n=6 and Q= } (r^2) \qquad (5.4)$$

$W_1 = (1/6)^2 - (0/6)^2 = 0.03$ $W_2 = (2/6)^2 - (1/6)^2 = 0.08$

$W_3 = (3/6)^2 - (2/6)^2 = 0.14$ $W_4 = (4/6)^2 - (3/6)^2 = 0.19$

$W_5 = (5/6)^2 - (4/6)^2 = 0.25$ $W_6 = (6/6)^2 - (5/6)^2 = 0.31$

Acceptability= (1x0.03) + (1x0.08) + (0.56x0.14) + (0.49x0.19) + (0.21x0.25) + (0.13x0.31)

⇨ Acceptability= 0.38

Linear Weighted Average (LWA) Operator

Acceptability = (1x0.15) + (1x0.18) + (0.13x0.20) + (0.56x0.13) + (0.21x0.16) + (0.49x0.18)

⇨ Acceptability= 0.55

5.4 Summary and Discussion of the Set of Reduced Criteria

If we look at the results that are calculated by including reduced criteria, which are landslide, earthquake, public perception, flow rate alteration, distance from the nearest environmentally sensitive area and terrorism, Gana HPP is the most feasible project. Results of public perception and terrorism criteria are the same for all projects since they are in the same district and results earthquake criterion are also the same for all projects since all the projects area are at relatively safe zones with regard to earthquake. On the other hand results of Gana HPP regarding to flow rate alteration and distance from the environmentally sensitive area more "acceptable", that is why it seems like the most feasible project according to results of all operators. As it can be seen in Table 5.5, Armutlu HPP is the least "acceptable" project, because it is close to a national park and it is in a landslide zone.

Table 5.5 Summary of the Acceptability Results Using Set of Reduced Criteria

	"and"	**"or"**	**OWA**	**LWA**
Cüneyt HPP	0.13	1	0.38	0.55
Gana HPP	0.21	1	0.51	0.68
Meydancık HPP	0.21	1	0.48	0.67
Armutlu HPP	0	1	0.23	0.43
Şavşat HPP	0	1	0.26	0.48

5.5 Results by Including Environmental Criteria

In this section, only environmental criteria are included in the calculations. The purpose of this data set is to show "environmental acceptability" of hydropower projects. Calculating "environmental acceptability" without making previous calculations may not make sense but it can support the decision. Included criteria for set of environmental criteria are; distance from the nearest environmentally sensitive area, flow rate alteration, destructed forest size and number of downriver tributaries criteria.

The calculations are carried out for “and”, “or” and OWA aggregation operators. Calculation of the Cüneyt hydropower plant is given below and calculations of other hydropower plants are given in Appendix E. Summary table of the results is given in Section 5.6.

Calculations of Set of Environmental Criteria of Cüneyt HPP

“And” Operator

- ⇨ Acceptability= $1 \cap 0.13 \cap 0 \cap 1$
- ⇨ Acceptability= 0

“Or” Operator

- ⇨ Acceptability= $1 \cup 0.13 \cup 0 \cup 1$
- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

The weights of OWA method for the new criteria are calculated according to Equation 5.5.

$$W_i = Q\left(\frac{i}{n}\right) - Q\left(\frac{i-1}{n}\right) \quad \text{where i= 1.2.3.4. n=4 and Q= } (r^2) \qquad (5.5)$$

$W_1 = (1/4)^2 - (0/4)^2 = 0.06$ $\qquad$ $W_2 = (2/4)^2 - (1/4)^2 = 0.19$

$W_3 = (3/4)^2 - (2/4)^2 = 0.31$ $\qquad$ $W_4 = (4/4)^2 - (3/4)^2 = 0.44$

- ⇨ Acceptability = (1x0.06) + (1x0.19) + (0.13x0.31) + (0x0.44)
- ⇨ Acceptability = 0.29

5.6 Summary and Discussion of the Set of Environmental Criteria

According to the evaluation including only environmental criteria, Gana HPP is much more “acceptable” than other hydropower plants. In environmental evaluation there are four criteria which are distance from the nearest environmentally sensitive area, flow rate alteration, destructed forest size and number of downriver tributaries. In the content of Gana HPP project, smaller forest area is destructed when it is compared with other projects; also residual water percentage of Gana project is higher than others. On the contrary, in the content of Armutlu HPP project “not acceptable” amount of forest is destructed. Also its distance from the nearest environmentally sensitive area makes it “the least acceptable” when compared with other projects.

Moreover, if “acceptability” results given in Table 5.6 are analyzed, it can be seen Gana HPP is the only one whose acceptability increase when the calculations are carried out with environmental criteria. Also, the acceptability results are close to each other when all criteria are included in the calculations, but acceptability results of Gana HPP is much greater if only environmental criteria are included in the calculations. Therefore it can be conclude that, if social impacts and geological features of the region are not included in assessments, Gana is the best project among other selected ones.

Table 5.6 Summary of the Original Acceptability Results Using Set of Environmental Criteria

	“and”	**“or”**	**OWA**
Cüneyt HPP	0	1	0.29
Gana HPP	0.33	1	0.71
Meydancık HPP	0	1	0.32
Armutlu HPP	0	1	0.30
Şavşat HPP	0	1	0.14

5.7 Summary of the Acceptability Scores

Acceptability results calculated with all aggregation techniques for all selected hydropower plants are given in Table 5.7.

Due to “extreme” approach of the “and” and “or” operators, results of those operator are the same or very close to each other. Therefore, making a choice by depending on those evaluations may not give proper results. On the contrary OWA and LWA operators are include importance of criteria and acceptability results consist of combination of all membership grades. In OWA and LWA operators’ calculations, any change in membership grade of any criterion can change acceptability results, while in “or” and “and” operators results change only if minimum or maximum membership grades change. As it is given in Table 5.7, results of “or” operators are the same for all HPPs, and results of “and” operators are either same or so close to each other.

Case study implementation results show that Gana HPP project is the most feasible one among all others according to the results of OWA operator. Also most of the results of “and” operator show that Gana is the most preferable project, on the other hand any kind of decision can be made according to the results of “or” operator.

Moreover results are evaluated with three different criteria combinations. The aim of making different combinations is; understanding the effects of specific criteria on overall results. Those results showed that as number of criteria increase, weight values become close to each other and it is becoming difficult to underline a criterion which is much more important than others. As a result, effect of each criterion on results increase as the number of criteria decrease, so it is important to keep number of criteria low as far as possible in order to see the influences of criteria on results.

Table 5.7 Summary of the Acceptability Results By Three Different Criteria Sets

HPP	Criteria Set	"and"	"or"	OWA	LWA
Cüneyt	All	0	1	0.38	-
	Reduced	0.13	1	0.38	0.55
	Environmental	0	1	0.29	-
Gana	All	0.14	1	0.49	-
	Reduced	0.16	1	0.51	0.68
	Environmental	0.33	1	0.71	-
Meydancık	All	0	1	0.41	-
	Reduced	0.21	1	0.48	0.67
	Environmental	0	1	0.32	-
Armutlu	All	0	1	0.28	-
	Reduced	0	1	0.23	0.43
	Environmental	0	1	0.30	-
Şavşat	All	0	1	0.28	-
	Reduced	0.16	1	0.26	0.48
	Environmental	0	1	0.14	-

5.8 Scenarios with Different Flow Rates and Public Perception Rates

After evaluation of all HPP projects with all operators by including all criteria, reduced criteria and only environmental criteria, results of those cases with proper flow rate alteration magnitudes are simulated.

5.8.1 Scenarios with Different Flow Rate Alterations

In the previous sections of the study, acceptability values of three different criteria set are given. In the first set all of the criteria are included in the calculations, while in second set reduced six criteria and in third set four environmental criteria are included in calculation.

In this section, result simulations calculated with different flow rate alteration values are given. Results of survey conducted to determine the weights of the criteria shows that flow rate alteration is the most important criterion, so it is important to find out its impact on acceptability results. Also flow rate alteration is the only criterion whose value can be changed by decision makers, membership values of rest of the criteria cannot be changed unless the location of the project changed. For these reasons, acceptability results are recalculated with "optimum" flow rate values according to Tennant, Q_{90} and Q_{50} methods.

In literature, there are four most known methods that are used to determine residual water amount to meet the requirements of the ecosystem. These are Tennant Method, Wetted Perimeter Method, PHABSIM Method and Q_{90} Method. The reason of selecting Tennant Method and Q_{90} Method is their extensive usage in literature, simplicity, little data requirement when they are compared with other methods.

Wetted Perimeter Method is the third most popular method in USA and it is used in six states (Jowett, 1997). In the methodology, wetted perimeter distance is measured at multiple sections of the river and a relationship is driven between wetted perimeter and discharge of the river sections by plotting a graph with collected data. Sections that are riffle sites or at sites where fish passage is likely to be limited are generally preferred as data collection sections. On the other hand, Manning equation, which is given in Equation 5.6, can also be used to model relationship between the cross section and the flow rate (Pang et al., 2012)

$$Q = \left(\frac{1}{n}\right) A^{5/3} P^{-2/3} S^{1/2} \tag{5.6}$$

Where; Q refers to the discharge (m^3/s); A refers to the Cross section area (m^2); P refers to the wetted perimeter (m); S refers to the hydraulic gradient; n refers to the roughness coefficient.

The lowest breakpoint in plotted P-Q curve represents the critical discharge below which habitat conditions for aquatic organisms rapidly become unfavourable (Gippel and Stewardson, 1998).

