SOLAR PV POWER PLANT SITE SUITABILITY ASSESSMENT BY GIS-BASED MCDM METHODOLOGY IN BEYPAZARI-ANKARA

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ABSTRACT

SOLAR PV POWER PLANT SITE SUITABILITY ASSESSMENT BY GIS-BASED MCDM METHODOLOGY IN BEYPAZARI-ANKARA

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Energy is the principal requirement of humankind and the major challenging subject is to utilize clean energy sources. Majority of the worldwide energy demand is met by fossil fuels which are finite and will eventually terminate. To provide a sustainable future and handle the growing effects of climate change, clean energy sources are becoming crucial worldwide. Solar energy draws attention due to being one of the most low-priced, infinite and environmentally friendly renewable energy resources.

The purpose of this study is to propose and implement a Geographic Information System (GIS)-based Multi-Criteria Decision Making (MCDM) methodology with a new hybrid approach integrating Analytical Hierarchy Process (AHP)-Fuzzy Ordered Weighted Averaging (OWA) with linguistic quantifier "all" to select priority sites for the solar PV power plant.

Environmental and regulatory objectives together with economic and technical criteria related with solar energy systems are determined through a comprehensive examination of literature, interviews and Turkish legislation. Membership degrees for each grid based on the defined objectives and criteria are calculated according to fuzzy membership functions. Then by the help of AHP, criteria weights are assigned to these membership degrees and aggregated using Fuzzy OWA “all” linguistic quantifier into overall potentials which are used to select priority sites. Finally, to determine the superior areas in terms of efficiency and production potential within the priority sites, solar radiation distribution along the potential sites are prepared as a resultant map of this study. Within the concept of this thesis, the proposed methodology is applied to the study area located within Beypazarı district of Ankara.

Keywords: Geographic Information Systems (GIS), Fuzzy Multi-Criteria Decision Making (MCDM), Analytical Hierarchical Process (AHP), Site Selection, Solar Energy.

ÖZ

CBS TABANLI ÇÖKV METODOLOJİSİ İLE PV GÜNEŞ ENERJİ SANTRAL SAHASI UYGUNLUK DEĞERLENDİRMESİ BEYPAZARI-ANKARA

Dikmeoğlu, Berrak
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Enerji, insanoğlunun temel ihtiyacıdır ve bu kapsamda en zorlayıcı husus temiz enerji kaynaklarından yararlanabilmektir. Dünyadaki enerji talebinin büyük kısmı sınırlı ve sona erecek olan fosil yakıtlarla karşılanmaktadır. Sürdürülebilir bir gelecek sağlamak ve iklim değişikliğinin artan etkileriyle başa çıkmak için temiz enerji kaynakları dünya çapında önem kazanmaktadır. Güneş enerjisi, en düşük fiyatlı, sonsuz ve çevre dostu yenilenebilir enerji kaynaklarından biri olması nedeniyle dikkat çekmektedir.

Bu çalışmanın amacı, güneş enerjisi santrali için öncelikli alanları seçmek üzere Analitik Hiyerarşi Prosesi (AHP)-Bulanık Sıralı Ağırlıklı Ortalama'nın dilsel nicelleştirici "tümü" ile birlikte kullanımını içeren yeni bir hibrit yaklaşımla Coğrafi Bilgi Sistemleri (CBS) tabanlı Bulanık Çok Ölçütlü Karar Verme (ÇÖKV) metodolojisi önermek ve uygulamaktır.

Güneş enerjisi sistemleriyle ilgili ekonomik ve teknik kriterler ile birlikte çevresel ve mevzuatsal hedefler detaylı bir literatür taraması, Türk mevzuatı ve röportajlarla belirlenmiştir. Tanımlanan amaç ve kriterlere dayanarak her bir piksel için üyelik dereceleri, bulanık üyelik fonksiyonlarına göre hesaplanmıştır. Daha sonra AHP yardımıyla, kriterlerin ağırlıkları üyelik derecelerine atanmış ve hibrit AHP-Bulanık Sıralı Ağırlıklı Ortalama'nın dilsel nicelleştirici "tümü" kullanılarak öncelikli alanları seçmek için kullanılan genel potansiyeller belirlenmiştir. Son olarak, öncelikli sahalardaki verimlilik ve üretim potansiyeli açısından üstün alanları belirlemek için, potansiyel sahalardaki güneş ışınımı dağılımı bu çalışmanın sonuç haritası olarak hazırlanmıştır. Tez kapsamında, önerilen metodoloji Ankara'nın Beypazarı ilçesinde bulunan çalışma alanına uygulanmıştır.

Anahtar Kelimeler: Coğrafi Bilgi Sistemleri (CBS), Bulanık Çok Ölçütlü Karar Verme (ÇÖKV), Analitik Hiyerarşi Prosesi (AHP), Alan Seçimi, Güneş Enerjisi.

To my beloved family,

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AHP: Analytical Hierarchical Process

CI: Consistency Index

COP21: Conference of Parties 21

CR: Consistency Ratio

CSP: Concentrating Solar Power

DEM: Digital Elevation Model

GIS: Geographic Information Systems

GW: Giga Watt

IEA: The International Energy Agency

IPCC: Intergovernmental Panel on Climate Change

ISES: International Solar Energy Society

Km: Kilometer

kWh: Kilowatt hour

m: Meter

m^2: Meter square

MCDM: Multi-Criteria Decision Making

MCE: Multi Criteria Evaluation

MJ: Mega Joule

MW: Mega Watt

NASA: National Aeronautics and Space Administration

OECD: The Organisation for Economic Co-operation and Development

OWA: Ordered Weighted Averaging

PSO: Particle Swarm Optimization

PV: Photovoltaic

RE: Renewable Energy

RES: Renewable Energy Sources

RI: Random Index

SWARA: Application of Stepwise Weight Assessment Ratio Analysis

TOPSIS: The Technique for Order of Preference by Similarity to Ideal Solution

UNEP: The United Nations Environment Programme

WASPAS: Weighted Aggregated Sum Product Assessment

WLC: Weighted Linear Combination

WMO: World Meteorological Organization

LIST OF SYMBOLS

SYMBOLS

%: percent

∈: element of

∉: not an element of

⊂: Subset

μ: Mu

α : Alpha

λ: Lambda

CHAPTER 1

INTRODUCTION

Energy is the national resource and principal requirement of humankind and in 21st century major challenging subject is to utilize clean energy sources (Sindhu et al. 2017) and it is crucial for socio-economic progress and enhancement of the life quality (Lee et al., 2015). Energy demand is controlled principally by growth of population, industry, economic development and geographic distribution, while the number of people that could be offered an admissible life standard depends heavily on produced energy's availability, costs and efficiency (Brewer et al., 2015). To meet this energy demand three energy resources that are fossil fuels, nuclear resources and renewable resources are used (Zoghi et al., 2017).

Recently, over eighty percent of the main global energy demand is met by fossil fuels. Globally, primary sources that contribute the total energy consumption can be listed as crude oil with thirty-one percent, coal with twenty-eight percent and natural gas with twenty-two percent respectively. Since, oil reserves are not evenly distributed all around the world, in the future this may cause political and economic crisis. It is obvious that fossil fuels are finite and will eventually terminate in the future. This depletion of fossil fuels will affect the price in a negative manner. Projections reveal that global energy demand will rise by 49% within the next 25 year. The growth of global oil consumption is also predicted to elevate from 86 million barrels per day in 2007 to 104 million barrels per day in 2030 (Uyan, 2013).

Although, majority of the world's energy supply is derived from the fossil fuels, the consumption of this conventional energy give rise to adverse effects to the environment, particularly harming air, water, land, climate, flora, fauna and wildlife. Due to the quick rise of oil and fossil fuel prices, most of the countries forced to develop new policies reducing the energy cost and environmental impact (Lee et al., 2015).

Because of the intense fossil fuel use, modern big-scale farming and land use change, the concentration of greenhouse gases have increased throughout the past 250 years. In addition, ice core data shows the fact that present concentrations of carbon dioxide and methane are greater than any time within the last 650 000 years. Even though fossil fuels are yet abundant, the global warming threat and the increasing consciousness about environmental pollution leads people to explore alternatives, like renewable and clean energy sources (Janke, 2010; Uyan, 2013; Lee et al., 2015).

The Kyoto Protocol, adopted in December 1997, is an international agreement linked to the United Nations Framework Convention on Climate Change and a crucial milestone affording to promote the renewable energy use (Carrion et al., 2007; Tahri et al., 2015). Similar to the Kyoto Protocol, the European Union also adopted the Green Paper. This started the controversy about the actions to be taken, goals to be reached and obstacles to overcome, on renewable energy sources (Carrion et al., 2007).

Likewise, in the 21st conference of the countries committed to climate change convention in Paris climate conference (COP21) in December 2015 the representatives of 195 countries signed a legally binding agreement to determine the environmental status of the earth. In this conference, the principal reason behind the greenhouse gases emission and global warming is considered as the growth of fossil fuels consumptions such as oil and gas (Noorollahi et al., 2016). According to the international commitments to the Conference of Parties 21 (COP21) in Paris, the energy needs to be produced by low-carbon strategies (Suh and Brownson, 2016).

To encourage worldwide supportive policies, the Intergovernmental Panel on Climate Change (IPCC) was founded by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). At the beginning of the 21^{st} century, the Renewable Energy (RE) plant installation was incentivized by sustainable growth action plan to satisfy the miscellaneous energies policies of the European Union (Sánchez-Lozano et al., 2015).

1.1. Renewable Energy

Renewable energies have natural sources that are repeatedly refreshed by nature and obtained directly or indirectly from the sun or from other natural flow and environmental mechanism (Ellabban et al., 2014).

Compared to other energy sources, renewable energy sources (RES) are cleaner sources and have minimal effects on the environment. As it is known, fossil fuel sources of energy are limited and will terminate. On the other hand, renewable energy sources are infinite and will not end. For worldwide energy production, solar and wind power sources are the maximum used ones (Uyan, 2013).

1.1.1. Global Renewable Energy Status

By 2016, renewable energy and modern renewables were representing respectively 18.2% and 10.4% of global gross energy consumption. Similar to the previous years in 2017, the number of countries having targets and supportive policies about renewable energy increased, and some regulations made their targets more assertive. While other renewable sectors grow at a very slow pace, powerful growth retained in the renewable energy sector. Remarkably solar photovoltaic (PV) capacity additions are almost twofold of wind power capacity that is placed in second place. Also, solar photovoltaic (PV) capacity addition is more than that of net capacity of coal, natural gas and nuclear energy merged capacities.

Renewable power generating capacity revealed its greatest yearly rise in 2017 by increasing the total capacity of nearly 9% that is more than that of year 2016. Due to the enhancements in the cost-competitiveness of solar and wind energy, approximately 70% of net adding to worldwide energy capacity in 2017 constituted by renewables. Solar PV formed almost 55% of recently utilized renewable energy capacity in 2017. Compared to the total adding of fossil fuels and nuclear energy, more solar energy capacity was inserted. Most of the remaining capacity adding formed by wind with 29% and hydropower with 11%. Many countries are successfully adding various renewable power to electricity systems in more and more large shares. Nearly six percent of worldwide novel electricity links between 2012 and 2016 are represented by renewable, stand-alone and off-grid single home or mini-grid systems (REN21, 2018).

In global perspective, according to yearly investment, net capacity increase and production in 2017 leading 5 countries listed based on various renewable energy sources are presented in Table 1.1. Turkey's rank among the top 5 countries based on geothermal power, hydropower, solar PV and solar water heating capacity respectively as 2nd, 5th, 5th and 2nd.

Table 1.1. Annual Investment /Net Capacity Additions /Production in 2017 (REN21, 2018)

	1	2	3	4	5
Investment in renewable power and fuels (not including hydro over 50 MW)	**China**	United States	Japan	India	Germany
Investment in renewable power and fuels per unit GDP[1]	**Marshall Islands**	Rwanda	Solomon Islands	Guinea-Bissau	Serbia
Geothermal power capacity	**Indonesia**	Turkey	Chile	Iceland	Honduras
Hydropower capacity	**China**	Brazil	India	Angola	Turkey
Solar PV capacity	**China**	United States	India	Japan	Turkey
Concentrating solar thermal power (CSP) capacity[2]	**South Africa**	-	-	-	-
Wind power capacity	**China**	United States	Germany	United Kingdom	India
Solar water heating capacity	**China**	Turkey	India	Brazil	United States
Biodiesel production	**United States**	Brazil	Germany	Argentina	Indonesia
Ethanol production	**United States**	Brazil	China	Canada	Thailand

[1] Countries considered include only those covered by Bloomberg New Energy Finance (BNEF); GDP (at purchasers' prices) data for 2016 from World Bank. BNEF data include the following: all biomass, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects with those less than 1 MW (small-scale capacity) estimated separately; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more. Small-scale capacity data used to help calculate investment per unit of GDP cover only those countries investing USD 200 million or more. [2] Only one country brought CSP capacity online in 2017, which is why no countries are listed in places 2, 3, 4 and 5.

The United Nations Sustainable Development Goals are designed to reach higher quality and more sustainable future for everyone. In order to overcome global challenges, that are poverty, inequality, climate, environmental degradation, prosperity, and peace and justice, seventeen goals were determined by the UN and these goals will be tried to be achieved till 2030. In this context, the 7th target is determined as affordable and clean energy (The United Nations [UN], n.d.).

1.1.2. Renewable Energy Status in Turkey

Turkey has a young and increasing population, in recent years is one of the quickest growing energy markets in the world with its low per capita electricity usage, rapid urbanization, and economic development (Toklu, 2013).

The electricity power demand in Turkey is predicted to be 573 billion kWh until the year 2020 and 760 billion kWh until the year 2030. Because of rapid economic growth, the electric power demand of Turkey is expanding around 4-6% annually. 75% of Turkey's total main energy consumption dominate by imported fossil fuels. Nevertheless, one of the government's priorities is to raise the percentage of renewable energy resources to 30 % of total energy production until 2023.

As presented in Table 1.2, at the end of 2017 Turkey had 85.2 GW of established electricity production capacity.