In order to apply wetted perimeter method, wetted perimeter area is needed which can only be achieved by making long term site visits. In the content of this thesis study it was impossible to make that kind of site visit, so the method is not one of the methods that are used in this study.

PHABSIM method was developed by the US Fish and Wildlife Service in 1970s. The first trials of the method were carried out in UK, but it has been used throughout the world since then. The method considers fish, invertebrates and macrophytes, including time series analysis, for ten rivers and produced a manual and software (Spence and Hickley, 2000).

In the method, software program is used to analyze changes in physical habitat due to changes in flow or channel morphology. Physical hydraulic modeling, hydrological modeling and species physical habitat preferences are used in the method to obtain an assessment of the quality of suitable habitat. The method can be used at physical habitat limits populations and although it provides quantitative output, it can also be used to provide a qualitative comparison between management options (Allian and El-Jabi, 2002).

PHABSIM is the most difficult method to apply among all other methods. In the PHABSIM applications, long and multiple site visits, multidisciplinary team work and technical background are needed. That is why, it was impossible to use this method in the content of this study because of the explained reasons.

As explained in the previous sections (Section 3.3.1.3), Tennant Method categorizes the expected level of environmental health of river systems under different minimum flow conditions. According to Table 3.5, in order to succeed "acceptable situation" in all seasons of the year, minimum 30% of the instream flow should be remained. Therefore acceptability results are calculated by assuming that 30% of instream waters are remained in all selected hydropower projects. If 30% of water is remained in the river, membership grade would be "0.4". In Table 5.10, Table 5.12 and Table 5.14 acceptability results of all selected projects for all criteria combinations are given which are calculated by taking membership grade of flow rate alteration criterion as "0.4".

Q_{90} Method was developed by the Northern Great Plains Resource Program (NGPRP 1974). The method suggests that flow that is equaled or exceeded 90% of the time is adequate for the river ecosystem to survive. In order to apply this method 20 years of flow rate data is needed. Monthly average of the data is used to determine Q_{90} value. Another similar method, Q_{50} method, represents the flow that is equaled or exceeded 50% of the time (Smakhtin et al., 2009), (Caissie et al.,2007). In Table 5.8, conservation status and needed methods to find out low flow requirement (LFR) is given. It is seen in the table that Q_{50} represents a better status than Q_{90} method and flow needed for Q_{50} is higher than Q_{90}, so if flow rate of Q_{90} is not sufficient to increase acceptability value in needed amount Q_{50} method may also be tried to increase acceptability. In this study results of both Q_{50} and Q_{90} method are given in following sections.

Table 5.8 Categorization and Description of Objectives of Environmental Water Management (Smakhtin et al., 2004)

Conservation Status or Management Objective	**Ecological Description**	**Management Perspective**	**Corresponding Low-flow Characteristics as a Measure of LFR**
Natural (unmodified)	Pristine condition or negligible modification and riparian habitat	Protected river and basins. Reserves and national parks. No water projects (dams, diversions etc.) allowed	Q50
Good (slightly or moderately modified)	Largely intact biodiversity and habitats despite water resources developments and/or basin modification	Minor water supply schemes or irrigation development present and/or allowed.	Q70
Fair (moderately or considerably modified)	The dynamics of the biota have been disturbed. Some sensitive species are lost and/or reduced in extent. Alien species may occur	Multiple disturbances associated with the need for socio-economic development, e.g. dams, diversions and transfers habitat modification and water quality degradation.	Q90
Poor (critically modified and degraded)	Habitat diversity and availability have declined. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem	Human population density and extensive water resources exploitation. Management intervention is needed to restore flow pattern, river habitat etc. This status is not acceptable from the management perspective.	N/A

In the content of this study, flow rates data are taken from environmental impact assessment reports of the projects which are obtained by Ministry of Environment and Urbanization. In environmental impact assessment report of Cüneyt HPP flow rate data between 1982 and 2004, in the report of Armutlu HPP the data between 1983 and 2009, in the report of Meydancık HPP the data between 1982 and 2010, in the report of Gana HPP the data between 2001 and 2010 and in the report of Şavşat HPP the data between 1963 and 2009 are exist. By using those data flow rates needed according to Q_{90} Method are determined, in Figure 5.1 determination of Cüneyt HPP is given as example and all the Q_{90} results of all selected hydropower plants are given in Table 5.9. Also in Table 5.11, Table 5.13 and Table 5.15 acceptability results of all selected projects for all criteria combinations are given which are calculated by taking membership grade of flow rate alteration criterion as given in Table 5.9. Results' summaries of all scenarios and discussions on those results are given in Section 5.8.2.

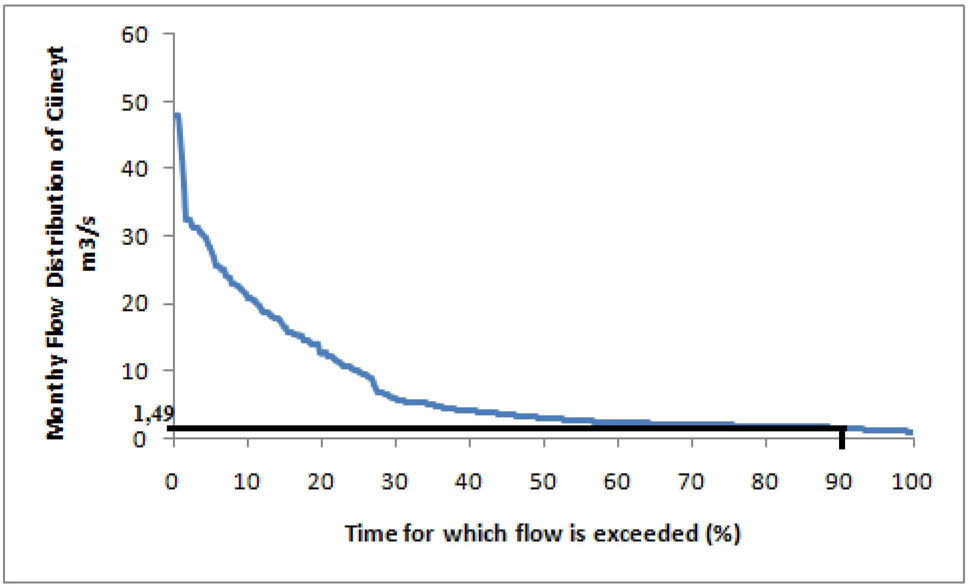

Figure 5.1 Minimum Flow Requirement Determination of Cüneyt HPP According to Q_{90} Method

Table 5.9 Needed Flow Rates and Membership Values of Selected Regions According to Q_{90} Method

	Needed Flow Rates According to Q_{90} (m^3/s)	**Average Flow Rates (m^3/s) in Study Areas**	**Residual Flow Rate Percents**	**Membership Grades**
Cüneyt HPP	1.49	7.09	21 %	0.22
Armutlu HPP	0.44	1.12	39 %	0.58
Meydancık HPP	2.66	10.24	26 %	0.32
Gana HPP	0.46	2.43	19 %	0.16
Şavşat HPP	2.30	5.56	41 %	0.62

As they are given in Table 5.10 and Table 5.11, if needed residual water by the ecosystem would be released, again Gana HPP project would be the most "acceptable" projects among others according to both Tennant and Q_{90} methods, when all the criteria are included in evaluations. Similarly, Armutlu would be the least "acceptable" project because of the explained reasons.

Table 5.10 Acceptability Results Using Set of All Criteria according to Tennant Method ($Q_{minimum}$= 30% of the average flow)

	"and"	**"or"**	**OWA**
Cüneyt HPP	0	1	0.42
Gana HPP	0.14	1	0.51
Meydancık HPP	0	1	0.44
Armutlu HPP	0	1	0.29
Şavşat HPP	0	1	0.30

Table 5.11 Acceptability Results Using Set of All Criteria According to Q_{90} Method

	"and"	**"or"**	**OWA**
Cüneyt HPP	0	1	0.40
Gana HPP	0.14	1	0.47
Meydancık HPP	0	1	0.43
Armutlu HPP	0	1	0.31
Şavşat HPP	0	1	0.33

If the simulation is carried out by including reduced criteria, again Gana HPP is the most "acceptable" project according to Tannant and Q_{90} methods and Armutlu is the least "acceptable" one for both cases. On the other hand, according to simulation that includes only environmental criteria again Gana HPP is the most "acceptable" project, and Armutlu HPP is the least "acceptable" project again. All of these results are summarized in Table 5.12 and Table 5.13 for set of reduced criteria and in Table 5.14 and Table 5.15 for set of environmental criteria.