Table 1.2. Partitioning of established capacity in Turkey by energy resources in 2016 and 2017 (Kaygusuz and Avci, 2018)

Power resources	Installed capacity (MW)(2016)	Installed capacity (MW)(2017)	Added Capacity (MW)(2016-2017)	Increase (%) (2016-2017)
Thermal power plants	44,411.7	46,926.5	2,514.8	5.7
Hydroelectric	26,681.1	27,273.1	592	2.2
Wind	5,751.3	6,516.2	764.9	13.3
Solar PV	832.5	3,420.7	2,588.2	310.9
Geothermal	820.9	1,063.7	242.8	29.6
Total	78,497.5	85,200.2	6,207.7	8.5

The percentages according to the electricity production sources are listed as follows: 55.08% for fossil fuels, 32.01% for hydro, 7.65% for wind, 4.01% for solar and 1.25% for geothermal (Kaygusuz and Avci, 2018).

Turkey has a significantly elevated amount of renewable energy potential especially in hydraulic, solar and wind energy. On account of averting the risks emerging due to the elevated grade of energy dependence and to develop a model for sustainable energy in our country, the issue of turning towards renewable energy resources is of particular importance. Therefore, Turkey should improve its energy self-sufficiency by managing its strong renewable energy potential (Kaygusuz and Avci, 2018).

1.2. Solar Energy

Sun is a clean, copious, and free source of energy that can compensate increasing energy use in both developed and developing countries. Without environmental contamination and effects on climate change, solar energy utilization provides social and economic welfare (Doljak and Stanojević, 2017).

To provide a sustainable future and handle the rising effects of global warming and climate change, clean technologies are becoming crucial worldwide (Sharma et al., 2012; Mahtta et al.., 2014). Since 99.8% of world energy derives from the Sun, solar energy is one of the most low-priced, clean and infinite renewable energy resources. Solar energy is used to encure heat, hot water, electricity, and even cooling. If only 0.1% of the world solar energy could be transformed to electric energy with ten percent efficiency rate, 3000 GW of energy will be produced, that is four times higher than the global annual power consumption (Zoghi et al., 2017).

Solar energy is the economically feasible option within renewables for big scale energy production (Bradford, 2006). Sun is the lasting energy source (Sorensen, 2004) and the two main types of solar energy, that are light and heat, constantly convert into remaining renewables. Curiously, solar power amount hitting the surface of Earth is six thousand times the existing global energy use and most of it remains unused (Mahtta et al., 2014).

1.2.1. Solar Energy Technologies

Considering their continuously rising production performance and capability to be used in various places, solar technologies are highly promising renewable resources. The fundamental characteristics of solar energy make it advantageous, particularly for developing countries, for many causes: Firstly, most developing countries are sited in zones with ideal access to solar radiation. Secondly, the majority of the present fossil fuel and energy sources could merely be consumed by exploiting the ecosystem and that causes social decline. Thirdly, increasing worldwide independency of fossil fuels rising the demand for solar technology and foster the enhancement of necessary studies, in this way reduces related costs. Fourthly, solar technologies are comparatively low-priced and convenient to both houses and settlements, and more solar power than ever before are used by residents of industrialized countries. Finally, among solar technologies, stationary solar designs can be excelled by combined with solar panels to obtain the highest comfort and sustainability when renewable energy for buildings considered. Solar energy can be transformed into electrical power by the help of different currently available technologies namely photovoltaic panels, concentrating solar thermal power, and concentrating photovoltaics (Devabhaktuni et al., 2013).

1.2.1.1. Solar Photovoltaic (PV) Panels

Solar PV panels are solid semiconductive instruments that transform the sun's rays into direct current electricity. Materials utilized on solar PV modules are monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, copper indium selenide, and cadmium telluride (Razykov et al., 2011). Solar PV manufacturing has been doubled up in every two years, growing with a mean of 48% every year from 2002, this makes solar PV the world's rapid-growing energy technology. Grid-connected PV electrical systems consist approximately 90% of the energy generating capacity. Photovoltaics can be ground-mounted or be integrated into the buildings as roof-mounted or wall-mounted (Devabhaktuni et al., 2013). Solar PV installations have been supported by incentives in many countries.

1.2.1.2. Global Status of Solar PV

In electricity generation, solar PV are playing an ever more significant role. Solar PV was the foremost source of new energy producing capacity in 2017, with more solar PV capacity installed worldwide than the net addition of fossil fuels and nuclear energy combined. Reasons lay behind global market growth can be listed as rising competitiveness of solar PV, increasing electricity demand in developing countries, increasing recognition of the potential of technology to reduce pollution, decrease carbon emissions and ensure energy accession. Worldwide renewable energy and fuels investment in 2017 totaled 279.8 billion US dollars almost the whole investment was composed of solar and wind energy. Solar PV composing nearly 55% of recently established renewable energy capacity. Due to new renewable energy installations dominated by solar PV, solar photovoltaics was once more the biggest employer. Supportively, global employment in solar PV was calculated as 3.4 million jobs in 2017 and the amount of employment was 9% higher than in 2016 (REN21, 2018).

1.2.1.3. Solar PV Status in Turkey

To begin with, Turkey is placed in a sunny belt between 36°C and 42°N latitudes, having a rich solar energy resource. Therefore, a considerable part of Turkey is convenient for solar power utilization. Turkey has a solar energy potential equivalent of 1.3 billion tons of oil. The amount of annual average total solar radiation varies from 1120 kWh/m^2 per year with 1971 sunshine hours in the Black Sea Region to 1460 kWh/m^2 per year with 2993 sunshine hours in the South East Anatolia (Toklu, 2013).

The yearly solar power potential of Turkey is considered to be 1015 kWh, which is 5700 times higher than the current electricity usage. Turkey gets an elevated level of solar radiation throughout the year with average daily sunshine duration about 7.5 h and solar energy intensity of 12.96 MJ/m^2.day. Solar potential of Turkey (Figure 1.1) without technical, economic or environmental constraints is predicted at 90 million tons of oil equivalent (Mtoe) per year (Kaygusuz and Avci, 2018).

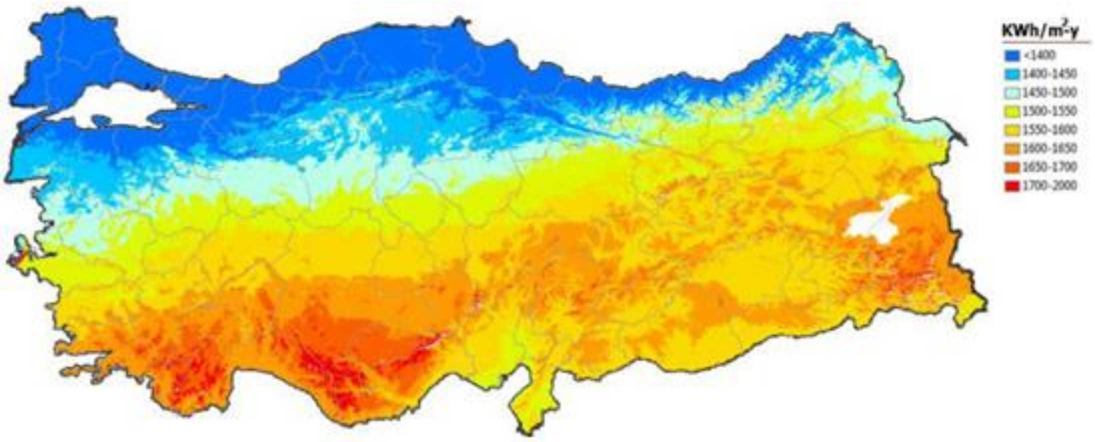


Figure 1.1. Solar Energy Potential in Turkey (Kaygusuz and Avci, 2018)

Solar energy potential in Turkey is revealed in Figure 1.1. In accordance with the solar energy potential atlas of Turkey prepared by the Ministry of Energy and Natural Resources, annual sunshine duration of 2741 hours (7.5 hours per day), the annual total incoming solar energy 1527 kWh/m².year (daily average of 4.18 kWh/m².day) was as calculated (Kaygusuz and Avci, 2018).

In 2018, the number of solar energy power plant in operation is 5868 and total installed solar power capacity has reached 5063 MW with 4981,2 MW of unlicensed and 81,8 MW licensed capacity. Moreover, the share of solar energy in whole electricity generation in Turkey has also raised to 2.5% with 7477.3 GWh (MENR, 2018).

Total solar energy generation of 0.465 Mtoe in 2008 elevated to 0.827 Mtoe in 2016, reached 0.877 Mtoe as of 2018 and is projected to increase to 5.5 Mtoe (5.5% of primary energy production) by 2025 (Kaygusuz and Avci, 2018; MENR, 2018).

1.2.2. Turkey Solar Energy Potential Atlas

Solar energy resources potential determination studies for Turkey were conducted by abolished General Directorate of Electrical Power Resources Survey and Development Administration. In this context, General Directorate of Electrical Power Resources Survey and Development Administration and Turkish State

Meteorological Service stations with 22-year solar measurement values obtained from 1985 to 2006 and three-dimensional digital terrain model were used to run "ESRI Solar Radiation Model" to prepare Turkey Solar Energy Potential Atlas. The model calculated the solar radiation values containing monthly averages obtained from the daily values of 12 months with 500 * 500 m resolution and mapped with geographic information system techniques. Measuring devices located inside the cities, aperiodic calibrations and using the old type of measuring devices for solar radiation measurements caused calculated solar energy potential values to be lower than the actual values. Therefore, up to 15% errors can occur in the measurements (Erkeç, 2016).

1.2.3. Environmental Impacts of Solar Energy

All methods for energy production and transmission have impacts on environment. Solar energy has a vital role to provide energy security while dealing with environmental concerns in developing countries (Mahtta et al., 2014). Solar energy technologies offer clear environmental benefits in comparison to conventional energy resources, in this way contributes the sustainable development (Tsoutsos, 2005). Within entire clean technologies, solar energy serves as the most powerful RES to reduce greenhouse gas emissions and global warming (Ramachandra et al., 2011). Similarly, solar photovoltaic (PV) seems very appealing for electricity generation among several solar energy technologies, since it is noise-free, has no carbon-dioxide emission along operational phase, is flexible in terms of scale and has quite an easy operation and maintenance (Dinçer, 2011).

Environmental impacts of solar energy can come out at various rates along the lifetime, varying between 25 and 40 years, during construction, operation, and decommission phases of a solar energy plant (Hernandez et al., 2014).

The effects of land use on ecosystems depend on particular factors like landscape topography, the area covered by solar PV, type of the land, distance from natural protection zones or sensitive ecosystems. The impacts and alteration on the landscape are likely to arise throughout the construction phase (Tsoutsos, 2005).

In the course of standard operation, solar PV systems spread no gas or liquid pollutants, and no radioactive materials. In the case of some special panels including minor amount of toxic materials, have a potential small risk that a fire in an array might result in small quantities of these substances to be released into the environment (Various, 1996). In big-scale facilities, hazardous materials release could cause a slight risk to public and occupational health may happen because of abnormal plant operations. Because of inappropriate storage of material, emissions to soil and groundwater may occur (OECD/IEA, 1998). In order to avert environmental pollution caused by toxic chemicals include within the cells, PV cells may be recycled during the decomposition phase (Hernandez et al., 2014).

Visual impact extremely depends on the type of design and the PV plant surroundings. It is clear that, the visual impact will be remarkably high in the case of PV plant installation near natural protection areas. Building mounted modules may have an affirmative aesthetic effect on modern buildings compared to historic ones having cultural importance. PV production is energy requiring and great amounts of bulk materials are needed. Moreover, little amount of scarce materials (In/Te/Ga) together with restricted amount of the toxic Cd are required (Tsoutsos, 2005).

The emissions due to modules transportation are negligible compared to those related to manufacturing. Transport-based emissions are yet only 0.1– 1% of manufacturing-based ones (OECD/IEA, 1998).

Throughout the operation, solar cells do not produce noise. However, for the duration of the construction phase, there will be a little noise as expected in other construction activities. Furthermore, during the construction phase and along the operation particularly for large-scale projects, some employment benefits exist (Tsoutsos, 2005).

1.3. Problem Definition

In future energy plans, many countries tend to move towards Renewable Energy Systems (RES) to minimize the unfavourable impacts of conventional fossil energy sources on the environment. Although the policy of renewable energy in Turkey is quite young, in this context it is intended to lay down strategic aims for renewable energy implementations. First Turkish law on RES utilization for electrical power production was approved on the 18th of May in 2005. After mentioned law enacted, particular regulations were published and some revisions have been done as the time passes. Regulations enforce the support mechanism of renewable energy which comprises the varied incentives supplied in the Renewable Energy Law.

Renewable targets for Turkey stated in the Energy Strategy Paper are; 30% of the entire electricity generation from renewables till 2023, the entire ready for use hydropower potential of Turkey will be used for producing electrical power till 2023, 600 MW geothermal power will be supplied by 2023, and 20,000 MW wind energy is aimed to be in operation in 2023 (Saygin and Cetin, 2011; MENR, 2010). Concordantly, listed items are the principal priorities in Turkey's energy policy:

- Promoting national equipment manufacturing for wind terminals, and solar energy panels.
- Supplying variety of resources by paying importance to national resources hereby promoting national markets.
- Promoting usage of solar energy (ratio for solar power is aimed to reach 37 % by 2100).
- The growing demand on renewables.
- Supplying source variety in natural gas and oil and making provisions to reduce risks depend on imports.
- Running energy activities taking environmental concerns into account.
- Presenting Turkey as an energy passageway and a significant station.
- Enhancing energy yield.

- Supplying energy to consumers with a low-cost, timely and satisfying the demand.
- Enhancing the investment opportunity and promoting free market strategy.

Whole priorities mentioned have been fostered by various legislation and incentives. As well as the incentives, some alterations or reconstructions of legislation related with the environmental subject are necessary to reduce the environmental impacts of renewable energy implementations.

It must be well understood that the application of wind and solar for energy generation is not only relying on the climatic conditions but also on the present level of technology and various other limiting factors such as geographic, economic, technical, regulatory, and social aspects. The theoretic potential, particularly with respect to solar radiation, of Turkey is evaluated at a superior level and limitless, even in terms of the energy need. Therefore the comprehensive investigation is necessary for the utilization of innovative technology.