Table 5.12 Acceptability Results Using Set of Reduced Criteria According to Tennant Method

	"and"	**"or"**	**OWA**	**LWA**
Cüneyt HPP	0.3	1	0.45	0.60
Gana HPP	0.3	1	0.52	0.70
Meydancık HPP	0.3	1	0.52	0.70
Armutlu HPP	0	1	0.25	0.45
Şavşat HPP	0.3	1	0.31	0.54

Table 5.13 Acceptability Results Using Set of Reduced Criteria According to Q_{90} Method

	“and”	**“or”**	**OWA**	**LWA**
Cüneyt HPP	0.3	1	0.40	0.57
Gana HPP	0.3	1	0.46	0.65
Meydancık HPP	0.3	1	0.50	0.68
Armutlu HPP	0	1	0.28	0.48
Şavşat HPP	0.3	1	0.35	0.58

Table 5.14 Acceptability Results Using Set of Environmental Criteria According to Tennant Method

	“and”	**“or”**	**OWA**
Cüneyt HPP	0	1	0.38
Gana HPP	0.4	1	0.74
Meydancık HPP	0	1	0.38
Armutlu HPP	0	1	0.33
Şavşat HPP	0	1	0.19

Table 5.15 Acceptability Results Using Set of Environmental Criteria According to Q_{90} Method

	"and"	**"or"**	**OWA**
Cüneyt HPP	0	1	0.32
Gana HPP	0.4	1	0.63
Meydancık HPP	0	1	0.35
Armutlu HPP	0	1	0.39
Şavşat HPP	0	1	0.23

After Tennant and Q_{90} method applications, results are calculated with another method which is Q_{50}, since the results cannot be changed with Tennant and Q_{90} and Q_{50} can be more effective to change the acceptability results. Q_{50} implies the median of monthly flow rate of river systems, in other words Q_{50} value is the flow rate value that is exceeded 50% of time (Caissie, 2007). Therefore needed flow rates according to Q_{50} method are higher than needed flow rates according to Tennant and Q_{90} methods; accordingly membership grades and acceptability values are greater than other methods. Q_{50} (median flow rate) values of selected run-of river hydropower plants and the calculated membership grades are given in Table 5.16.

Table 5.16 Needed Flow Rates and Membership Values of Selected Regions According to Q_{50} Method

	Needed Flow Rates According to Q_{50} (m^3/s)	**Average Flow Rates (m^3/s) in Study Areas**	**Residual Flow Rate Percents**	**Membership Grades**
Cüneyt HPP	3.04	7.09	43 %	0.66
Armutlu HPP	0.66	1.12	59 %	0.98
Meydancık HPP	4.46	10.24	44 %	0.68
Gana HPP	1.06	2.43	44%	0.88
Şavşat HPP	3.37	5.56	61%	1.00

Table 5.17 Acceptability Results Usingset of All Criteria According to Q_{50} Method

	"and"	**"or"**	**OWA**
Cüneyt HPP	0	1	0.45
Gana HPP	0.14	1	0.57
Meydancık HPP	0	1	0.47
Armutlu HPP	0	1	0.34
Şavşat HPP	0	1	0.36

Table 5.18 Acceptability Results Using Set of Reduced Criteria According to Q_{50} Method

	"and"	**"or"**	**OWA**	**LWA**
Cüneyt HPP	0.3	1	0.50	0.66
Gana HPP	0.3	1	0.63	0.79
Meydancık HPP	0.3	1	0.59	0.75
Armutlu HPP	0	1	0.33	0.56
Şavşat HPP	0.3	1	0.40	0.66

Table 5.19 Acceptability Results Using Set of Environmental Criteria According to Q_{50} Method

	"and"	**"or"**	**OWA**
Cüneyt HPP	0	1	0.46
Gana HPP	0.4	1	0.95
Meydancık HPP	0	1	0.46
Armutlu HPP	0	1	0.49
Şavşat HPP	0	1	0.30

In application of Q_{50} method, residual water amounts are so high that it may make the projects economically unfeasible, but even in this case acceptability values are not high enough to change the decision about hydropower plants. Acceptability results of Q_{50} method are higher than acceptability results of Tennant and Q_{90} methods as expected, however the results of Q_{50} method showed one more time that changing membership value of one criterion is not make great change in acceptability value.

Although Tennant method has certain advantages in calculations, there are some disadvantages of the method that makes it impracticable. Tennant method is limited from ecological perspectives and it does not sufficiently represent the dynamic and variable nature of the water bodies (Islam, 2010). Therefore usage of Tennant method in river bodies whose flow regime is changeable may not be practicable. Plus Tennant gives more accurate results in regions where slope is low than regions where slope is high. Black Sea region is an example of regions that flow regime is changeable and the slope is high, but because of the limited conditions of this study, Tennant and Q_{90} and Q_{50} methods are the only options to show impact of flow rate alteration on environment.

5.8.2 Summary of the Acceptability Scores for Different Minimum Released Flow Conditions

Results of “and” and “or” operators do not let decision makers to decide, since the results are the same almost all cases, for this reason result comparisons are carried out according to the results of OWA and LWA operators.

If the results given in Table 5.7 and the results given in Table 5.20 are compared, it can be seen that acceptability results of all hydropower projects increase if recommended residual flow rates are released in river bodies. Also the most dramatic changes are observed in Cüneyt HPP’s results since planned residual water of Cüneyt project is the lowest one. On the other hand results of Gana project is the one whose results are affected in small amount, since the planned residual flow rate is the highest one. As might be expected, results of environmental criteria set are the most affected ones, because the number of criteria is less than other sets so influence of each criterion is greater than other sets. Also, results of LWA operator are greater than results of OWA operator since the importance of flow rate alteration criterion is higher than its importance in OWA operator. Plus, Table 5.20 shows that results calculated using Tennant method are so similar with results calculated using Q_{90} method while results of Q_{50} method are about 10% higher than other methods. It proves the consistency of the Tennant and Q_{90} methods and conservativeness of Q_{50} method when it is compared with Tennant and Q_{90} method.

Table 5.20 Acceptability Results Using Different Set of Criteria and Minimum Flow Conditions

	TENNANT (Q_{min} = 30% of the average flow)				**Q_{90}**				**Q_{50}**			
	All	Reduced		Env.	All	Reduced		Env.	All	Reduced		Env.
	OWA	OWA	LWA	OWA	OWA	OWA	LWA	OWA	OWA	OWA	LWA	OWA
Cüneyt	0.42	0.45	0.60	0.38	0.40	0.40	0.57	0.32	0.45	0.50	0.66	0.46
Gana	0.51	0.52	0.70	0.74	0.47	0.46	0.65	0.63	0.57	0.63	0.79	0.95
Meydancık	0.44	0.52	0.70	0.38	0.43	0.50	0.68	0.35	0.47	0.59	0.75	0.46
Armutlu	0.29	0.25	0.45	0.33	0.31	0.28	0.48	0.39	0.34	0.33	0.56	0.49
Şavşat	0.30	0.31	0.54	0.19	0.33	0.35	0.58	0.23	0.36	0.40	0.66	0.30

5.8.3 Scenario with Different Public Perception Rates

As mentioned before there are only two criteria that can be changed by the decision makers. One of them is flow rate alteration which is simulated with different values and other one is public perception. Making changed in public perception rate is not as easy as in flow rate alteration, but by applying efficient persuasion studies in project regions, decision of local residents may be changed. In the content of this study, public perception simulation was carried out by assuming 70% of local residents are convinced that hydropower plants do not have negative effects on both ecology and the society and they should be supported by the governments. Results of this simulation for all hydropower projects and for all operators are given in Table 5.21.

Table 5.21 Summary of the Acceptability Results with Changed Public Perception Data

	OWA with All Criteria	**OWA with Reduced Criteria**	**LWA with Reduced Criteria**
Cüneyt HPP	0.47	0.52	0.68
Gana HPP	0.61	0.50	0.65
Meydancık HPP	0.51	0.65	0.78
Armutlu HPP	0.39	0.40	0.59
Şavşat HPP	0.39	0.45	0.65

5.9 Summary of the Results

In this study ten different criteria are used to evaluate five different hydropower projects with regard to their environmental and social impacts. In evaluations four different aggregation method are used and results showed that, “and” and “or” operators do not give detailed result data to compare the projects with each other.

In most of the cases, results are the same for all projects or very close to each other, so that it is almost impossible to make decision by depending on those results. On the contrary, OWA and LWA operators give reasonable results that make comparison possible. Making calculations with OWA and LWA methods is decision makers' choice, if decision makers want to define importance of the criteria by themselves, they can prefer LWA method, and otherwise OWA can be chosen.

Moreover results are evaluated with three different criteria sets. The aim of making different combinations is; understanding the effects of specific criteria on overall results. Those results showed that as number of criteria increase, weight values become close to each other and it is becoming difficult to underline a criterion which is much more important than others. All of the results are summarized in Table 5.22.

According to Table 5.22, original values, changed flow rate values and changed public perception values of the selected projects that are calculated by including all criteria are so similar to each other, so we can conclude that changing membership value of a single criterion does not affect the acceptability results in considerable amount. However, it should be underlined that changing the membership value of public perception criterion is more effective than changing the value of flow rate alteration criterion.

If set of reduced criteria's results are analyzed, relatively bigger change can be observed between the original values and changed flow rates, changed public perception values, when they are compared to changes in set of all criteria. Also difference between the original values and changed flow rate values are bigger than original values and changed public perception values. That is because the difference between the weights cannot affect the results when number of criteria is ten but it can be observed as the number of criteria decreased to six.

Similarly, original results of set of environmental criteria are not so different than changed flow rate results. The biggest difference is observed in Armutlu projects' result since its original membership value of flow rate alteration criterion is the lowest among other projects consequently membership value alteration is the biggest among other projects.

The results calculated with original values and changed values show that, change in a single criterion does not affect the acceptability results in remarkable amount. If decision makers want to change acceptability of the projects, multiple criteria have to be positively changed. Although making changes in criteria such as landslide and earthquake seem almost impossible, taking precautions against the results of these events may help making the project more feasible and decision makers may include these precautions in this study. Otherwise the only option is changing the location of the project in order to change membership values of the criteria.