Conventional systems for energy production have harmful impacts on environment and renewables could be the answer to these problems; despite that, it is unlikely not to impact the environment during the power generation (Tsoutsos et al., 2005). That is to say, somewhat, every renewable energy system has unwanted impacts on the environment but these impacts are significantly tolerable compared to those of conventional energy systems. Because Renewable Energy Systems can create various environmental impacts, that are generally associated with the geographic position of these plants, before implementing these systems detailed analyses must be performed to identify the ideal sites associating with maximum energy production potential and minimum environmental impact.

1.4. Literature Survey

To consult, examine and edit the data, map or any spatial information Geographic Information System (GIS) is a strong tool. Therefore, GIS is becoming gradually more popular for site selection studies in recent years. Determination of the ideal site for a solar energy plant can be improved by building up a decision support model which combines Geographic Information System with multi criteria. Site selection can be affected by several criteria and application of multi criteria decision making (MCDM) methods can ease the selection of ideal site for solar PV plants by taking the principal factors into consideration.

One of the multicriteria approaches that GIS-MCDM has focused is the Analytic Hierarchy Process (AHP), which was introduced by Saaty in 1980, one of the most effective tools to deal with complicated decision making, and assisting the decision maker to determine preferences and to obtain the best decision (Jankowski, 1995). To handle inaccuracy and reduce the bias, AHP is controlled the consistency of the decision maker's evaluations. AHP reduces the complexity by using pairwise comparisons and deal with both subjective and objective parts of a decision. Besides the stand-alone use of the AHP method, integration with MCDM methods also exists (Al Garni and Awasthi, 2018).

Although MCDM is successfully used in different data, it is still not completely matched with uncertain and deficient information. Due to the flexible and dynamic character of MCDM, in order to strengthen the decision theory, fuzzy sets theory is introduced to struggle with problems that could not be solved with MCDM technique (Abdullah, 2013).

Fuzzy methods are preferred for criteria or objectives not having sharply defined boundaries since they can be described by fuzzy sets (Zadeh, 1965). In fuzzy set theory, membership function let to define degrees of satisfaction or membership for each alternative according to the fuzzy criteria. For site selection, individual satisfaction degrees of each criterion are calculated for each alternative. And then those individual satisfaction degrees are aggregated into overall satisfaction degree that can be used for comparison of alternatives. In decision making depends on the combination of fuzzy criteria and fuzzy constraints, highest membership grade provides the best alternative.

Previously mentioned aggregation process of each individual satisfaction degrees to an overall satisfaction degree helps to facilitate the decision making. For this purpose most widely used operators for aggregation are; the intersection operation which is described as the minimum of the two individual membership functions this operation requires satisfaction of all of the criteria in Fuzzy set theory and it is equal to the AND operation in Boolean algebra while the union operation is described as the maximum of the two individual membership functions this operation requires satisfaction of any of the criteria in Fuzzy set theory and it is equal to the OR operation in Boolean algebra. However, in the cases requiring a large set of evaluation criteria, conventional OWA operators have limited applicability (Yager, 1996). Decision makers could need satisfaction like most, many, half, some or a few of the criteria in real world problems. In this kind of situations, the primary aspects of the decision problem likely to be defined by means of fuzzy linguistic quantifiers such as all, most, many, half or at least 80% of the criteria must be satisfied, etc. (Malczewski, 2006). This reveals that an enhancement of the conventional OWA is needed thereby it could fit situations including qualitative expressions in the form of fuzzy quantifiers (Yager, 1988, 1996). Consequently, in this thesis, Fuzzy, AHP and OWA linguistic quantifier “all” are applied for the decision making process of solar PV power plant site selection.

1.4.1. Previous Studies

In this part, previously published conference proceedings, journal papers and theses within time interval 2007 and 2019 are reviewed. Table 1.3 sum up the studies related to solar PV site selection. As it is seen in Table 1.3 the GIS-AHP applications are within the most frequently used methods for combining AHP with other decision support techniques. Pure AHP studies accounted for 9 of 57 studies and 16% of all studies. Similarly, other AHP integrated methods were 9 in 57 studies and 16% of all studies.

Table 1.3. Previous Studies Related to Solar Photovoltaic (PV) Site Selection (modified form Al Garni and Awasthi, 2018)

No	References	Applied Technique	Renewable Energy Sources	Location
1	(Effat, 2013)	AHP	PV	Ismailia, Egypt
2	(Uyan, 2013)	AHP	Solar farms	Konya, Turkey
3	(Watson and Hudson, 2015)	AHP	PV-Wind	South, United Kingdom
4	(Rumbayan and Nagasaka, 2012)	AHP	Solar-wind-geothermal	Indonesia
5	(Tahri et al., 2015)	AHP	PV	South, Morocco
6	(Yunna and Geng, 2014)	AHP	Solar-wind	China
7	(Doljak and Stanojevic, 2017)	AHP	PV	Serbia
8	(Aran Carrion et al., 2008)	AHP	PV	Andalusia, Spain
9	(Noorollahi et al., 2016)	FAHP	PV	Iran
10	(Suh and Brownson, 2016)	FAHP	PV	Ulleung, Korea
11	(Sa´nchez-Lozano et al., 2013)	AHP-TOPSIS	PV	Cartagena, Spain
12	(Charabi and Gastli, 2011)	AHP-Fuzzy OWA	PV	Oman
13	(Sindhu et al., 2017)	AHP-Fuzzy TOPSIS	PV	India
14	(Zoghi et al., 2015)	AHP-Fuzzy-WLC	Solar farms	Isfahan, Iran
15	(Lee et al., 2015)	FAHP-DEA	PV	Taiwan
16	(Sanchez-Lozano et al., 2014)	ELECTRE	PV	Murcia, Spain
17	(Jun et al., 2014)	ELECTRE-II	PV-Wind	China
18	(Fernandez-Jimenez et al, 2015)	Fuzzy-distance decay	PV	La Rioja, Spain
19	(Aydin et a., 2013)	Fuzzy OWA	PV-Wind	West, Turkey
20	(Liu et al., 2017)	Grey Cumulative	PV	Northwest, China
21	(El-azab and Amin, 2015)	Transmitted Energy	Solar farms	MENA
22	(Lee et al., 2017)	Fuzzy ANP and VIKOR	PV	Taiwan
23	(Jain et al., 2011)	Simulation scenarios	PV	India
24	(Wu et al., 2013)	Matter-Element	PV-Wind	China
25	(Vafaeipour et al., 2014)	SWARA-WASPAS	Solar farms	Iran
26	(Chen et al., 2014)	DEMATEL-DANP	Solar farms	China
27	(Sun et al., 2013)	Geospatial supply	PV	Fujian, China
28	(Boran et al., 2010)	Axiomatic design	PV	Turkey
29	(Gomez et al., 2010)	Binary PSO	PV	Jaen, Spain
30	(Brewer et al., 2015)	WLC	PV	Southwest, USA
31	(Perpin˜a Castillo et al., 2016)	WLC	PV	EU-28
32	(Janke, 2010)	WLC	PV-Wind	Colorado, USA
33	(Anwarzai and Nagasaka, 2017)	WLC	PV-CSP-Wind	Afghanistan

34	(Sabo et al., 2017)	Generation-demand	PV	Malaysia
35	(Niblick and Landis, 2016)	GIS-Join	PV-Wind-Biomass	United States
36	(gherboudj and Ghedira, 2016)	GIS-Join	Solar farms	United Arab Emirates
37	(Mentis et al., 2015)	GIS-Near	Solar-wind-hydro diesel	Nigeria
38	(Khan and Rathi, 2014)	GIS-Intersect	PV	Rajasthan, India
39	(Alami Merrouni et al., 2014)	GIS-Overlay	PV	East of Morocco
40	(Wang et al., 2016)	GIS-Overlay	PV	Tibet, China
41	(Calvert and Mabee, 2015)	GIS-Overlay	PV-Bioenergy	Ontario, Canada
42	(Massimo et al., 2014)	GIS-Overlay	Solar	Frosinone, Italy
43	(Arnette and Zobel, 2011)	GIS-Multiply	PV-wind-biomass	Appalachian Mountains, United States
44	(Gormally et al., 2012)	GIS-Overlay	PV-wind-hydro-bioenergy	Cumbria, United Kingdom
45	(Borgogno et al., 2014)	ANN	PV	Italy
46	(Rumbayan et al., 2012)	ANN	Solar farms	Indonesia
47	(Besarati et al., 2013)	RETScreen-Solar irradiation	Solar farms	Iran
48	(Chakraborty et al., 2014)	NASA-Solar irradiation	PV	India
49	(Polo et al., 2015)	GIS-Solar irradiation	Solar farms	Vietnam
50	(Sliz-Szkliniarz, 2013)	GIS-Solar irradiation	Solar-Wind-Biomass	Kujawsko, Poland
51	(Mahtta et al., 2014)	GIS-Solar irradiation	PV-CSP	India
52	(Belmonte et al., 2009)	GIS-Solar irradiation	Solar-Wind-Biomass-Hydro	Salta, Argentina
53	(Carrio´n et al., 2008)	GIS-Solar irradiation	PV	Andalusia, Spain
54	(Martins et al., 2007)	GIS-Solar irradiation	Solar farms	Brazil
55	(Akçay and Atak, 2018)	AHP-TOPSIS	Solar farms	Turkey
56	(Rangel et al., 2017)	AHP	Solar farms	North of Rio de Janeiro State
57	(Izeiroski and Idrizi, 2018)	GIS-WLC	Solar-Hydro	Prespa Lake Region in Macedonia

AHP, analytical hierarchy process; ELECTRE, elimination and choice translating reality; FAHP, fuzzy analytical hierarchy process; GIS, geographical information system; TOPSIS, Technique for order preference by similarity to ideal solution; WLC, weighted linear combination.

1.5. Purpose and Scope

The purpose of this study is to propose and implement Geographic Information System-based Multi-Criteria Decision Making methodology with a new hybrid approach integrating AHP-Fuzzy OWA with linguistic quantifier “all” to select priority sites, associating with highest energy production potential and at the same time environmentally favorable areas, for the solar PV power plant.

Environmental and regulatory objectives and economic and technical criteria associated with solar PV power plants are determined through a detailed examination of literature, interviews with both General Directorate of Electrical Power Resources Survey and Development and International Solar Energy Society (ISES) – Turkey division (GÜNDER) and Turkish laws, legislation and regulations.

Membership degrees for each grid based on the defined objectives and criteria are calculated according to fuzzy membership functions. Then by the help of AHP, criteria weights are assigned these membership degrees and aggregated using Fuzzy OWA “all” linguistic quantifier into overall potentials which are used to select priority sites. Finally, to determine the superior areas in terms of efficiency and production potential within the priority sites, solar radiation distribution along potential sites are prepared as a resultant map of this study. Within the concept of thesis, the proposed methodology is applied to a study area in H27-c sheet located (center coordinates: 40.124023-31.874637) within Beypazarı district of Ankara. H27-c sheet was chosen as the study area because it contains almost all the criteria used in previous studies and is an area where all these criteria can be tested.

CHAPTER 2

METHODOLOGY

The methodology of this study is described in detail for the site selection technique proposed to determine the ideal solar power plant site. The flowchart for the proposed site selection methodologies are presented below in Figure 2.1.

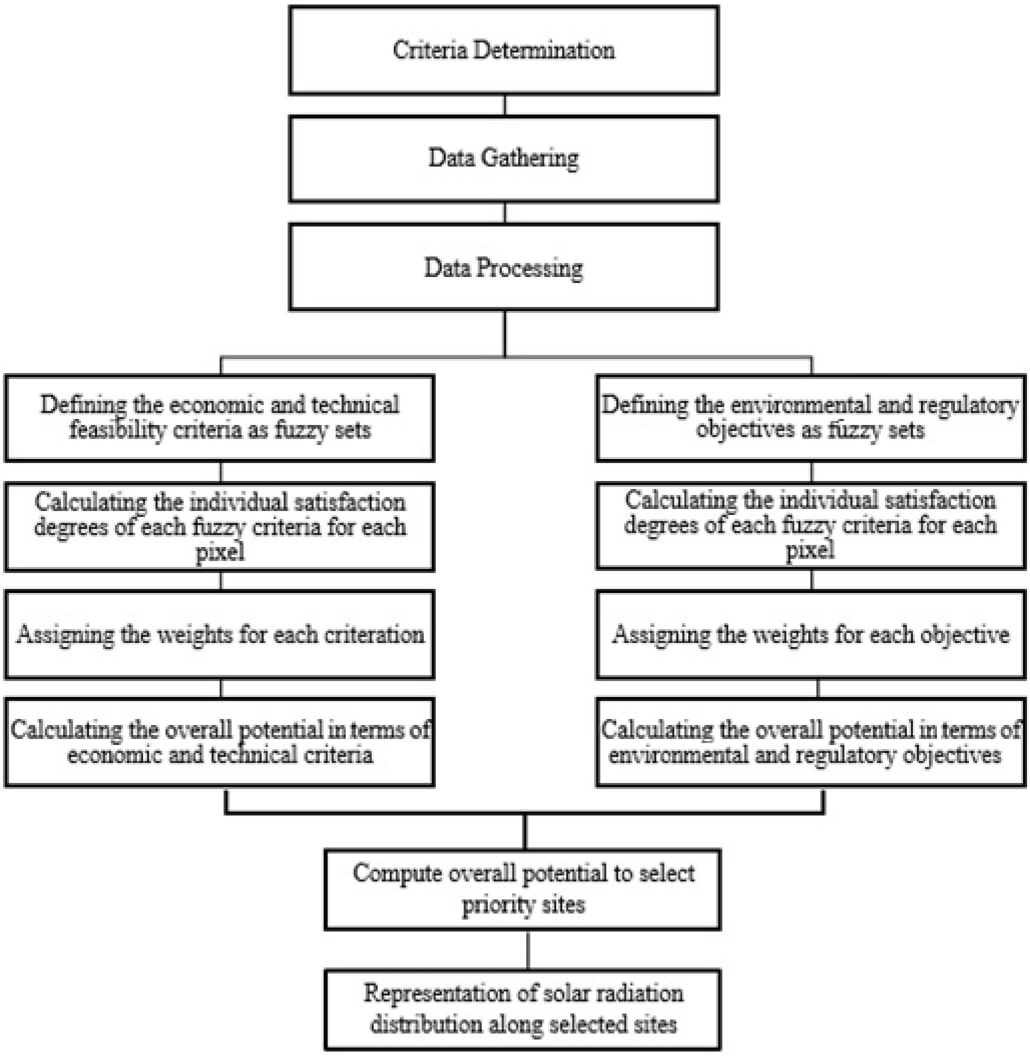


Figure 2.1. Methodology of site selection for solar PV power plants

To begin with, environmental and regulatory objectives together with economic and technical feasibility criteria are identified. Secondly, environmental and regulatory objectives and economic and technical feasibility criteria related data are gathered and by the help of ArcGIS software collected data are processed. The following step is to define fuzzy membership functions of environmental and regulatory objectives as well as economic and technical feasibility criteria. Later on, according to defined membership functions of these fuzzy sets, individual satisfaction degrees for each objective and criteria are calculated pixel-wise. Then, weights are assigned for each criterion by the aid of the Analytical Hierarchy Process (AHP). Afterwards, by using Fuzzy Ordered Weighted Averaging (OWA) MCDM methodology, which is an operation to dealing with the problem of aggregating multicriteria to form an overall decision, with “all” linguistic quantifier, that is corresponding the satisfaction of all the criteria, overall potentials are calculated in terms of environmental and regulatory objectives and with respect to economic and technical feasibility criteria. Subsequently, to determine the priority sites for solar PV installations overall potentials in terms of both objectives (environmental and regulatory) and criteria (economic and technical) are aggregated. Finally, solar radiation distribution along potential solar PV plant areas are revealed to identify the superior areas in terms of efficiency and production potential within the selected PV sites.

2.1. Study Area

In this thesis, H27-c sheet (center coordinates: 40.124023-31.874637) within the boundaries of Beypazarı district of Ankara province is chosen as the study area because it contains almost all the criteria to be used in the proposed site selection methodology of the solar PV power plant area (Figure 2.2).

The study area is split into 100 * 100 m grids and every single grid represents an alternative solar power plant site. The one-hectare area is needed both for ground mounted PV plant having 0.5 MW capacity and solar tracker PV plant with 1MW capacity (García-Garrido, 2012). For this reason, in order to obtain this 10000 m^2

area and to evaluate every single cell of the map as a possible PV plant site, raster cell size in this study was selected as 100*100 metres.

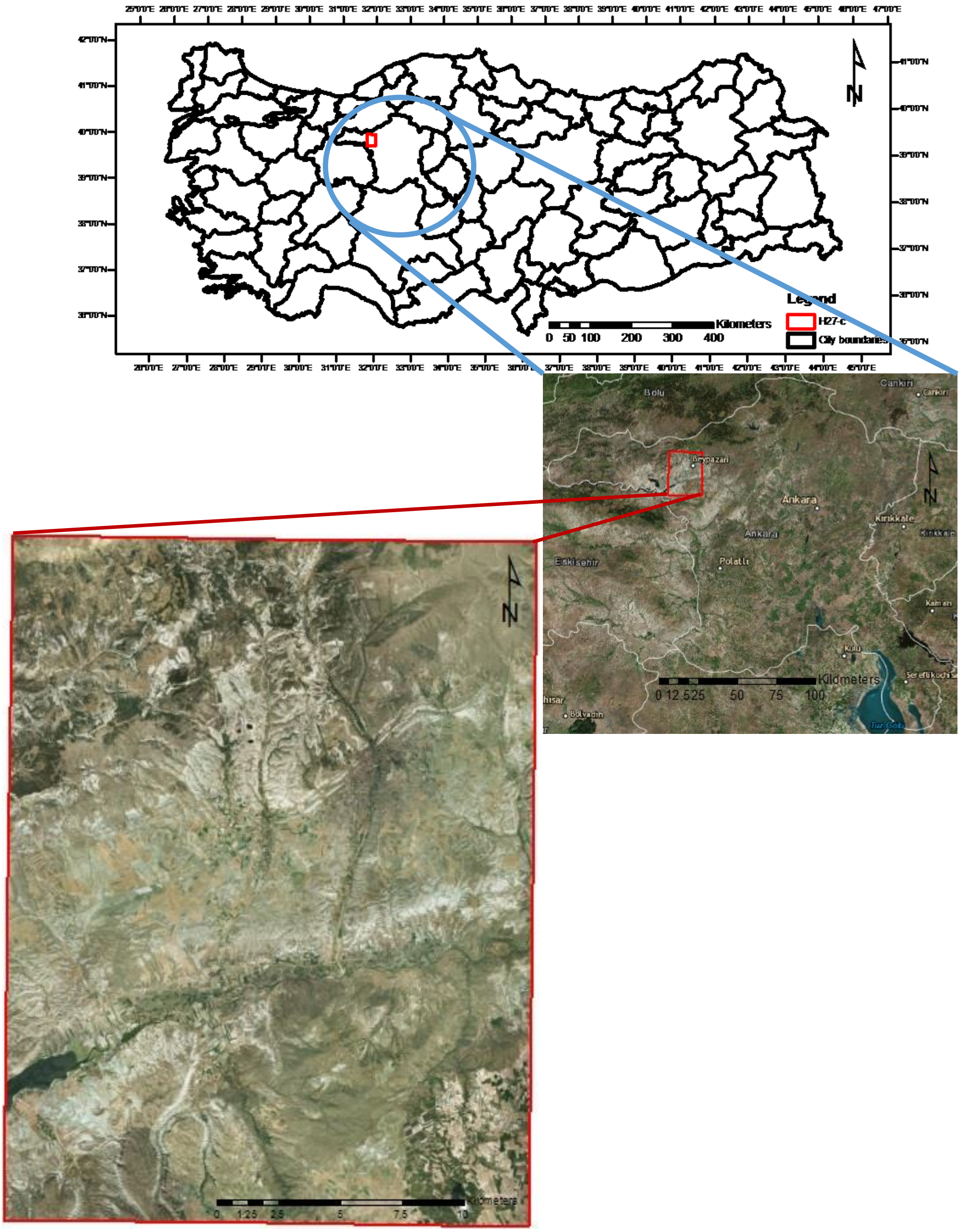


Figure 2.2. Study Area

2.2. Available Data Sets

Determination of environmentally, legally, technically and economically feasible solar PV plant sites require various data namely, agricultural areas, lakes, wetlands, rivers, natural protection zones, forest areas, slope, transmission lines, settlement areas, roads and solar radiation values.

Solar potential atlas for Turkey were generated by abolished General Directorate of Electrical Power Resources Survey and Development Administration. This atlas with 500 * 500 m resolution was prepared by the aid of ESRI Solar Radiation Model according to State Meteorology Affairs stations' solar radiation values gathered between 1985 and 2006. Some of the necessary data such as Natural protection zones with 1/25000 scale, forest areas with 1/100000 scale, lakes with 1/500000 scale, wetlands with 1/25000 scale, agricultural areas with 1/25000 and settlement areas with 1/25000 scale are obtained from Republic of Turkey Ministry of Agriculture and Forestry. Road network data are prepared by digitizing the maps derived from the General Directorate of Maps. Digital Elevation Model USGS Earth Explorer SRTM data with 30 m resolution is used to generate slope and rivers. Transmission lines data are taken from the Başkent Electricity Distribution Inc. with 1/2000 scale.

Comprehensive information related to the gathered data is presented below in Table 2.1. As seen in Table 2.1 necessary data are gathered in various formats. All these data are converted into ESRI Shapefile to be analyzed in ArcGIS software.

Table 2.1. Available data sets information

Data	Source	Scale
Solar Radiation	General Directorate of Electrical Power Resources Survey and Development Administration	500 * 500 m
Natural Protection Zones	Republic of Turkey Ministry of Agriculture and Forestry	1/25000
Forest Areas		1/100000
Lakes		1/500000
Wetlands		1/25000
Agricultural Areas		1/25000
Settlement areas		1/25000
Road Network	General Directorate of Maps	1/25000
DEM	USGS Earthexplorer SRTM	30 * 30 m
Transmission Lines	Başkent Electricity Distribution Inc.	1/2000

2.3. Determination of Criteria and Representation as Fuzzy Sets

To express the theory of fuzzy sets, the main idea in classical set theory need to be well grasped. The classical set concept in mathematics is very straightforward. A set is defined as a gathering of well-described objects. These objects can either belong to the set or not.

In the universe U classical set $A \subset U$ is defined by the function $\mu_A(x)$ that gets the value 1 or 0, representing whether or not $x \in U$ is a member of A:

$$\mu_A(x) = \begin{cases} 1 \; for \; x \in A \\ 0 \; for \; x \notin A \end{cases}$$

Thus $\mu_A(x) \in \{0,1\}$ and $\mu_A(x)$ function merely gets the values 1 or 0.

Presume that function A may get value within the interval [0, 1]. Thus membership concept is no longer crisp but turns into fuzzy by means of demonstrating partial belonging or membership degree.

R is a fuzzy set and defined as

$$R = \{(x, \mu_R(x))/x \in A, \mu_R(x) \in [0,1]\}$$

Where $\mu_R(x)$ is a membership function; $\mu_R(x)$ defines the degree of belongingness of any element in A to fuzzy set R (Abdullah, 2013).

As explained above in terms of mathematical expressions, an object in conventional set is either in (corresponds to value 1) or out (corresponds to value 0) of the set. In contrast, besides keeping the qualitative categories of complete membership and non-membership, the fuzzy set allows partial membership in the range from 0 to 1. In this manner, fuzzy sets unite both quantitative and qualitative evaluation (Ragin, 2000).

The flexibility to define procedures to assign membership degree in fuzzy sets provide extensive chances to fuzzy set theory to be used in different areas such as multi-criteria decision making.

In this study, environmental and regulatory objectives and also economic and technical feasibility criteria are defined separately in terms of fuzzy sets. The suitability grade for alternative sites based on each objective and criterion is established by the help of related fuzzy sets membership functions. Since, between criteria values and site suitability only linearly increasing or decreasing relationship can be defined, linear membership functions are used in this study.

2.3.1. Environmental and Regulatory Objectives

First of all, the literature review was conducted to determine environmental and regulatory objectives, current laws, regulations and legislation were examined in detail. As a result of these detailed investigations, environmental and regulatory objectives have been determined as distance to agricultural areas, lakes, wetlands, rivers, natural protection zones, forest areas and airports. All of these objectives are presented in Table 2.2, together with a description of the similar studies in which the objectives are used, with the relevant explanations, with the range of relevant data and the function that represents the fuzzy set used in this study.

According to the 5403 numbered Land Protection and Land Use Law in Turkey, agricultural areas must be preserved to maintain the natural functions of the land. Indeed, PV installations impact on land relies on the area amount of PV installation, land type, and distance to the biodiversity and the sensitive ecosystems (Tsoutsos et al., 2005). In similar studies, it is accepted that the distance of the solar PV plants to agricultural areas should be at least 100 meters so that the agricultural area is not adversely affected (Hafeznia et al., 2017). Moreover, in some other studies, it is evaluated that the most suitable areas are sites more than 500 meters away from agricultural areas (Merrouni et al., 2017; Yousefi et al., 2018). According to the present literature and the relevant law, in order not to damage the cultivable lands, in this study unsuitable areas are defined as the sites closer than 100 meters to the agricultural areas and the most suitable areas are identified as the sites located more than 500 meters away from the agricultural areas (Table 2.2).

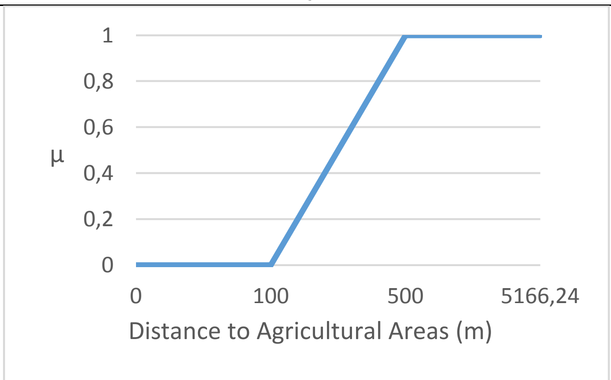
Based on previous studies and present regulations, in terms of distance to lakes and wetlands, to preserve topographic and ecologic characteristics the sites located more than 2500 meters are identified as suitable (Official journal number: 10341) and sites placed more than 5000 meters are considered as most suitable areas (Aydın et al., 2013; Yousefi et al., 2018).

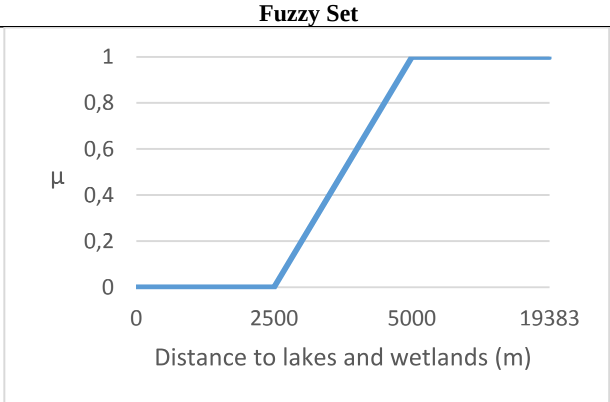
In a similar manner, according to the distance to rivers, suitable areas are defined in Table 2.2 as the sites not closer than 100 meters to rivers (Carrion et al., 2008; Aydın et al., 2013; Anwarzai et al., 2016) and the most suitable areas are determined as the sites located greater than 200 meters away from the rivers (Hafeznia et al., 2017). Protection of PV panels from the flood damage is important since any breakage is occurred in panels hazardous materials used within PV cells may leak to river. Moreover construction materials necessary for PV plant installation may also pollute the rivers during construction stage. In addition to all these reasons behind the selection of this fuzzy set function, building up a big scale structure closer than 100 meter to rivers is forbidden to prevent contamination of water based on Turkish regulations.