Table 5.22 Summary of All Calculated Results

	Original Values			Changed Flow Rate						Changed Public Perception	
				Tennant		Q_{90}		Q_{50}			
HPP	**Criteria Set**	**OWA**	**LWA**	**OWA**	**LWA**	**OWA**	**LWA**	**OWA**	**LWA**	**OWA**	**LWA**
Cüneyt	All	0.38	-	0.42	-	0.40	-	0.45	-	0.47	-
	Reduced	0.38	0.55	0.45	0.60	0.40	0.57	0.50	0.66	0.52	0.68
	Environmental	0.29	-	0.38	-	0.32	-	0.46	-	-	-
Gana	All	0.49	-	0.51	-	0.47	-	0.57	-	0.61	-
	Reduced	0.51	0.68	0.52	0.70	0.46	0.65	0.63	0.79	0.50	0.65
	Environmental	0.71	-	0.74	-	0.63	-	0.95	-	-	-
Meydancık	All	0.41	-	0.44	-	0.43	-	0.47	-	0.51	-
	Reduced	0.48	0.67	0.52	0.70	0.50	0.68	0.59	0.75	0.65	0.78
	Environmental	0.32	-	0.38	-	0.35	-	0.46	-	-	-
Armutlu	All	0.28	-	0.29	-	0.31	-	0.34	-	0.39	-
	Reduced	0.23	0.43	0.25	0.45	0.28	0.48	0.33	0.56	0.40	0.59
	Environmental	0.30	-	0.33	-	0.39	-	0.49	-	-	-
Şavşat	All	0.28	-	0.30	-	0.33	-	0.36	-	0.39	-
	Reduced	0.26	0.48	0.31	0.54	0.35	0.58	0.40	0.66	0.45	0.65
	Environmental	0.14	-	0.19	-	0.23	-	0.30	-	-	-

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Hydropower is the most preferred renewable energy generation technique in the world. However environmental and social impacts of hydropower plants are ignored because of inevitability of energy in human beings' daily lives. Plus, economic feasibility is the primary consideration of investors unless they are forced by government to make environmental and social feasibility studies. Therefore feasibility studies of energy projects include only economic evaluations, but this thesis study environmental and social aspects of run-of river hydropower projects are evaluated as distinct from previous feasibility studies

In proposed methodology, acceptability of the project is tried to be measured with ten different criteria. At the end of the study acceptability values of hydropower projects can be evaluated and compared with other project options by decision makers. Any acceptability value, which values above it can be thought as acceptable and values below that value can be considered as not acceptable, can be specified, but it is not thought as a mission of this thesis study, making that specification is considered as decision makers' choice.

Ideally, the methodology should be applied at the feasibility stage of the projects before the construction starts like environmental impact assessment reports. The difference between the explained methodology in this study and environmental impact assessment reports is evaluation of social aspect. Therefore the methodology can be used as a part of "strategic environmental impact assessment reports which are also include social evaluations. Comparison of the environmental impact assessments of selected projects in Şavşat and the results of this study showed that; projects that are acceptable according to the environmental impact assessment reports may not be acceptable in terms of this evaluation methodology. For example; 10% residual water is assumed as low flow requirement boundary in environmental impact assessment reports while it has to be 60% in order to be acceptable for this study. Similarly, destructed forest areas are not considered as a problem if determined price of trees is paid, but destructed forest size is evaluated in this study even if the price is paid. Consequently, results of environmental impact assessment reports and proposed methodology in this study may not be the same and cannot be replaced by each other.

Application of the methodology should include more than one hydropower project. Since the aim of the methodology is to compare location options of the projects rather than making decision about a location by implementing the given calculations. Implementers of the methodology are decision makers or professional consultants of decision makers or governmental institutions that give permission for hydropower construction.

Methodology implementation in Şavşat/Artvin showed that Gana hydropower project is the most acceptable one among five selected projects. If acceptability values are analyzed it is seen that acceptability results of set of all criteria are more closer to each other, while acceptability results of set of environmental criteria are so different. Membership grades of selected hydropower plants are quite close to each other except for destructed forest size criterion. Membership grades of destructed forest size criterion of Cüneyt, Meydancık, Armutlu and Şavşat hydropower plants are zero while the value is one for Gana hydropower plant. The effect of the difference between Gana HPP and other HPPs is seen in set of environmental criteria more specifically, since the number of criteria is the less than other sets. Therefore if three criteria set (set of all criteria, set of reduced criteria and set of environmental criteria) are compared; set of environmental criteria set is the most sensitive one, any change in membership of any criteria can make big changes in acceptability results. On the contrary, set of all criteria and set of reduced criteria are not affected from changes as in set of environmental criteria.

Set of all criteria and set of reduced criteria are prepared to be replaced by each others; if the data is available implementers should use set of all criteria but if it is difficult to obtain related data, set of reduced criteria can be used to measure acceptability. On the other hand, set of environmental criteria is prepared to be used to make environmental evaluation, so it should be used together with results of set of all criteria or set of reduced criteria.

After evaluation of acceptability values, membership grades of flow rate alteration and public perception rates are changed to see whether acceptability can be increased by changing the membership grade of a criterion or not. Flow rate alteration and public perception criteria are the only ones that can be changed by decision makers. That is why those two criteria are selected to make recalculations. However the recalculation results showed that changing membership grade of a criterion does not make significant change in acceptability results. Consequently, by looking at results of Şavşat/ Artvin implementation, we can say that; if acceptability of a project is aimed to increase, multiple criteria have to be changed positively.

Flow rate alteration changes are made according to three different methods; Tennant, Q_{90} and Q_{50}. According to the results Tennant and Q_{90} methods give similar results while Q_{50} gives 10% higher results than other two methods, so if decision makers try to increase membership grade of flow rate alteration criterion, Q_{50} method should be preferred.

Another conclusion from Şavşat results is that; results of “and” and “or” operators are not useable in this kind of decision making studies, because the acceptability results are very close to each other so that it is impossible to make decision by using those results. On the contrary results of OWA and LWA methods are practical and they give chance to make comparison between the projects. If ordered weighted averaging (OWA) and linear weighted averaging (LWA) methods are compared, it is seen that LWA results are 20% greater than OWA results in almost all of the selected projects, since weight of flow rate alteration has the highest weight. Therefore, if decision makers want to underline some criteria, LWA method should be used. Otherwise OWA method can be used for evaluation. Although explained advantages and disadvantages of aggregation methods are observed in Şavşat case study, making choice between those methods is also thought as decision makers' duty.

During the methodology implementation, the most difficult part was the data collection. All of the used data are either obtained by governmental institutions after complicated application period or collected by site visits. Also in Turkey, some of needed data are not collected by responsible institutions or collected data are not reliable which make applications impossible. Another problems related with data collection is reaction of local residents. Especially in project areas that are on legal trial, residents reject to attend surveys.

Fuzzy set identification is another difficult part of the study. In this study fuzzy set identification was carried out by making detailed literature research for most of the criteria and taking expert opinions for some of the criteria. However it should not be forgotten that prepared fuzzy sets include subjectivity by nature of multi-criteria decision making analysis and because of fuzzy set boundary identification methodology of this study. If the boundaries of fuzzy sets would be identified by depending on experiments and advanced experiences about the case study site, results would be more realistic, so subjectivity of fuzzy set boundary identification process can be thought as limitation of this study.

If the conditions would allow, some of the criteria could be analyzed more detailed. For example; for destructed forest size criterion, beside water channel lengths, constructed road distances could be included in calculations or another land use types such as agricultural lands, residential areas could be included in the assessments. In literature there are some studies that include other land use types, but in the content of this study comparison of land use types with each other was not preferred and including constructed road in the calculations was impossible because of missing data. Also landslide evaluation could be done by including some other geological data such as geologic map, land use map, elevation map of the regions in addition to landslide inventory map. However that kind of evaluation need detailed data and technical background. Another improvable criterion is distance from the nearest environmentally sensitive area. For the sensitive areas that are close to the case study areas, buffer zone determination study could be done rather than using data obtained by the literature. Similar criticism can be made for flow rate alteration criterion. The needed flow rate amount in case study areas could be analyzed with field works. However, both criteria need long term site visits, multi discipliner studies and financial support whose none of them are available for this thesis study. The last criterion that can be developed is public perception. Survey preparation and application phases could be performed with psychology professional, by this way detailed analyze could be succeed which reveal the reasons of rejections and distributions of answers according to participants' profiles. All of these mentioned revisions can be considered as recommendations for the future studies.