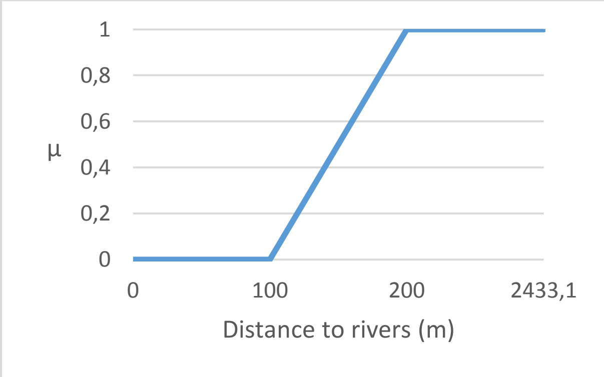
In accordance with 6831 numbered Law of Forest, on forest areas, only the constructions for public interest are authorized if activities are extremely necessary to build. Moreover, based on National Parks Regulation, activities that disrupt the natural balance and the integrity of the landscape and incompatible with the natural environment are not allowed. Besides, it is stated in Decree-Law on the Establishment of the Presidency of the Prime Ministry Special Environmental Protection Agency that only the constructions and operations that are compatible with nature are authorized. In the light of these law, regulations and related studies, to protect from the adverse effects of PV systems to natural protection zones and forest areas, the sites at least 500 meters away (Garcia-Garrido et al., 2012; Uyan, 2013; Hafeznia et al., 2017; Yousefi et al., 2018) is defined as suitable and sites placed more than 1000 meters away (Zoghi et al., 2015; Watson et al., 2015) are assigned as most suitable areas (Table 2.2).

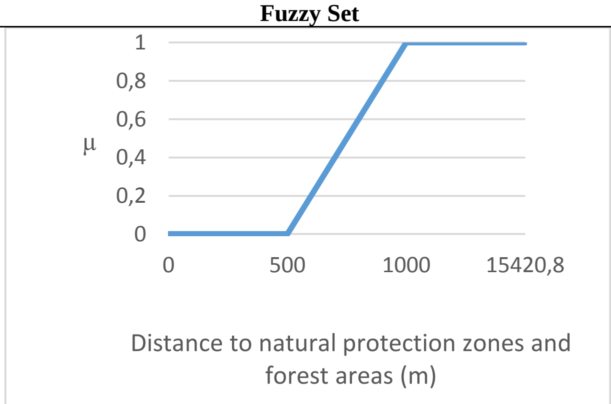
According to the circular of construction criteria around the airports published by Directorate General of Civil Aviation, in order to ensure flight security, no building should be planned or constructed within the first 3000-meter section of the airport landing-departure corridors from the beginning of the runway. However in this study, since an airport does not exist within 3000 meters of the study area, this circular has not been taken into consideration in the study (Table 2.2).

Table 2.2. Fuzzy set functions for environmental and regulatory objectives together with relevant literature, explanation and available data range

<table>
<tr><th>Environmental & Regulatory objectives</th><th>Criteria</th><th>Reference</th><th>Explanation</th><th>Data Range</th></tr>
<tr><td rowspan="8">Agricultural areas</td><td rowspan="8">Distance to agricultural areas</td><td>Law number: 5403
(5403 Land Protection and Land Use Law 19.07.2005 25880)</td><td>Agricultural areas must be preserved to maintain the natural functions of the land</td><td rowspan="6">0-5166,24 m</td></tr>
<tr><td>Yousefi et al. (2018)</td><td>500-2000m
most suitable</td></tr>
<tr><td>Merrouni et al. (2017)</td><td>>500m</td></tr>
<tr><td>Hafeznia et al. (2017)</td><td>>100m</td></tr>
<tr><td>Aydın et al. (2013)</td><td>>1000m</td></tr>
<tr><td>Tsoutsos et al. (2005)</td><td>Due to large-scale PV plant establishment agricultural areas may be damaged</td></tr>
<tr><td colspan="3">Fuzzy Set</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td rowspan="2">Lakes
and wetlands</td><td rowspan="2">Distance to lakes and wetlands</td><td>Official journal number: 10341 (Implementing Regulation Amending the Regulation on the Protection of Wetlands 01.08.2017)</td><td>>2500m
(At least 2.5 km buffer zone to preserve topographic and ecologic characteristics)</td><td rowspan="2">0-19383 m</td></tr>
<tr><td>Official journal number: 30224 (Protection of Drinking and Potable Water Basins Regulation 28.10.2017 http://www.resmigazete.gov.tr/eskiler/2017/10/20171028-8.htm)</td><td>Long distance protection area article number 12
(item 6) In areas between 2000 and 5000 meters horizontally from the maximum water level, industrial facilities that do</td></tr>
</table>

Environmental & Regulatory objectives	**Criteria**	**Reference**	**Explanation**	**Data Range**
			not produce and store hazardous wastes and materials and also not generate industrial wastewater are allowable. (item 14) Establishment of solar and wind power plants are allowable provided that the regulatory procedures of the Ministry are satisfied.	
		Merrouni et al. (2017)	>500m	
		Yousefi et al. (2018)	1000 m<x<20 km acceptable 5-10 km most suitable	
		Hafeznia et al. (2017)	>200 m	
		Noorollahi et al. (2016)	>1000 m	
		Aydın et al. (2013)	>2500 m suitable >5000 m most suitable	
		Fuzzy Set		
				
Rivers	Distance to rivers	Official journal number: 21374 (Implementing Regulation Amending Some Articles of the Regulation on the Implementation of Coastal Law 13.10.1992)	>100 m	**0-2433,1 m**
		Yousefi et al. (2018)	500m<x<20km acceptable 2-10km most suitable	
		Hafeznia et al. (2017)	>200m	
		Anwarzai et al. (2016)	>100m	
		Noorollahi et al. (2016)	>1000m	
		Aydın et al. (2013)	>100m, >500m most suitable	
		Carrion et al. (2008)	>100m	

Environmental & Regulatory objectives	Criteria	Reference	Explanation	Data Range
		Fuzzy Set		
				
Natural protection zones and forest areas	Distance to natural protection zones and forest areas	Yousefi et al. (2018)	>500m, >2000m most suitable	**0-15420,8 m**
		Hafeznia et al. (2017)	>500m	
		Zoghi et al. (2015)	>1000m	
		Noorollahi et al. (2016)	>2000m	
		Watson et al. (2015)	>1000m	
		Uyan (2013)	>500m	
		Garcia-Garrido et al. (2012)	>500m, >6000m most suitable	
		Law number: 6831 (Law of Forest 08.09.1956)	On forest areas, only the constructions for public interest are authorized if activities are extremely necessary to build.	
		Official journal number: 20341 (Decree-Law on the Establishment of the Presidency of the Prime Ministry Special Environmental Protection Agency 13.11.1989)	Only the constructions and operations that are compatible with nature are authorized.	
		Official journal number: 19309 (National Parks Regulation 12.12.1986)	Activities that disrupt the natural balance and the integrity of the landscape and incompatible with the natural environment are not allowed.	

Environmental & Regulatory objectives	Criteria	Reference	Explanation	Data Range
		Fuzzy Set		
				
Flight security	Distance to airport	Directorate General of Civil Aviation (Circular of construction criteria around the airports 24.07.2012)	>3000 m	**Negligible**

2.3.2. Economic and Technical Feasibility Criteria

While economic and technical feasibility criteria are identified, again comprehensive literature survey is performed and also interviews with both General Directorate of Electrical Power Resources Survey and Development and International Solar Energy Society (ISES) – Turkey division (GÜNDER) were conducted. As a result of these detailed investigations, economic and technical feasibility criteria have been assigned as solar radiation amount, slope percentage, distance to transmission lines, distance to roads, distance to settlement areas, aspect, sunshine duration and distance to faults. All of these criteria related information together with fuzzy set functions are given in Table 2.3.

Comprehensive investigations reveal that the most important criteria for solar PV site selection is solar radiation value and according to previous studies, the appropriate amount of solar radiation lies between 1000 and 2900 kWh/m^2-year (IEA, 2010; Brewer et al., 2015). Most of the studies agreed that the solar radiation value more than 1600 kWh/m^2-year might be accepted as suitable for solar PV site selection. Since the effect of the solar radiation value on the priority area selection is more important compared to the other criteria and due to the presence of an acceptable level of radiation value in the whole study area, in order to not to mask the effects of other criteria the solar radiation value is used as an independent criterion by giving the distributions along the final selected priority areas. In the fuzzy set function related to solar radiation values, site suitability and radiation values are defined as directly proportional (Table 2.3).

The slope is another criterion frequently used in solar power plant site selection. Slope values have been used in various studies by considering the different limit values. When the previous studies are examined, it is seen that this difference is resulted due to the topographic variance of the study areas. According to many of previous studies seen in table 2.3, slope lower than 3 % is assigned as most suitable. Moreover, in some studies, areas having slope percent lower than 5 is defined as suitable. In addition to that, with respect to several studies slope higher than 10 is accepted as unsuitable and limiting value (Asakereh et al., 2014; Watson et al., 2015; Hafeznia et al., 2017; Yousefi et al., 2018). Similarly, in fuzzy set function based on slope percentages, areas having slope percentage lower than 3 % is defined as the most suitable areas, between 3 to 5 % is identified as highly suitable areas, between 5 to 10 % is characterized as suitable areas and higher than 10 % is defined as technically unsuitable areas (Table 2.3).

When the previous studies are examined in terms of distance to transmission lines, it is noticed that 3 (Uyan, 2013; Sindhu et al., 2017), 10 (Baban et al., 2000; Aydın et al., 2013; Sabo et al., 2017) and 50 (Ontario Power Authority, 2013; Calvert et al., 2015; Noorollahi et al., 2016) kilometers are used as limit values in the studies. By considering the distance values of the transmission lines in the study area which reaches up to 3805.26 m, the fuzzy set function related to this criterion is defined as directly proportional to the site suitability value (Table 2.3).

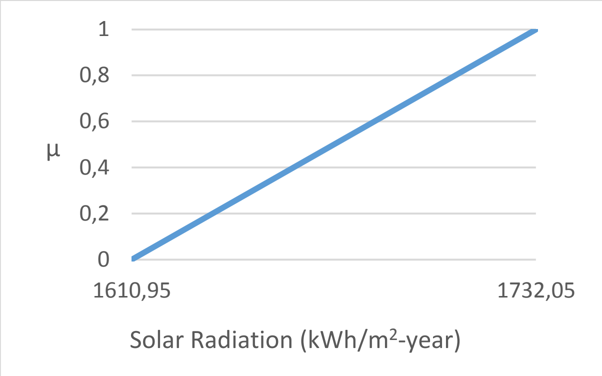
In order to reduce the cost of produced energy supply to minimize the transmission line distance and reduce the transmission loss, distance to settlement areas needs to be minimized. However, to reduce the visual impact and not to prevent the development of the residential area, distance should be left between settlement areas and solar power plant areas. Although, in some studies, 10 km is chosen as the maximum feasible distance to provide energy to the settlement area (Carrion et al., 2008; Anwarzai et al., 2017), in this study this upper limit is negligible since maximum criteria value is lower than the upper limiting value. Based on all these explanations, in this study, the areas where the distance to settlement areas are less than 500 meters are determined as inappropriate areas while for areas more than 500 meters distance the fuzzy set function between distance and conformity is defined as inversely proportional (Table 2.3).

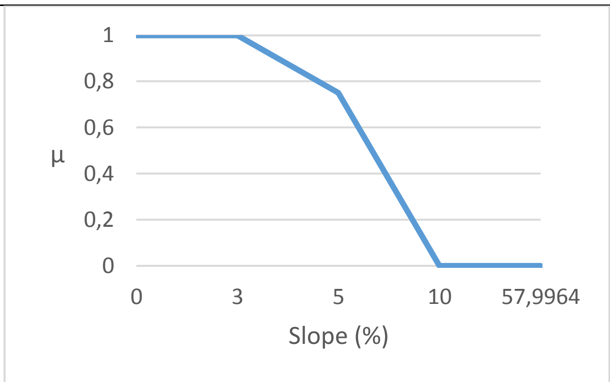
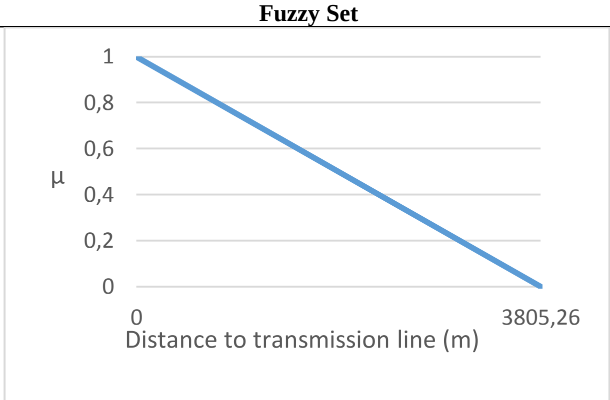
Minimizing the distance to roads reduce the construction and maintenance costs. On the other hand, solar panels may affect driving safety by glare. In addition to that, any accident happened on the road may harm the PV panels thus there should be a safe approach distance defined to protect the plant. According to this information and previous studies, 100 meters is defined as a safe approach distance and areas having the distance to roads less than 100 meters are identified as unsuitable areas. Moreover, the fuzzy set function for the sites having more than 100 meters distance to roads is defined as inversely proportional with suitability (Table 2.3).

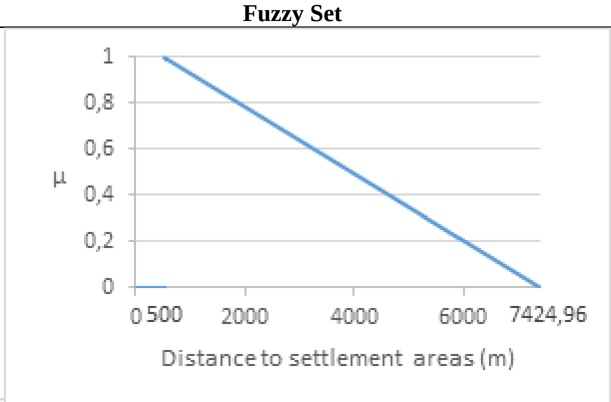
Aspect and sunshine duration are used as criteria in some of the previous studies. However, since these criteria were used in preparing the solar radiation map obtained from the relevant ministry, these two criteria were not taken into account in order to avoid the repeated use of the criteria. Similar to these negligible criteria, distance to fault criterion is also not taken into account in this study since the distance to fault criterion is considered during project stage of the panel carrier systems based on the information gathered from the interview conducted (Table 2.3).

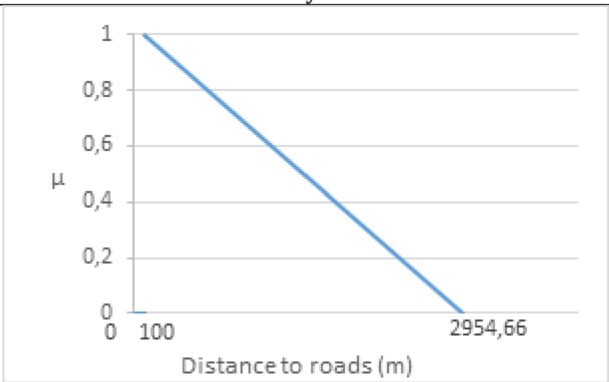
Table 2.3. Fuzzy set functions for economic and technical feasibility criteria together with relevant literature, explanation and available data range

Economic & Technical objectives	Criteria	Reference	Explanation	Data Range
Solar Energy Generation Potential	Solar radiation	Yousefi et al. (2018)	>4.5 kWh/m^2-day (1600 kWh/m^2-year) 6 kWh/m^2-day most suitable	Min: 1610,95 Max: 1732,05 kWh/m^2-year
		Kereush et al. (2017)	>1100 kWh/m^2-year	
		Hafeznia et al. (2017)	>4.5 kWh/m^2-day (1600 kWh/m^2-year) 6 kWh/m^2-day most suitable	
		Noorollahi et al. (2016)	>1300 kWh/m^2-year	
		Anwarzai et al. (2016)	>3,5 kWh/m^2-day (1300 kWh/m^2-year)	
		Zoghi et al. (2015)	>1500 kWh/m^2-year	
		Brewer et al. (2015)	>3 kWh/m^2-day (1100 kWh/m^2-year) <8 kWh/m^2-day (2900 kWh/m^2-year)	
		Gherboudj et al. (2015)	>1600 kWh/m^2-year	
		Massimo et al. (2014)	>1600 kWh/m^2-year	
		Mahtta et al. (2014)	>4 kWh/m^2-day (1400 kWh/m^2-year)	
		Aydın et al. (2013)	>4,5 kWh/m^2-day (1600 kWh/m^2-year)	
		USEPA (2013)	>1300 kWh/m^2-year	
		International Energy Agency Paris, World Energy Look (2010)	>1000 kWh/m^2-year	
		[EPA] Environmental Protection Agency (2009) (http://epa.gov/renewableenergyland/maps/pdfs/utility_pv_us.pdf)	Solar radiation amount between 5 – 6 kWh/m^2-day (1800 kWh/m^2-year) are identified as very good in terms of energy production.	
		General Directorate of Renewable Energy web page (http://www.yegm.gov.t	>1500 kWh/m^2-year	

Economic & Technical objectives	Criteria	Reference	Explanation	Data Range
		r/yenilenebilir/g_enj_tekno.aspx)		
		Fuzzy Set		
				
Slope	Slope percentage	Yousefi et al. (2018)	<10% acceptable, <2% most suitable	**0-57,9964 %**
		Hafeznia et al. (2017)	<10% acceptable, <3% most suitable	
		Kereush et al. (2017)	5-15% acceptable	
		Sabo et al. (2017)	<5%	
		Aly et al. (2017)	<3%	
		Anwarzai et al. (2016)	<5%	
		Suh et al. (2016)	<18%	
		Wang et al. (2016)	<5%	
		Noorollahi et al. (2016)	<11%	
		Brewer et al. (2015)	<3,1%	
		Castillo et al. (2015)	>16% poorly suitable, >30% technically unsuitable	
		Watson et al. (2015)	<10%	
		Lozano et al. (2015)	<5%	
		Zoghi et al. (2015)	<3% most suitable, 10-20% acceptable	
		Gherboudj et al. (2015)	<4%	
		Mahtta et al. (2014)	<2,1%	
		Asakereh et al. (2014)	<10% acceptable, <3% most suitable	
		Aydın et al. (2013)	<7% acceptable, <3% most suitable	
		Uyan (2013)	<3%	
		Mondino et al. (2013)	<15% acceptable, <3% most suitable	
		Arnette et al. (2011)	<15% acceptable, <2,5% most suitable	
		Charabi et al. (2011)	<5%	
		Gastli et al. (2010)	<5%	
		Hang et al. (2008)	<3%	
		Carion et al. (2007)	<2%	

Economic & Technical objectives	Criteria	Reference	Explanation	Data Range
		Bravo et al. (2007)	<7% acceptable, <3% most suitable 3-10% aspect SE-SW	
		Fuzzy Set		
				
Transmission Lines	Distance to Transmission Lines	Sindhu et al. (2017)	<3000m	**0-3805,26 m**
		Sabo et al. (2017)	500m<x<10km	
		Noorollahi et al. (2016)	<50km	
		Brewer et al. (2015)	<37,5km	
		Calvert et al. (2015)	<50km	
		Khan et al. (2014)	<15km	
		Aydın et al. (2013)	<45km, <10km most suitable	
		Uyan (2013)	<3000m	
		Ontario Power Authority (2013)	<50km	
		Baban et al. (2000)	<10km	
		Fuzzy Set		
				
Settlement Areas	Distance to Settlement Areas	Yousefi et al. (2018)	500m<x<7km, 1,5-2 km most suitable	**0-7424,96 m**
		Merrouni et al. (2018)	>2000m	
		Sindhu et al. (2017)	>500m	

Economic & Technical objectives	Criteria	Reference	Explanation	Data Range
		Kereush et al. (2017)	>500m	
		Hafeznia et al. (2017)	>500m	
		Noorollahi et al. (2016)	>500m, <45km	
		Anwarzai et al. (2017)	<10km	
		Zoghi et al. (2015)	>500m, <15km	
		Castillo et al. (2016)	>500m	
		Watson et al. (2015)	>500m	
		Tahri et al. (2015)	>2000m	
		Effat (2013)	>2000m	
		Uyan (2013)	>500m	
		Aydın et al. (2013)	>1000m, 5-10km most suitable, <20km	
		Carrion et al. (2008)	5km<x<10km	
		Fuzzy Set		
				
Roads	Distance to roads	Yousefi et al. (2018)	>500m acceptable 1000-6000m most suitable	**0-2954,66 m**
		Merrouni et al. (2018)	>100m	
		Sabo et al. (2017)	500m<x<10km	
		Hafeznia et al. (2017)	>300m	
		Anwarzai et al. (2017)	<10km	
		Noorollahi et al. (2016)	100m<x<50km	
		Lozano et al. (2014)	100m<x<50km	
		Zoghi et al. (2015)		

Economic & Technical objectives	Criteria	Reference	Explanation	Data Range
			>250m	
		Brewer et al. (2015)	>0,56km	
		Castillo et al. (2016)	<5000m	
		Uyan (2013)	>100m	
		Effat (2013)	>200m	
		Sebzipravar 2007	>250m	
		Fuzzy Set		
				
Aspect	Aspect-Azimuth	Kereush et al. (2017)	110-200° (Southeast, South, Partly Southwest)	**0-359,51 -1(flat)**
		Watson et al. (2015)	SW-SE (135-225°)	
		Tahri et al. (2015)	1. S, 2. SW, 3.SE	
		Mondino et al. (2015)	135-225°	
		Arnette et al. (2011)	112,5-247,5°	
		Szkliniarz (2013)	Slope <3%, aspect is not important, Slope <6%, aspect 90-270°, Slope<15%, aspect 135-225°, Slope<35%, aspect 157,5-202,5°	
Sunshine Duration	Sunshine Duration	General Directorate of Renewable Energy web page (http://www.yegm.gov.tr/yenilenebilir/g_enj_tekno.aspx)	>2000h	**Min: 2432,83 h Max: 2553,80 h**
Faults	Distance to faults	Yousefi et al. (2018)	>1000m, >6000m most suitable	**0-22652,4 m**
		Hafeznia et al. (2017)	>200m, >1000m most suitable	
		Noorollahi et al. (2016)	>500m	

2.4. Analytic Hierarchy Process (AHP)

AHP is one of the mostly applied Multi Criteria Evaluation (MCE) tools. AHP provides the consideration of both subjective and objective elements in ranking the alternatives (Eldrandaly, 2012). The pairwise comparisons technique which is known as the Analytical Hierarchy Process (AHP) has been proposed by Saaty in 1977 within the concept of a decision-making process. AHP was built up by using different analytical resources apart from GIS softwares and first GIS application of AHP was in 1991 (Rao et al., 1991). Since development of AHP, it has been used in a wide range of applications in different fields such as site selection (Eldrandaly, 2012). The relative importance of the two criteria concerned in defining suitability for the stated goal is related to the comparisons. Nine-point continuous scale for ratings are given below in Table 2.4.

Table 2.4. Pairwise comparison scale (Saaty, 1977)

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

While weights are assigned, in every potential pairing each criterion is compared and results of each pairwise comparison are recorded into comparison or ratio matrix. Because this comparison matrix is symmetrical, just filling the lower part of the triangle is sufficient. The rest of the matrix cells are multiplicative inverse of that lower triangle. In order to obtain the best fitting weights, calculation of pairwise comparison matrix's principal eigenvector is needed.

When the operations explained below are followed then a good approximation might be reached.

To begin with, the values belong to every column of the pairwise comparison matrix are summed. Secondly, the normalized pairwise comparison matrix is prepared by dividing every cell in the matrix by their column total value. And then, the average of the cells in every row of the normalized matrix is calculated by dividing the total of normalized scores for every row by the criteria number. This calculation gives an estimate of relative weights of the related criteria. These weights might be commented as the average of entire possible criteria comparison ways.

Since various pathways exist to assign relative importance of criteria with comparison or ratio matrix, consistency degree determination is also possible to improve the ratings. The consistency ratio (CR) is defined by Saaty in 1977 as a possibility that the matrix ratings can be produced randomly and according to Saaty the matrices having CR value higher than 0.10 should be reconsidered.

To calculate the CR, first of all, the weighted sum vector is determined by multiplication of the first criterion weight with the first row of the original pairwise comparison matrix, and then second criterion weight with the second row, this procedure is applied for each row till the last criteria weight, and later on these values are summed up for each rows; finally, the consistency vector calculated by dividing the weighted sum vector to the previously calculated criterion weights. After the calculation of these consistency vectors, average value of the consistency vector (λ) is calculated by dividing the consistency vector to the number of criteria (n). Then from the derived λ, which must be equal or greater than the number of considered criteria, the consistency index that gives a measure of deviation from consistency is calculated according to the formula given below (Equation 2.1):

$$CI = \frac{\lambda - \mathrm{n}}{n - 1} \tag{2.1}$$

The random index (RI) that relies on criteria number is the CI of the randomly created pairwise comparison matrix. Random inconsistency indices (RI) for various numbers of criteria is formed by Saaty and given below in Table 2.5.

Table 2.5. RI for different number of criteria (Saaty, 1977)

n	RI	n	RI	n	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.54
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

After the calculation of CI and RI, consistency ratio CR is calculated simply by dividing the consistency index (CI) to the random index (RI) as represented in the formula below (Equation 2.2):

$$CR = \frac{CI}{RI} \tag{2.2}$$

Before the determination of criteria weights considering the environmental-regulatory suitability and economic-technical feasibility, the relative importance order of criteria considered in previous related studies are examined in detailed and given in Table 2.6.

Table 2.6. Criteria importance ranking in previous study and this study

		Aran Carrion et al., 2007	Kengpol et al., 2012	Effat, 2013	Uyan, 2013	Chen et al., 2014	Vafaeipour et al., 2014	Watson and Hudson, 2015	Tahri et al., 2015	Sanchez-Lozano et al., 2015	Brewer et al., 2015	Noorollahi et al, 2016	Merrouni et l., 2017	Sindhu et al., 2017	Doljak and Stanojevic, 2017	Fang et al., 2018	**This study**
Environmental and Regulatory Objectives	Agricultural Areas	5	-	-	1	4	-	-	5	3	-	6	-	6	1	4	**4**
	Lakes and Wetlands	-	6	-	-	-	-	-	-	-	-	-	4	-	-	-	**3**
	Rivers	-	6	-	-	-	-	-	-	-	3	-	3	-	-	-	**2**
	Natural Protection Zones and Forest Areas	6	4	-	-	-	-	3	-	-	-	-	-	4	-	-	**1**
Economic and Technical Feasibility Criteria	Solar Radiation	1	1	1	-	1	2	1	1	2	1	1	1	2	3	2	**1***
	Slope	3	7	-	4	5	-	-	2	5	2	5	2	-	2	3	**1**
	Aspect	4	7	2	-	7	-	-	3	6	-	-	-	-	4	3	**-**
	Transmission Lines	7	2	3	2	7	1	2	-	4	3	2	6	5	-	5	**2**
	Settlement areas	8	5	5	3	2	3	4	3	8	-	4	5	3	-	-	**4**
	Roads	7	-	4	5	3	4	3	4	7	2	3	7	1	-	5	**3**
	Faults	-	3	-	-	-	5	-	-	-	-	-	-	-	-	-	**-**
	Sunshine Duration	2	-	-	-	-	-	-	-	-	-	7	-	-	5	1	**-**
	Elevation	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	**-**
	Substations	7	-	-	-	6	-	-	-	1	-	-	-	-	-	-	**-**

* Solar radiation is the most important criterion but it is evaluated separately in this study.