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URL 1 District Governorship of Şavşat http://www.savsat.gov.tr/? (Access May 2013)

URL 2 State Hydraulic Work http://www.dsi.gov.tr/dsi-resmi-istatistikler (Access February 2015)

APPENDIX A

FLOWRATE DATA OF SELECTED HYDROPOWER PLANTS

YIL	EKİM	KASIM	ARALK	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZRN	TEMMZ	AGUST	EYLÜL	ORT.
1963	2,46	2,53	2,54	2,65	2,91	3,57	13,27	18,44	17,52	10,72	5,18	3,06	7,07
1964	2,93	2,76	2,59	2,46	2,50	4,25	10,79	14,18	11,31	4,84	2,87	2,64	5,33
1965	2,48	2,89	2,77	2,48	2,49	5,42	11,13	13,93	10,73	5,37	2,97	2,54	5,42
1966	3,35	3,18	3,02	3,55	3,61	5,40	10,01	13,63	10,04	5,43	2,97	2,84	5,59
1967	2,53	2,58	2,71	2,40	2,35	3,59	9,44	14,84	9,81	8,26	4,17	3,56	5,52
1968	3,15	3,05	3,64	3,14	3,26	6,15	18,81	17,14	10,98	6,50	4,47	4,40	7,06
1969	4,77	5,07	3,93	3,46	3,33	6,62	11,80	15,80	9,46	5,11	3,49	3,34	6,33
1970	3,83	3,01	2,84	2,59	2,91	5,16	11,10	9,53	6,86	3,80	2,91	2,53	4,75
1971	2,97	2,77	2,80	2,30	2,05	5,18	8,58	13,93	10,98	5,51	3,96	2,48	5,28
1972	2,57	2,56	3,09	2,31	2,29	4,08	11,06	11,20	11,24	5,58	3,30	3,31	5,22
1973	3,30	3,17	2,38	2,16	2,67	3,09	6,62	10,09	9,21	5,14	2,58	2,17	4,38
1974	2,69	3,06	2,55	2,11	2,28	5,26	7,88	12,28	7,84	3,39	2,52	3,12	4,58
1975	2,32	2,37	2,34	2,16	2,12	4,08	10,60	11,26	9,34	4,36	2,30	2,27	4,63
1976	2,61	2,33	2,08	2,51	2,51	4,40	11,87	14,48	11,88	6,69	3,47	2,66	5,64
1977	3,31	3,10	2,89	2,41	3,02	4,45	8,38	12,66	10,03	6,22	3,16	2,55	5,10
1978	3,05	2,86	2,57	2,52	3,42	5,69	11,37	14,71	10,33	6,27	3,22	2,56	5,72
1979	2,64	2,63	2,50	2,60	3,23	4,27	8,50	11,59	10,47	5,93	2,93	2,29	4,98
1980	3,11	4,80	3,87	3,27	3,17	5,85	15,30	14,38	9,26	4,80	3,12	2,48	6,12
1981	2,82	2,77	2,91	2,54	2,30	3,96	6,81	11,14	12,91	6,48	3,06	2,22	4,99
1982	2,54	2,96	2,67	2,38	2,19	3,08	11,03	13,40	9,52	4,94	2,82	2,36	5,01
1983	2,43	2,28	1,89	1,77	1,87	3,11	6,14	8,75	6,90	3,37	1,70	1,99	3,52
1984	2,40	3,32	3,88	2,81	2,52	4,30	8,52	12,07	10,94	6,41	3,31	2,58	5,42
1985	2,31	2,42	1,92	1,81	2,01	3,29	11,60	12,91	7,58	3,33	2,04	1,82	4,42
1986	3,01	3,40	3,41	2,68	3,40	6,01	11,29	12,99	14,06	6,48	3,04	2,31	6,00
1987	3,05	3,38	2,53	2,87	4,21	3,77	11,33	20,50	12,95	6,63	3,46	2,62	6,44
1988	2,32	3,56	3,93	3,48	3,50	5,81	16,74	19,92	16,43	9,64	4,49	3,61	7,79
1989	4,42	6,58	5,37	3,36	2,88	7,18	13,59	10,56	8,33	3,95	2,09	2,06	5,87
1990	1,41	2,63	3,02	1,81	1,96	4,06	14,18	23,42	7,23	2,80	2,32	2,21	5,59
1991	2,56	2,94	2,43	1,67	1,82	5,83	13,34	9,67	8,01	3,69	2,33	2,18	4,70
1992	2,62	3,33	2,63	2,26	2,24	4,11	9,74	12,60	13,36	7,09	3,97	3,06	5,58
1993	3,59	3,73	3,47	2,88	2,88	5,05	13,69	16,50	14,08	7,41	4,03	2,85	6,68
1994	2,17	3,52	2,95	2,52	2,41	5,20	12,36	12,22	7,65	3,04	2,85	2,81	4,97
1995	2,61	3,05	2,32	3,42	3,14	4,35	8,12	14,97	6,50	3,71	2,80	2,39	4,70
1996	3,03	3,97	2,81	2,24	2,46	3,23	5,49	12,18	8,59	3,03	1,68	2,97	4,31
1997	4,25	3,25	3,45	4,37	3,50	4,33	14,51	20,85	10,46	4,48	2,58	2,62	6,55
1998	3,11	2,50	2,59	2,50	3,31	5,84	15,60	15,30	8,33	2,89	2,29	2,32	5,55
1999	2,26	2,40	2,57	2,13	2,47	4,39	9,06	16,21	12,01	7,30	3,35	2,62	5,56
2000	2,62	11,49	5,37	4,26	2,72	4,58	14,77	14,44	10,10	2,86	2,11	2,22	6,46
2001	2,30	2,17	2,06	2,03	1,84	5,21	8,19	11,45	5,36	2,47	2,39	2,16	3,97
2002	2,13	2,73	2,05	2,28	3,48	9,36	16,11	19,81	18,10	7,62	4,40	3,78	7,75
2003	3,64	3,73	2,82	2,81	2,55	2,95	11,35	12,64	5,01	3,43	2,12	2,71	4,60
2004	3,41	6,08	4,76	2,82	2,66	10,04	11,74	22,99	14,01	5,16	3,25	2,98	7,49
2005	2,86	2,83	2,75	2,64	2,81	5,49	18,15	17,05	9,39	3,04	2,69	3,03	6,06
2006	2,80	3,56	3,00	2,62	2,71	4,94	11,26	14,46	10,27	5,00	2,88	2,57	5,51
2007	2,80	3,55	3,00	2,64	2,73	4,94	11,60	14,62	10,32	4,98	2,89	2,56	5,55
2008	2,82	3,59	3,03	2,68	2,75	4,97	11,62	14,72	10,35	5,00	2,91	2,57	5,58
2009	2,82	3,63	3,05	2,66	2,76	4,99	11,61	14,72	10,30	4,95	2,89	2,56	5,58

Figure A-1 Şavşat HPP Monthly Flow Rate Data Between 1963-2009

Year	m3/sec												Avg.
	X	*XI*	*XII*	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	
1982	0,774	0,732	0,592	0,539	0,499	0,815	3,83	5,78	2,88	1,490	0,982	0,457	1,614
1983	0,874	0,729	0,584	0,516	0,526	1,320	4,14	4,28	2,98	1,440	0,604	0,604	1,550
1984	0,824	1,110	0,672	0,587	0,582	1,090	2,45	3,29	2,43	1,010	0,685	0,512	1,270
1985	0,355	0,412	0,369	0,347	0,386	0,666	5,06	7,03	2,67	0,664	0,504	0,526	1,582
1986	1,020	0,790	0,579	0,501	0,508	0,954	4,35	4,40	3,55	1,060	0,420	0,462	1,550
1987	0,762	0,577	0,511	0,521	0,671	0,615	2,35	6,97	3,37	0,903	0,520	1,050	1,568
1988	0,772	0,596	0,475	0,402	0,415	0,816	3,68	5,56	4,93	1,200	1,150	1,590	1,80
1989	1,300	1,240	0,935	0,599	0,528	2,55	10,90	7,45	4,83	1,310	0,412	0,649	2,73
1990	0,810	0,599	0,545	0,429	0,452	1,140	4,32	8,60	4,20	1,360	0,479	0,594	1,96
1991	0,910	1,080	0,637	0,452	0,445	1,390	4,51	3,52	2,34	0,950	0,425	0,469	1,427
1992	0,363	0,361	0,346	0,358	0,360	0,575	2,37	7,17	7,19	1,650	0,592	0,479	1,82
1993	1,490	1,310	0,543	0,428	0,399	0,756	3,84	9,52	5,75	1,680	0,587	0,732	2,25
1994	0,538	2,20	0,682	0,619	0,460	0,973	6,62	5,17	2,80	0,855	0,499	0,447	1,82
1995	1,050	0,752	0,511	0,498	0,590	1,070	2,60	5,91	3,00	0,971	0,491	0,691	1,511
1996	1,240	1,080	0,599	0,615	0,637	0,722	2,28	5,50	2,86	0,789	0,381	0,487	1,433
1997	0,850	0,643	0,599	0,629	0,505	0,539	4,06	7,24	4,76	1,690	0,704	0,870	1,92
1998	1,020	0,800	0,398	0,398	0,434	0,652	5,29	5,89	3,28	0,783	0,533	0,517	1,666
1999	0,555	0,588	0,625	0,524	0,602	1,090	2,54	5,27	3,60	1,95	0,831	0,639	1,568
2000	0,646	3,99	1,390	1,050	0,681	1,160	4,68	4,53	2,99	0,697	0,519	0,549	1,91
2001	0,560	0,531	0,507	0,503	0,464	1,340	2,26	3,39	1,400	0,608	0,587	0,531	1,057
2002	0,527	0,666	0,508	0,557	0,846	2,76	5,23	6,83	6,49	2,10	1,110	0,927	2,38
2003	0,891	0,908	0,682	0,680	0,618	0,713	3,40	3,61	1,300	0,865	0,528	0,664	1,238
2004	0,985	1,560	1,170	0,698	0,673	3,29	3,65	6,14	3,58	1,150	0,657	0,529	2,01
Avg.	0,831	1,011	0,629	0,541	0,534	1,174	4,10	5,78	3,62	1,182	0,617	0,651	1,723

Figure A-2 Cüneyt HPP Monthly Flow Rate Data Between 1982-2004

YIL	EKİM	KASIM	ARALIK	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZİRAN	TEMMUZ	AĞUSTOS	EYLÜL	YILLIK ORT
2001	0,66	0,53	0,44	0,39	0,40	2,16	3,58	3,89	2,29	0,82	0,43	0,50	1,34
2002	0,67	1,41	0,86	0,61	1,12	3,22	7,24	9,53	10,57	3,53	0,98	0,86	3,38
2003	1,10	1,00	0,48	0,64	0,57	0,59	4,20	4,16	1,66	0,93	0,63	1,03	1,42
2004	1,67	2,05	1,31	0,79	0,85	4,13	4,76	7,69	5,88	1,81	0,86	0,72	2,71
2005	0,57	0,73	0,66	0,88	0,82	1,92	9,85	9,83	4,82	1,50	0,75	0,71	2,74
2006	3,46	2,55	2,07	0,70	0,68	1,76	6,46	7,51	2,67	1,08	0,34	0,55	2,49
2007	0,73	0,73	0,65	0,48	0,59	1,21	1,91	16,86	10,71	2,89	1,54	0,70	3,25
2008	0,71	1,23	1,03	0,59	0,74	6,77	9,75	4,63	7,01	1,23	1,00	0,40	2,92
2009	0,40	0,39	0,42	0,40	0,46	0,74	1,32	7,89	3,94	1,55	1,29	1,06	1,66
2010	1,28	0,78	0,99	1,27	1,36	3,38	4,96	8,16	5,00	1,00	0,37	0,30	2,40

Figure A-3 Gana HPP Monthly Flow Rate Data Between 1983-2009

Su Yılı	EKİM	KASIM	ARALIK	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZİRAN	TEMMUZ	AĞUSTOS	EYLÜL	YILORT
1982	3.840	4.220	3.230	2.870	2.590	4.790	24.110	36.140	18.160	9.310	5.870	2.270	9.783
1983	5.170	4.200	3.180	2.700	2.770	7.980	26.050	26.910	18.860	8.980	3.320	3.320	9.453
1984	4.850	6.770	3.800	3.200	3.030	6.630	15.470	20.730	15.380	6.110	3.880	2.660	7.709
1985	1.510	1.940	1.620	1.450	1.740	3.690	31.520	43.650	16.790	3.730	2.610	2.740	9.416
1986	6.180	4.610	3.140	2.600	2.640	5.660	27.370	27.620	22.340	6.390	2.000	2.300	9.404
1987	4.410	3.130	2.660	2.730	3.780	3.400	14.770	43.290	21.240	5.350	2.720	6.240	9.477
1988	4.460	3.260	2.410	1.870	1.860	4.740	23.130	34.710	30.800	7.350	6.910	9.910	10.951
1989	7.950	7.620	5.590	3.280	2.780	16.050	66.770	46.080	30.300	8.040	1.930	3.550	16.662
1990	4.080	3.020	2.650	1.820	2.240	7.540	27.550	52.900	26.010	8.510	2.400	2.940	11.805
1991	4.720	6.510	3.500	2.250	2.450	10.120	28.340	21.980	15.480	5.800	2.160	2.140	8.788
1992	1.540	1.680	1.630	1.580	1.520	3.960	19.020	43.680	43.200	10.450	3.390	2.610	11.188
1993	10.020	8.870	3.420	2.640	2.610	5.490	27.950	60.240	36.560	10.270	3.340	3.830	14.603
1994	2.640	12.270	3.900	3.540	2.820	7.520	41.810	31.930	16.900	4.950	2.610	2.080	11.081
1995	5.470	3.950	2.590	2.740	3.280	6.780	17.320	37.170	18.790	5.910	2.340	3.390	9.144
1996	6.870	6.480	3.310	3.220	3.090	3.900	13.690	33.100	17.380	4.420	1.640	2.450	8.296
1997	4.530	3.260	3.490	4.020	2.870	3.540	25.870	46.310	28.540	9.690	3.500	4.520	11.678
1998	5.560	4.160	2.090	1.820	2.210	4.590	34.390	36.800	20.140	4.000	2.500	2.380	10.053
1999	2.720	3.380	3.770	1.710	2.060	4.520	17.610	31.570	20.510	8.660	3.770	2.630	8.576
2000	2.820	12.320	6.760	4.180	3.890	6.530	35.650	28.120	19.640	4.290	2.100	2.010	10.693
2001	2.950	2.440	2.040	1.810	1.860	8.940	14.420	15.630	9.500	3.650	1.990	2.300	5.628
2002	3.020	6.010	3.790	2.750	4.850	13.020	27.950	36.260	39.990	14.220	4.290	3.780	13.328
2003	4.770	4.390	2.200	2.900	2.610	2.690	16.710	16.640	7.010	4.020	2.840	4.470	5.938
2004	6.930	8.510	5.640	3.520	3.770	16.460	18.860	29.640	23.010	7.620	3.790	3.220	10.914
2005	2.610	3.280	2.960	3.060	3.650	7.960	37.200	37.370	19.080	6.370	3.330	3.180	10.838
2006	13.090	10.380	8.250	3.430	3.510	8.310	24.050	27.440	10.940	5.110	1.860	2.620	9.916
2007	3.430	3.760	3.280	2.680	3.530	6.760	10.220	59.380	36.310	11.010	6.080	4.350	12.566
2008	2.990	6.730	4.420	2.680	2.460	13.990	27.030	19.100	16.750	6.200	2.800	3.750	9.075
2009	4.430	3.740	2.920	2.060	1.670	3.670	7.960	17.060	20.500	9.850	4.330	5.390	6.965
2010	3.950	5.320	4.390	4.810	5.490	11.710	17.960	37.110	41.920	14.970	5.630	4.020	13.107

Figure A-4 Meydancık HPP Monthly Flow Rate Data Between 1982-2010

YIL	EKİM	KASIM	ARALIK	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZİRAN	TEMMUZ	AĞUSTOS	EYLÜL	ORT.
1983	0,72	0,65	0,59	0,56	0,57	0,90	2,09	2,15	1,61	0,96	0,60	0,60	1,00
1984	0,70	0,82	0,63	0,59	0,58	0,81	1,38	1,74	1,38	0,78	0,64	0,56	0,83
1985	0,50	0,62	0,60	0,49	0,51	0,63	2,49	3,32	1,47	0,63	0,56	0,57	1,01
1986	0,78	0,68	0,69	0,56	0,56	0,75	2,19	2,20	1,85	0,79	0,52	0,54	1,00
1987	0,67	0,59	0,56	0,57	0,63	0,61	1,34	3,20	1,77	0,73	0,57	0,79	1,01
1988	0,67	0,60	0,55	0,52	0,52	0,69	1,90	2,70	2,43	0,85	0,83	1,02	1,11
1989	0,90	0,87	0,74	0,60	0,57	1,42	4,97	3,50	2,39	0,90	0,52	0,62	1,50
1990	0,25	0,50	0,59	0,33	0,36	0,81	2,94	4,89	1,47	0,64	0,44	0,42	1,13
1991	0,49	0,56	0,46	0,30	0,34	1,18	2,76	1,99	1,64	0,73	0,44	0,41	0,94
1992	0,50	0,50	0,49	0,50	0,49	0,59	1,35	3,30	3,31	1,65	0,60	0,55	1,10
1993	0,98	0,96	0,68	0,53	0,51	0,67	1,97	4,39	2,78	1,06	0,59	0,66	1,30
1994	0,41	0,09	0,57	0,48	0,46	1,05	2,56	2,53	1,56	0,59	0,55	0,54	1,00
1995	0,50	0,38	0,44	0,67	0,61	0,87	1,66	3,10	1,32	0,73	0,54	0,45	0,94
1996	0,59	0,79	0,54	0,42	0,47	0,63	1,11	2,52	1,76	0,69	0,30	0,58	0,86
1997	0,65	0,63	0,68	0,67	0,69	0,86	3,01	4,34	2,15	0,89	0,49	0,50	1,33
1998	0,60	0,48	0,60	0,48	0,85	1,18	3,24	3,17	1,71	0,56	0,43	0,44	1,12
1999	0,43	0,40	0,49	0,40	0,47	0,88	1,88	3,37	2,48	1,49	0,66	0,50	1,12
2000	0,50	2,37	1,08	0,85	0,52	0,91	3,06	2,99	2,09	0,66	0,39	0,42	1,31
2001	0,43	0,41	0,38	0,38	0,34	1,05	1,68	2,36	1,08	0,47	0,45	0,41	0,70
2002	0,40	0,53	0,38	0,43	0,68	1,92	3,35	4,13	3,98	1,56	0,96	0,75	1,58
2003	0,71	0,72	0,54	0,52	0,48	0,54	2,33	2,49	0,93	0,62	0,36	0,50	0,89
2004	0,77	1,23	0,94	0,56	0,54	2,30	2,51	3,81	2,46	0,82	0,62	0,40	1,41
2005	0,55	0,55	0,53	0,51	0,54	1,11	3,78	3,54	1,93	0,50	0,52	0,59	1,23
2006	0,83	0,86	0,73	0,49	0,55	1,42	2,50	2,98	1,09	0,73	0,36	0,42	1,08
2007	0,53	0,58	0,52	0,45	0,71	1,28	2,22	6,93	2,61	0,81	0,67	0,52	1,48
2008	0,45	0,75	0,83	0,42	0,47	1,84	2,97	3,00	2,20	0,78	0,49	0,50	1,21
2009	0,49	0,47	0,48	0,52	0,53	0,86	1,41	2,99	1,69	1,30	0,93	0,70	1,03

Figure A-5 Armutlu HPP Monthly Flow Rate Data Between 1983-2009

APPENDIX B

OFFICIAL ANSWER OF ARTVIN PROVINCIAL DIRECTORATE OF SECURITY

T.C.
ARTVİN VALİLİĞİ
İl Emniyet Müdürlüğü

Sayı : 77692028 .7998.(63233).09 — 26/12/2013
Konu : Pelin TEMEL AYDOĞDU' ya ait dilekçe

Sayın:
Pelin TEMEL AYDOĞDU
(pelintemel@gmail.com)

İlgi : Valilik Makamının 06/12/2013 tarihli dilekçesi.