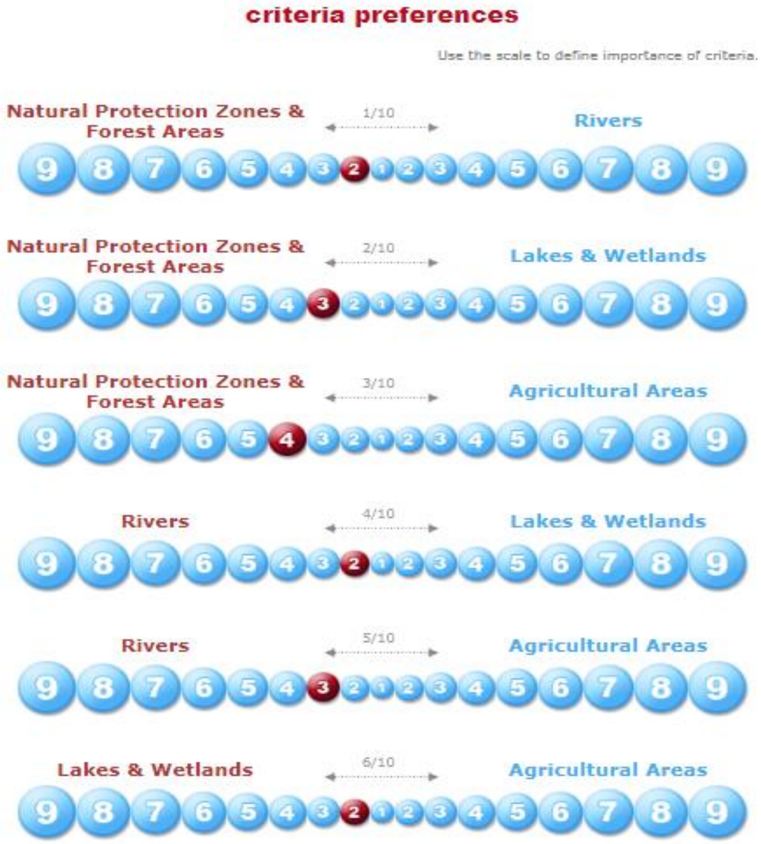
When the previous studies were examined, it was determined that various criteria were used in different studies with the different order of importance. As previously explained, in this study, agricultural areas, lakes, wetlands, rivers, natural protection zones and forest areas are considered as Environmental and Regulatory Objectives, while slope, transmission lines, roads and settlement areas are considered as Economic and Technical Feasibility criteria.

Along with all these, the Solar Radiation criterion, which is considered as the most important criterion by almost all previous studies, has also been used separately to avoid shadowing the effects of other criteria. The slope is considered to be the second most important place in the literature after solar radiation. However, since solar radiation was evaluated independently in this study, it was considered that the slope would be the most important criterion due to variant slope in the study area. The third important economic and technical feasibility criterion has been determined as the distance to the transmission lines by taking into consideration the rankings in the previous studies in order to reduce the construction cost and transmission loss. The fourth important economic and technical feasibility criterion has been identified as the distance to roads considering the rankings in previous studies in order to reduce construction and maintenance costs. Although the distance to settlement areas criterion is considered more important than the distance to roads criterion in some studies and vice versa in some other studies, the distance to the settlement areas was determined as the fifth most important criterion in this study due to the absence of a large settlement area.

Although there are not many studies on environmental and regulatory criteria, based on the comparison of the existing studies with each other and engineering judgement, Natural Protection Zones and Forest Areas, Rivers, Lakes and Wetlands and Agricultural Areas were determined respectively as the first, second, third and fourth important criterion.

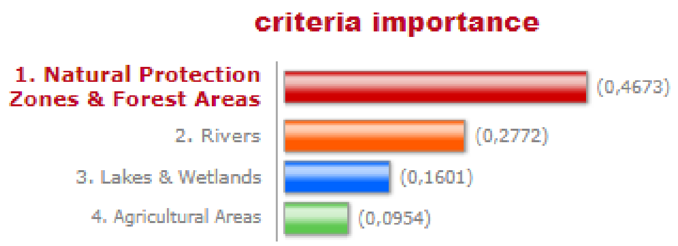
The calculations for determining the weight of the criteria for environmental and regulatory objectives are presented respectively below in Figure 2.3. Pairwise comparisons with respect to nine-point continuous scale and pairwise comparison matrix shown in Figure 2.3.

From the AHP calculations given in Figure 2.3, weights for Natural Protection Zones and Forest Areas, Rivers, Lakes and Wetlands and Agricultural Areas are calculated respectively as 0,4673, 0,2772, 0,1601 and 0,0954 with an acceptable consistency ratio of 0,0115.



criteria preferences	Natural Protection Zones & Forest Areas	Rivers	Lakes & Wetlands	Agricultural Areas
Natural Protection Zones & Forest Areas	1	2	3	4
Rivers	1/2	1	2	3
Lakes & Wetlands	1/3	1/2	1	2
Agricultural Areas	1/4	1/3	1/2	1

CI: 0,0103 CR: 0,0115 λ: 4,0308



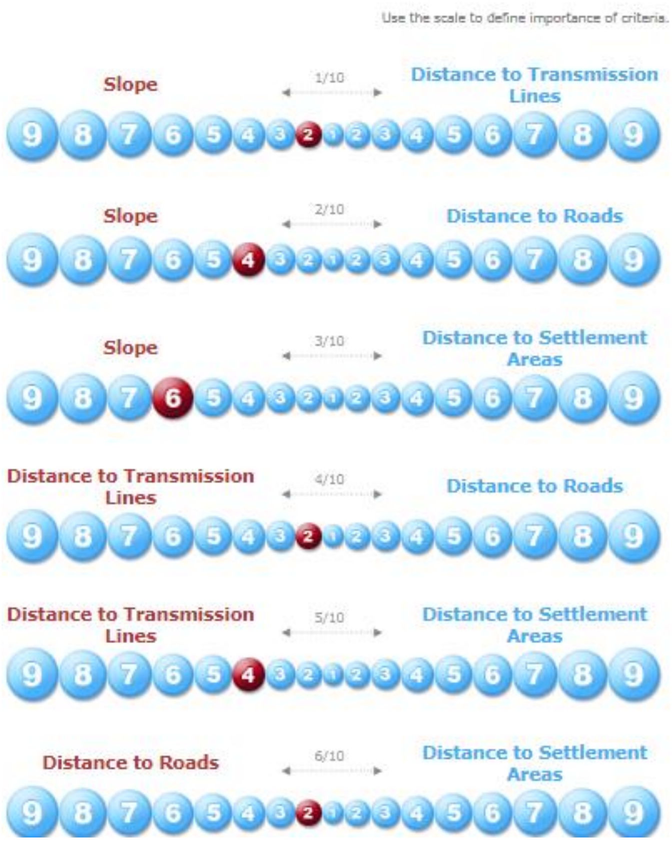
consistency ratio (CR): 0,0115

Figure 2.3. Environmental and regulatory objectives criteria weights, nine-point continuous scale pairwise comparisons and pairwise comparison matrix

The calculations for determining the weight of the criteria for economic and technical feasibility are presented respectively in Figure 2.4. Pairwise comparisons for economic and technical feasibility criteria according to nine-point continuous scale and pairwise comparison matrix shown in Figure 2.4 below.

From the AHP calculations given in Figure 2.4, weights for Slope, Distance to Transmission lines, Distance to Roads and Distance to Settlement areas are calculated respectively as 0,5132, 0,2751, 0,1376 and 0,0741 with an acceptable consistency ratio of 0,0040.

criteria preferences

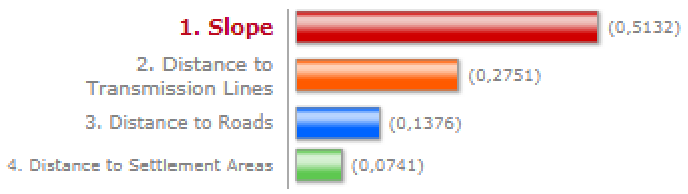


intermediate steps

criteria preferences	Slope	Distance to Transmission Lines	Distance to Roads	Distance to Settlement Areas
Slope	1	2	4	6
Distance to Transmission Lines	1/2	1	2	4
Distance to Roads	1/4	1/2	1	2
Distance to Settlement Areas	1/6	1/4	1/2	1

CI: 0,0035 CR: 0,0040 λ: 4,0106

criteria importance



consistency ratio (CR): 0,0040

Figure 2.4. Economic and technical feasibility criteria weights, nine-point continuous scale pairwise comparisons and pairwise comparison matrix

2.5. Ordered Weighted Averaging (OWA)

Ordered Weighted Averaging (OWA), which is developed by Yager in 1988 (Yager, 1988), utilizes a group of multi-criteria operators and contains two types of weights namely importance or criterion weights and order weights. Importance or criterion weight is assigned to a specific criterion, objective or attribute for every location in a study area, to represent its relative importance based on decision-makers choices. Order weights are assigned to re-ordered criterion values, independent from the source of criterion for each value, with decreasing order. The first order weight is dedicated to the greatest weighted criterion values for each and every location, the second order weight to the second highest weighted criterion values, and this operation continue till the last order weight is assigned to the lowest weighted criterion values. Order weights are the fundamental of OWA operations. OWA operations are used to ease the establishment of various land use strategies ranging from an extremely pessimistic (similar to Boolean AND operation) through all intermediate or neutral to an extremely optimistic (similar to Boolean AND operation). Therefore, OWA might be considered as conventional GIS combination procedures' extension (Drobne and Lisec, 2009; Eldrandaly, 2013).

As it is mentioned before, decision-makers could need satisfaction like most, many, half, some or a few of the criteria while dealing with real world problems. The operation to combine the criteria based on an expression concerning the relationship between the evaluation criteria is called the quantifier guided multi-criteria evaluation (Yager, 1996). Depending on the type of statements linguistic quantifiers are separated as absolute linguistic quantifiers and relative or proportional linguistic quantifiers (Zadeh, 1983). Expressions as about 3, almost 6, more than 8 can be the examples of the absolute quantifiers. While, statements corresponding proportional quantity such as all, most, many, a few can be classified as relative linguistic quantifiers (Malczewski, 2006).

Ordered Weighted Averaging is composed essentially of three steps. First, the defined or calculated weights according to user preferences are multiplied by the normalized criterion values. Secondly, the results are reordered. Thirdly, the order weights, which are only rely on the selected α value (Table 2.7) and are independent from the chosen criteria, are calculated and applied.

Order weight calculation formula (Equation 2.3) with i-th order of weight and n criteria or objectives:

$$\left(\frac{i}{n}\right)^{\alpha} - \left(\frac{i-1}{n}\right)^{\alpha} \tag{2.3}$$

Table 2.7. The linguistic quantifiers for selected values of the α parameter (Malczewski, 2006)

α	**Quantifier**
$\alpha \to 0$	At least one
$\alpha = 0.1$	At least a few
$\alpha = 0.5$	A few
$\alpha = 1$	Half (identity)
$\alpha = 2$	Most
$\alpha = 10$	Almost all
$\alpha = 1000$	All

In this study, "all" is selected as a linguistic quantifier since, it is supposed that meeting "all" of the environmental and regulatory objectives and economic and technical feasibility criteria is a reasonable expectation. By using “all” relative linguistic quantifier, areas that are not satisfying the decision makers’ choices or preferences for any of the criteria is eliminated/masked during OWA aggregation process while calculating overall potentials.

In some studies, it is recommended that the capacities of AHP, which is a comprehensive approach for decision-making, might be enhanced by a combination of the fuzzy linguistic OWA operators (Yager and Kelman, 1999). This idea is adopted in this study and AHP is used in combination with OWA to strengthen the decision-making.

2.6. Selection of Priority Sites

After hybrid AHP-FuzzyOWA MCDM procedure completed for environmental-regulatory objectives and economic-technical feasibility criteria, overall suitabilities based on these objectives and criteria are obtained. Later on, to identify the priority sites for solar PV power plants, overall potentials with respect to both objectives (environmental and regulatory) and criteria (economic and technical) are aggregated pixel-wise according to specified selection rules introduced in Table 2.8 below.

Table 2.8. Priority site selection rules (modified form Aydın et al., 2010)

Overall Satisfaction Degree Based on Economic and Technical Feasibility Criteria	Overall Satisfaction Degree Based on Environmental and Regulatory Objectives	Decision
0.5-1.0	0.5-1.0	Select as a priority site for PV energy production.
0.5-1.0	0.0-0.5	Eliminate for the present – because of environmental and regulatory factors. Re-evaluate after remedial actions are applied or present status of the area have changed.
0.0-0.5	0.5-1.0	Eliminate – because of unsatisfactory economic and technical feasibility.
0.0-0.5	0.0-0.5	Eliminate – because of both inadequate feasibility and environmental factors.

As it is described in the priority site selection rules, both for economic-technical feasibility criteria and environmental-regulatory objectives overall satisfaction degrees greater than 0.5 is characterized as priority sites for PV plant. With respect to both economic-technical and environmental-regulatory aspects, areas or pixels with satisfaction degree lower than 0.5 are identified as inadequate areas according to targets and these areas are eliminated. On the other hand, areas having satisfaction degree greater than 0.5 with respect to environmental and regulatory objectives and lower than 0.5 with respect to economic and technical criteria are eliminated, since these areas are designated as economically and technically unfeasible areas. Contrary to previous case, areas having satisfaction degree greater than 0.5 in terms of economic and technical aspects and lower than 0.5 in terms of environmental and regulatory aspects are eliminated for the present situation but after remedial actions are taken or present status of the area have changed then these areas might be re-evaluated.

Finally, after all these field selection rules have been defined and applied, this study has been terminated by showing the distribution of solar radiation amounts on selected sites in order not to shadow the other criteria used for evaluations.

CHAPTER 3

DATA PROCESSING

The methodology proposed and explained in the previous chapter will be applied to the available data sets step by step in this part of the thesis and suitable areas for the solar power plant will be determined within the study area.

To begin with, maps for each criterion are generated according to the fuzzy sets membership functions defined for environmental and regulatory objectives.

First environmental and regulatory criterion is agricultural areas. Agricultural areas are selected from the Republic of Turkey Ministry of Agriculture and Forestry data and represented in Figure 3.1.

Afterward, distance to agricultural areas raster map with 100-meter cell size is prepared by using Euclidean distance spatial analyst tool in GIS (Figure 3.2). While distance maps are calculated, adequate amount data outside the study area are also taken into account in order to avoid missing data or incorrect cell value towards the edges. This procedure is applied for all distance map calculations in this study.

After the distance map is prepared, fuzzy membership map revealed in Figure 3.3 is generated with respect to the previously defined fuzzy set membership function for distance to agricultural areas criterion given in Table 2.2.