İlgi sayıda kayıtlı yazı ile Pelin TEMEL AYDOĞDU isimli şahıs Orta Doğu Teknik Üniversitesi Çevre Mühendisliği Bölümünde Yüksek Lisans öğrencisi olduğunu, Tez konusu olarak Şavşat İlçesinde bulunan Hidroelektrik Santraller hakkında "Çevresel Duyarlılık Analizi" ile bu kapsamda bölgenin terör eylemlerine odak olup olmadığı, son 20 yılda meydana gelen olayların sayısı hakkında bilgi verilmesi hususunda gereğinin yapılmasını talep etmektedir.

Dilekçede belirtilen konu ile ilgili Terörle Mücadele Şube Müdürlüğü görevlilerince yapılan arşiv incelemesinde ilimiz Şavşat ilçesinde 1993 yılında (3) adet terör olayı gerçekleşmiş olup 1994 yılından itibaren terör olayı meydana gelmemiştir.

Bilgilerinize arz/rica ederim.

Hüsrev SALMANER
İl Emniyet Müdürü
1.Sınıf Emniyet Müdürü

DAĞITIM:

1-Valilik Makamına
2-Pelin TEMEL AYDOĞDU adına

APPENDIX C

SURVEY 1

Name/Surname:

SECTION-1

Following questions are prepared to be used in a thesis study that is carried out at Middle East Technical University Environmental Engineering Department. Your answers will be evaluated according to privacy policy and they will not be used in anywhere else except for the mentioned thesis study.

Survey Place:

Survey Date:

1- What is your age?

____

2- What is your gender?
   a) Female
   b) Male
3- What is your marital status?
   a) Married
   b) Single
4- What is your occupation?
   a) Farmer
   b) Fisher
   c) Artisan
   d) Public servant

e) Other________

5- What is your educational background?

a) No education
b) Primary school
c) High school
d) Undergraduate
e) Graduate/PhD

6- Do you have your own house?

a) Yes
b) No

7- What is your monthly average income?

____

8- Do you live in village/district that the survey conducted?

a) Yes
b) No

If your answer is "yes" for the question 8 please answer questions 9 and 10. If the answer is "no", continue with Section-2.

9- Are you a resident of the village/district that the survey conducted?

a) Yes
b) No (If the answer is "no" please mention your hometown)

____

10- For how many years you live in the village/district that survey conducted?

____

SECTION-2

11- Do you think that you live in clean environment?

a) Yes
b) No
c) No idea

12- What are the environmental problems of the region? (You can choose multiple alternatives)

   a) Insufficient protection of forests
   b) Air pollution
   c) Noise pollution
   d) Pollution of water resources
   e) Others______

13- What is the biggest problem of the region?

   a) HPPs and problems related with them
   b) Unemployment
   c) Transportation
   d) Education
   e) Others_______

14- Which sectors should be supported to make the region develop? (You can choose multiple alternatives)

   a) Agriculture
   b) Stockbreeding
   c) Beekeeping
   d) Tourism
   e) Industry
   f) Energy investments
   g) Others_______

15- Do HPPs have positive effects on the economical development of the region?

   a) Yes (If your answer is "yes" please explain these effects)
   b) No
   c) No idea

16- Do HPPs endanger the organisms living in the region?

   a) Yes
   b) No
   c) No idea

17- Do HPPs have negative effects on water quality of the region?

a) Yes
b) No
c) No idea

18- Do HPPs affect the amount of the water resources of the region?
a) Yes
b) No
c) No idea

19- Do you think protests that are aimed to prevent HPPs in your village/district are right, proper and sufficient enough?
a) Yes
b) No
c) No idea

20- Do you think that HPPs will be beneficial for the next generations?
a) Yes (If your answer is “yes” please explain the benefits)
b) No
c) No idea

21- When you consider negative and positive effects of the HPPS, do you think that should HPPs be supported by government?
a) Yes
b) No
c) No idea

In today’s conditions 70% of the consumed energy is imported from other countries and every year energy demand increase 7%. In order to meet this demand government develops an energy strategy that depends on native and renewable energy sources. By this way energy will be generated with lower cost and also renewable resources will be exploited. Therefore cancelling HPP projects will result with use of other energy sources and increase in energy generation costs. Accordingly electricity utility bills’ prices will increase.

22- When you consider the conditions explained above, will you be volunteer for canceling of HPP projects and increase in electricity utility bills?

a) Yes

b) No

c) No idea

23- If your answer is "yes" for the question 22, what percentage increase would you be volunteer?

____

APPENDIX D

SURVEY 2

Dear Sir/Madam,

I need expert opinion on my master thesis which I am currently pursuing in Environmental Engineering Department of Middle East Technical University. In the thesis, I am developing a method that analyses the effects of run-of-river hydropower plants on environment and society. With this method, it is aimed that whether the regions with high hydropower potential are suitable for constructing plants with respect to environmental and social criteria.

There are 6 criteria chosen as a result of extensive literature research. However; in order to determine the importance of criteria, your expert opinion is highly needed. For the criteria given in the table, you can rate their importance considering the impact of hydropower plants on environment and society. Survey results will be used for scientific purposes and your personal info will be kept confidential. Thank you for your time.

Best regards,

Pelin TEMEL AYDOĞDU

Graduate School Student

Environmental Engineering Department of METU

NOTE: You can contact pelin.temel@metu.edu.tr for any question about the survey.

EXAMPLE:

1) How important is *landslide sensitivity of the region* for construction of hydropower plants?
2) How important is *terrorist attack risk* for construction of hydropower plants?

If your answers are "*Low*" for Question 1 and "*Medium*" for Question 2, you can mark the importance of the criterion as given below:

Risk Criterion	**Low**	**Medium**	**High**	**Very High**
Landslide	X			
Terrorism		X		

YOUR INSTITUTION:

a) Public **b) Private (Consultancy)** **c) University** **d) Others**

YOUR INTEREST AREAS:

Please rate the importance of risk criteria below for construction of hydropower plants.

Risk Criterion	Low	Medium	High	Very High	Comment
Landslide					
Earthquake					
Public perception					
Flow rate alteration					
Distance from the nearest environmentally sensitive area					
Terrorism					

Table D-1 Results of the Survey

Participant No.	Landslide	Earthquake	Public Perception	Flow Rate Alteration	Dist. from Sensitive Area	Terrorism
1	4	3	2	1	1	1
2	4	3	2	3	1	3
3	2	2	2	1	2	1
4	4	4	3	4	3	1
5	3	4	3	4	3	2
6	2	3	2	2	1	2
7	4	2	1	4	4	2
8	2	2	3	4	4	2
9	2	2	3	4	3	2
10	2	2	2	2	1	2
11	3	2	4	2	3	3
12	2	3	2	3	1	2
13	4	3	3	3	3	3
14	1	2	3	3	2	2

Table D-1 (continued)

Participant No.	Landslide	Earthquake	Public Perception	Flow Rate Alteration	Dist. from Sensitive Area	Terrorism
15	2	2	3	4	3	2
16	4	4	2	3	2	3
17	3	4	1	4	4	1
18	2	1	1	4	1	1
19	3	3	4	4	1	3
20	2	2	1	2	2	3
21	4	4	3	1	1	3
22	2	3	3	1	2	3
23	3	1	1	2	2	1
24	3	3	3	4	4	3
25	3	1	1	3	3	1
26	4	4	3	3	3	3
27	2	3	4	4	4	3
28	2	3	3	4	2	2

Table D-1 (continued)

Participant No.	**Landslide**	**Earthquake**	**Public Perception**	**Flow Rate Alteration**	**Dist. from Sensitive Area**	**Terrorism**
29	4	4	3	4	4	3
30	2	3	2	4	2	2
31	4	4	2	3	1	2
32	4	4	2	3	3	3
33	4	4	4	4	2	3
34	2	2	4	4	4	2
35	4	4	4	4	4	4
36	4	3	4	4	2	1
37	2	2	4	4	2	1
38	3	3	4	4	2	1
39	2	3	4	4	3	1

APPENDIX E

CALLCULATIONS

<u>Calculations of Set of All Criteria of Gana HPP</u>

Table E-1 Membership Summary of Gana HPP

Criteria	Membership Grade of Gana HPP
Distance from the Nearest Sensitive Area	1.00
Earthquake	1.00
Flow Rate Alteration	0.33
Destructed Forest Size	1.00
Terrorism	0.56
Public Perception	0.21
Landslide	1.00
Dist. from the Nearest Residential Area	0.14
Population Density	1.00
Number of Downriver Tributaries	1.00

<u>"And" Operator</u>

Acceptability=

$1.00 \cap 1.00 \cap 0.33 \cap 1.00 \cap 0.56 \cap 0.21 \cap 1.00 \cap 0.14 \cap 1.00 \cap 1.00$

⇨ Acceptability= 0,14

“Or” Operator

Acceptability=
$1.00 \cup 1.00 \cup 0.33 \cup 1.00 \cup 0.56 \cup 0.58 \cup 1.00 \cup 0.14 \cup 1.00 \cup 1.00$

⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability= (1x0.01) + (1x0.03) + (1x0.05) + (1x0.07) + (1x0.09) + (1x0.11) + (0.56x0.13) + (0.33x0.15) + (0.21x0.17) + (0.14x0.19)

⇨ Acceptability= 0.49

Calculations of Set of All Criteria of Meydancık HPP

Table E-2 Membership Summary of Meydancık HPP

Criteria	Membership Grade of Meydancık HPP
Distance from the Nearest Sensitive Area	1.00
Earthquake	1.00
Flow Rate Alteration	0.21
Destructed Forest Size	0
Terrorism	0.56
Public Perception	0.21
Landslide	1.00
Dist. from the Nearest Residential Area	0.26
Population Density	1.00
Number of Downriver Tributaries	1.00

“And” Operator

Acceptability=
$1.00 \cap 1.00 \cap 0.21 \cap 0 \cap 0.56 \cap 0.21 \cap 1.00 \cap 0.26 \cap 1.00 \cap 1.00$

⇨ Acceptability= 0

“Or” Operator

Acceptability=
$1.00 \cup 1.00 \cup 0.21 \cup 0 \cup 0.56 \cup 0.21 \cup 1.00 \cup 0.26 \cup 1.00 \cup 1.00$

⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability= (1x0.01) + (1x0.03) + (1x0.05) + (1x0.07) + (1x0.09) + (0.56x0.11) + (0.26x0.13) + (0.21x0.15) + (0.21x0.17) + (0x0.19)

⇨ Acceptability= 0.41

Calculations of Set of All Criteria of Armutlu HPP

Table E-3 Membership Summary of Armutlu HPP

Criteria	Membership Grade of Armutlu HPP
Distance from the Nearest Sensitive Area	0.77
Earthquake	1.00
Flow Rate Alteration	0.30
Destructed Forest Size	0
Terrorism	0.56
Public Perception	0
Landslide	0
Dist. from the Nearest Residential Area	0.39
Population Density	1.00
Number of Downriver Tributaries	1.00

"And" Operator

Acceptability= $0.77 \cap 1.00 \cap 0.30 \cap 0 \cap 0.56 \cap 0 \cap 0 \cap 0.39 \cap 1.00 \cap 1.00$

⇨ Acceptability= 0

"Or" Operator

Acceptability= $0.77 \cup 1.00 \cup 0.30 \cup 0 \cup 0.56 \cup 0 \cup 0 \cup 0.39 \cup 1.00 \cup 1.00$

⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability= (1x0.01) + (1x0.03) + (1x0.05) + (0.77x0.07) + (0.56x0.09) + (0.39x0.11) + (0.30x0.13) + (0.17x0.15) + (0x0.17) + (0x0.19)

⇨ Acceptability= 0.2

Calculations of Set of All Criteria of Şavşat HPP

Table E-4 Membership Summary of Şavşat HPP

Criteria	Membership Grade of Şavşat HPP
Distance from the Nearest Sensitive Area	0.17
Earthquake	1.00
Flow Rate Alteration	0.16
Destructed Forest Size	0
Terrorism	0.56
Public Perception	0
Landslide	1.00
Dist. from the Nearest Residential Area	0.19
Population Density	1.00
Number of Downriver Tributaries	1.00

"And" Operator

Acceptability= $0.17 \cap 1.00 \cap 0.16 \cap 0 \cap 0.56 \cap 0 \cap 1.00 \cap 0.19 \cap 1.00 \cap 1.00$

⇨ Acceptability= 0

“Or” Operator

Acceptability=
$0.17 \cup 1.00 \cup 0.16 \cup 0 \cup 0.56 \cup 0 \cup 1.00 \cup 0.19 \cup 1.00 \cup 1.00$

- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability= (1x0.01) + (1x0.03) + (1x0.05) + (1x0.07) + (0.56x0.09) + (0.19x0.11) + (0.17x0.13) + (0.16x0.15) + (0x0.17) + (0x0.19)

- ⇨ Acceptability= 0.28

Calculations of Set of Reduced Criteria of Gana HPP

“And” Operator

Acceptability= $1.00 \cap 1.00 \cap 0.33 \cap 0.56 \cap 0.21 \cap 1.00$

- ⇨ Acceptability= 0.21

“Or” Operator

Acceptability= $1.00 \cup 1.00 \cup 0.33 \cup 0.56 \cup 0.21 \cup 1.00$

- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability=
(1x0.03)+(1x0.08)+(1x0.14)+(0.56x0.19)+(0.33x0.25)+(0.21x0.31)

- ⇨ Acceptability= 0.51

Linear Weighted Average (LWA) Operator

Acceptability=
(1x0.15)+(1x0.18)+(0.33x0.20)+(0.56x0.13)+(0.21x0.16)+(1x0.18)

- ⇨ Acceptability= 0.68

Calculations of Set of Reduced Criteria of Meydancık HPP

"And" Operator

Acceptability= 1.00 ⋂ 1.00 ⋂ 0.21 ⋂ 0.56 ⋂ 0.21 ⋂ 1.00

- ⇨ Acceptability= 0.21

"Or" Operator

Acceptability= 1.00 ⋃ 1.00 ⋃ 0.21 ⋃ 0.56 ⋃ 0.21 ⋃ 1.00

- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability=
(1x0.03)+(1x0.08)+(1x0.14)+(0.56x0.19)+(0.21x0.25)+(0.21x0.31)

- ⇨ Acceptability= 0.48

Linear Weighted Average (LWA) Operator

Acceptability=
(1x0.15)+(1x0.18)+(0.21x0.20)+(0.56x0.13)+(0.21x0.16)+(1x0.18)

- ⇨ Acceptability= 0.67

Calculations of Set of Reduced Criteria of Armutlu HPP

"And" Operator

Acceptability= $0.77 \cap 1.00 \cap 0.30 \cap 0.56 \cap 0 \cap 0$

⇨ Acceptability= 0

"Or" Operator

Acceptability= $0.77 \cup 1.00 \cup 0.30 \cup 0.56 \cup 0 \cup 0$

⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability=
(1x0.03)+(0.77x0.08)+(0.56x0.14)+(0.30x0.19)+(0x0.25)+(0x0.31)

⇨ Acceptability= 0.23

Linear Weighted Average (LWA) Operator

Acceptability=
(0.77x0.15)+(1x0.18)+(0.30x0.20)+(0.56x0.13)+(0x0.16)+(0x0.18)

⇨ Acceptability= 0.43

Calculations of Set of Reduced Criteria of Şavşat HPP

"And" Operator

Acceptability= $0.17 \cap 1.00 \cap 0.16 \cap 0.56 \cap 0 \cap 1.00$

⇨ D= 0

"Or" Operator

Acceptability= 0.17 ⋃ 1.00 ⋃ 0.16 ⋃ 0.56 ⋃ 0 ⋃ 1.00

- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

Acceptability=
(1x0.03)+(1x0.08)+(0.56x0.14)+(0.17x0.19)+(0.16x0.25)+(0x0.31)

- ⇨ Acceptability= 0.26

Linear Weighted Average (LWA) Operator

Acceptability=
(0.77x0.15)+(1x0.18)+(0.16x0.20)+(0.56x0.13)+(0x0.16)+(1x0.18)

- ⇨ Acceptability= 0.48

Calculations of Set of Environmental Criteria of Gana HPP

"And" Operator

- ⇨ Acceptability= 1 ⋂ 0.33 ⋂ 1 ⋂ 1
- ⇨ Acceptability= 0.33

"Or" Operator

- ⇨ Acceptability= 1 ⋃ 0.33 ⋃ 1 ⋃ 1
- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

- ⇨ Acceptability = (1x0.06) + (1x0.19) + (1x0.31) + (0.33x0.44)
- ⇨ Acceptability = 0.71

Calculations of Set of Environmental Criteria of Meydancık HPP

“And” Operator

- ⇨ Acceptability= 1 ⋂ 0.21 ⋂ 0 ⋂ 1
- ⇨ Acceptability= 0

“Or” Operator

- ⇨ Acceptability= 1 ⋃ 0.21 ⋃ 0 ⋃ 1
- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

- ⇨ Acceptability = (1x0.06) + (1x0.19) + (0.21x0.31) + (0x0.44)
- ⇨ Acceptability = 0.32

Calculations of Set of Environmental Criteria of Armutlu HPP

“And” Operator

- ⇨ Acceptability= 0.17 ⋂ 0.30 ⋂ 0 ⋂ 1
- ⇨ Acceptability= 0

“Or” Operator

- ⇨ Acceptability= 0.17 ⋃ 0.30 ⋃ 0 ⋃ 1
- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

- ⇨ Acceptability = (1x0.06) + (0.30x0.19) + (0.17x0.31) + (0x0.44)
- ⇨ Acceptability = 0.17

Calculations of Set of Environmental Criteria of Şavşat HPP

"And" Operator

- ⇨ Acceptability= 0.77 ⋂ 0.16 ⋂ 0 ⋂ 1
- ⇨ Acceptability= 0

"Or" Operator

- ⇨ Acceptability= 0.77 ⋃ 0.16 ⋃ 0 ⋃ 1
- ⇨ Acceptability= 1

Ordered Weighted Average (OWA) Operator

- ⇨ Acceptability = (1x0.06) + (0.77x0.19) + (0.16x0.31) + (0x0.44)
- ⇨ Acceptability = 0.26