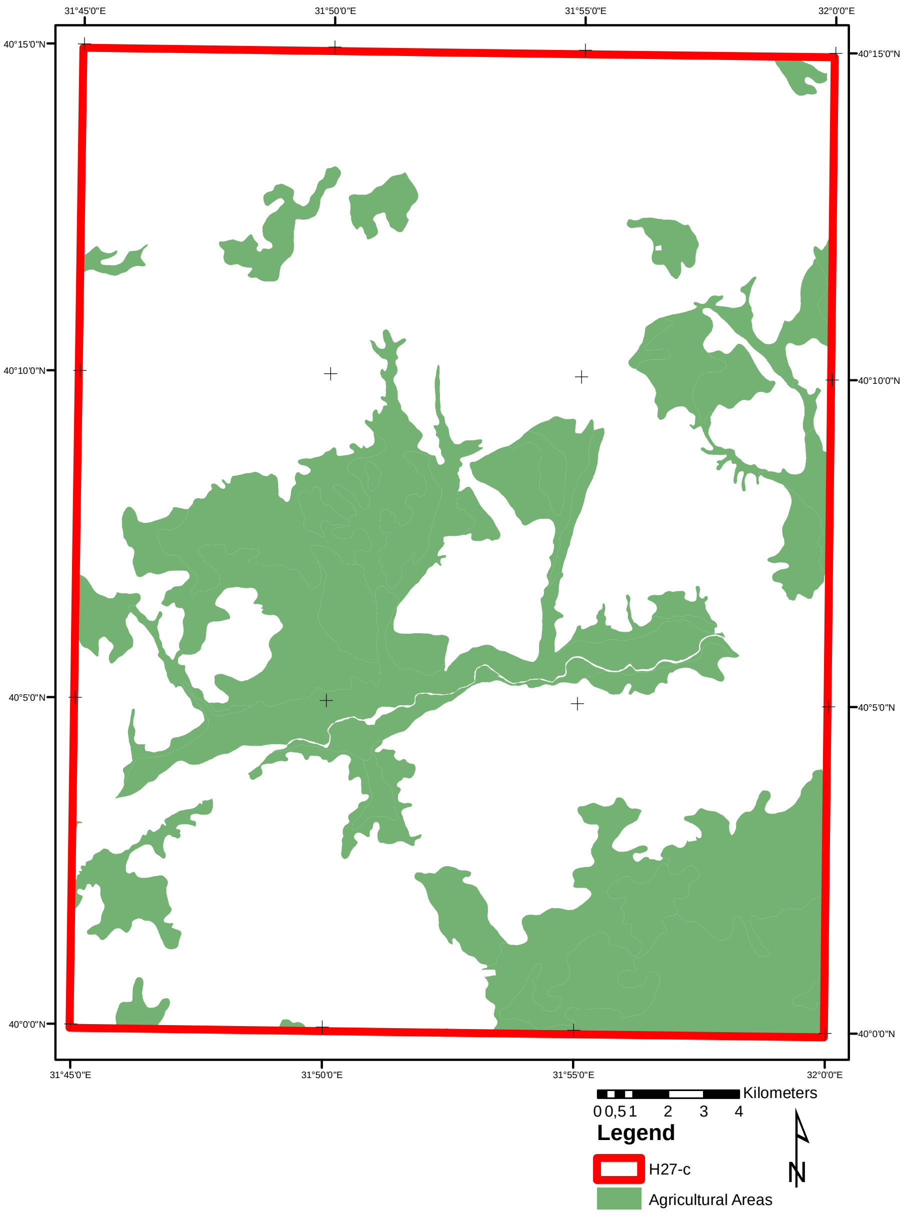


Figure 3.1. Agricultural areas

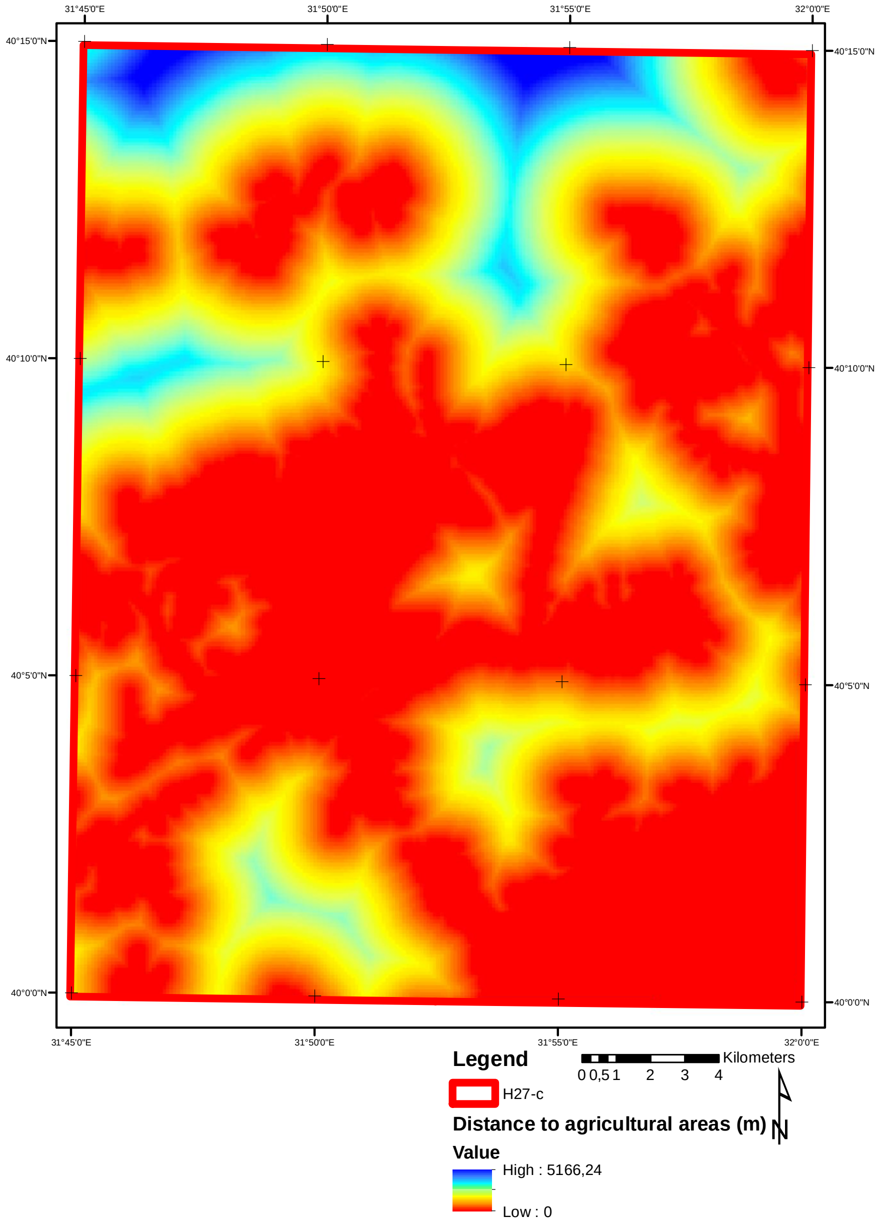


Figure 3.2. Distance to agricultural areas map

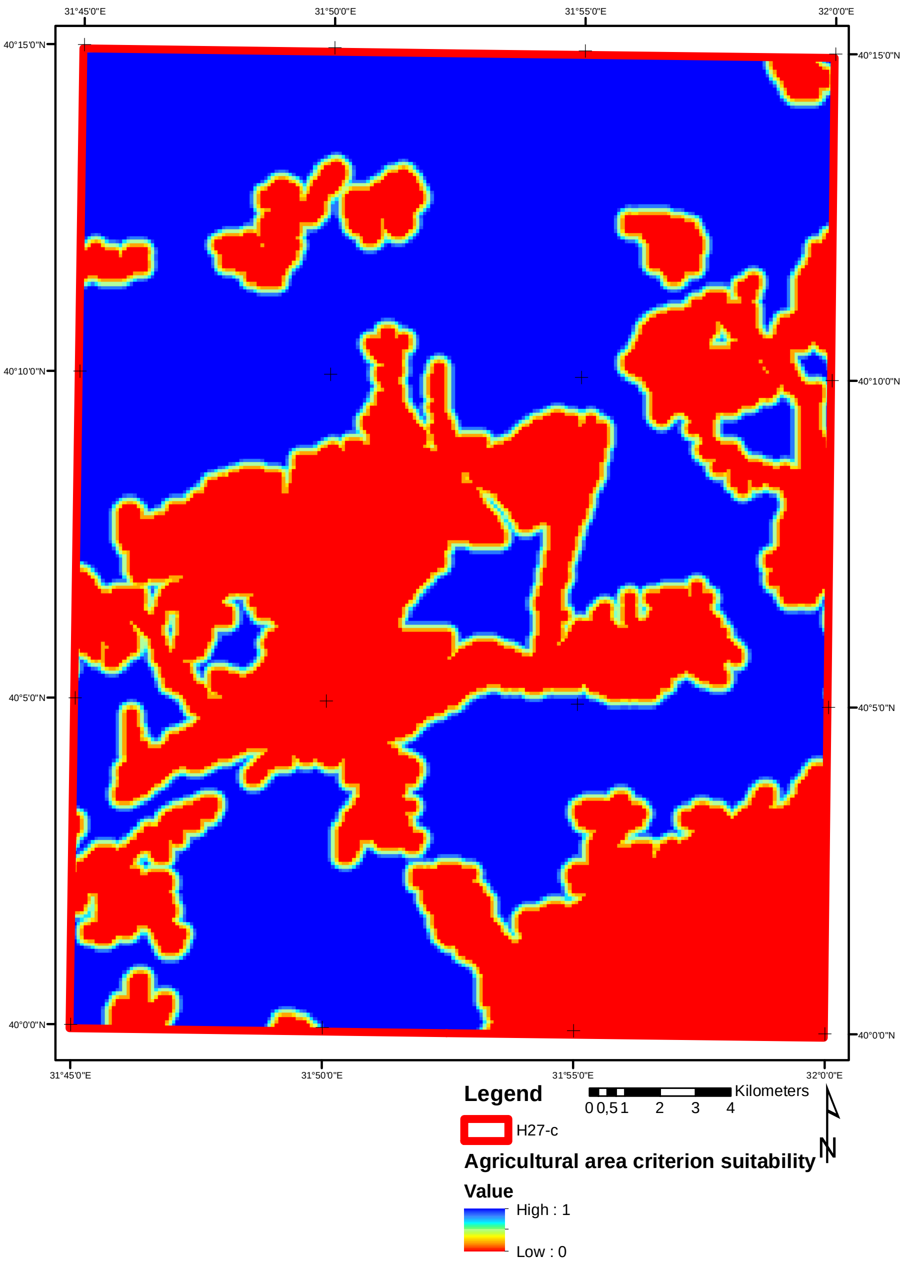


Figure 3.3. Suitability map according to fuzzy membership function for distance to agricultural areas criterion

Second environmental and regulatory criterion is lakes and wetlands. From the Republic of Turkey Ministry of Agriculture and Forestry data, lakes, wetlands, dams are combined together and presented in Figure 3.4. As previously mentioned, in order to avoid missing data or incorrect cell value towards the edges before the distance map calculation adequate amount data outside the study area, shown with red frame, are also considered.

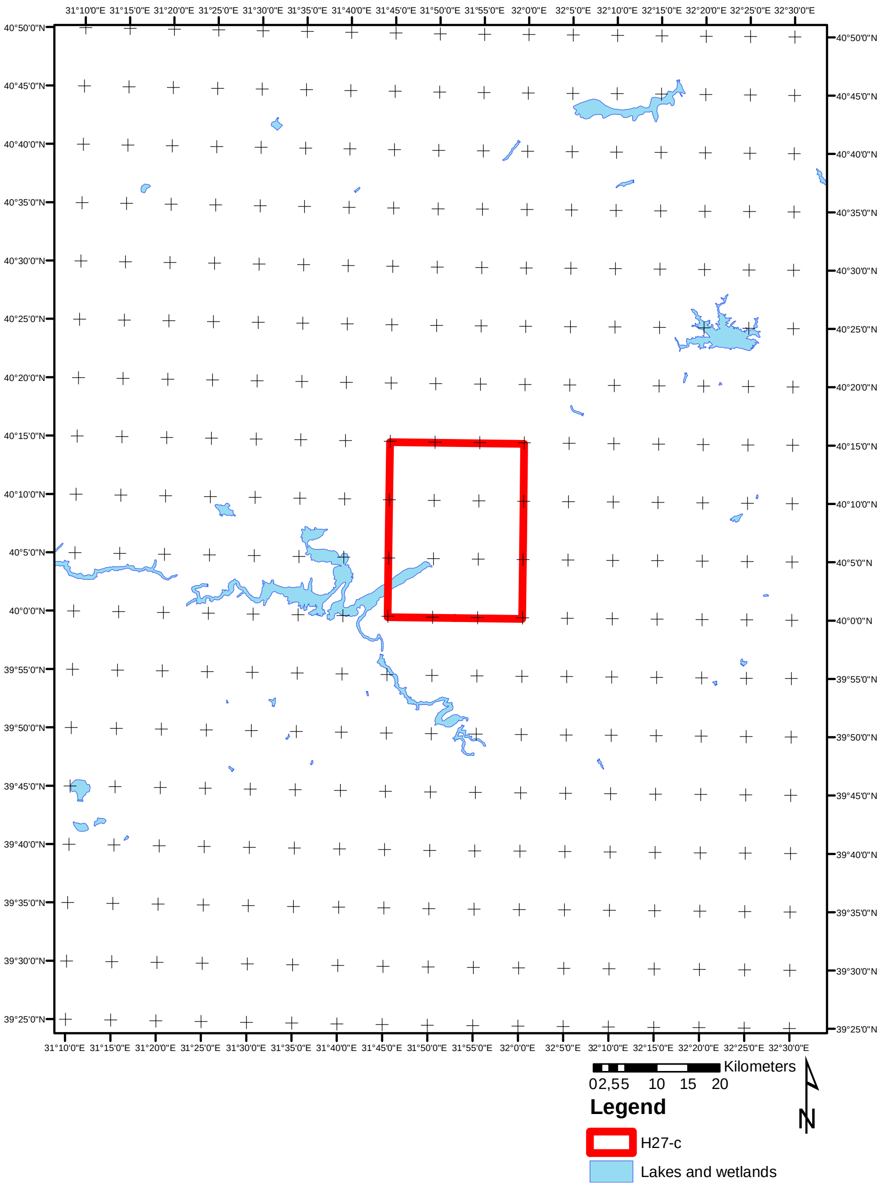


Figure 3.4. Locations of lakes and wetlands around the study area

The distance from lakes and wetlands for every location inside of the study area is calculated with the conversion of the selected vector data into raster data by the aid of Euclidean distance spatial analyst tool with 100-meter cell size (Figure 3.5).

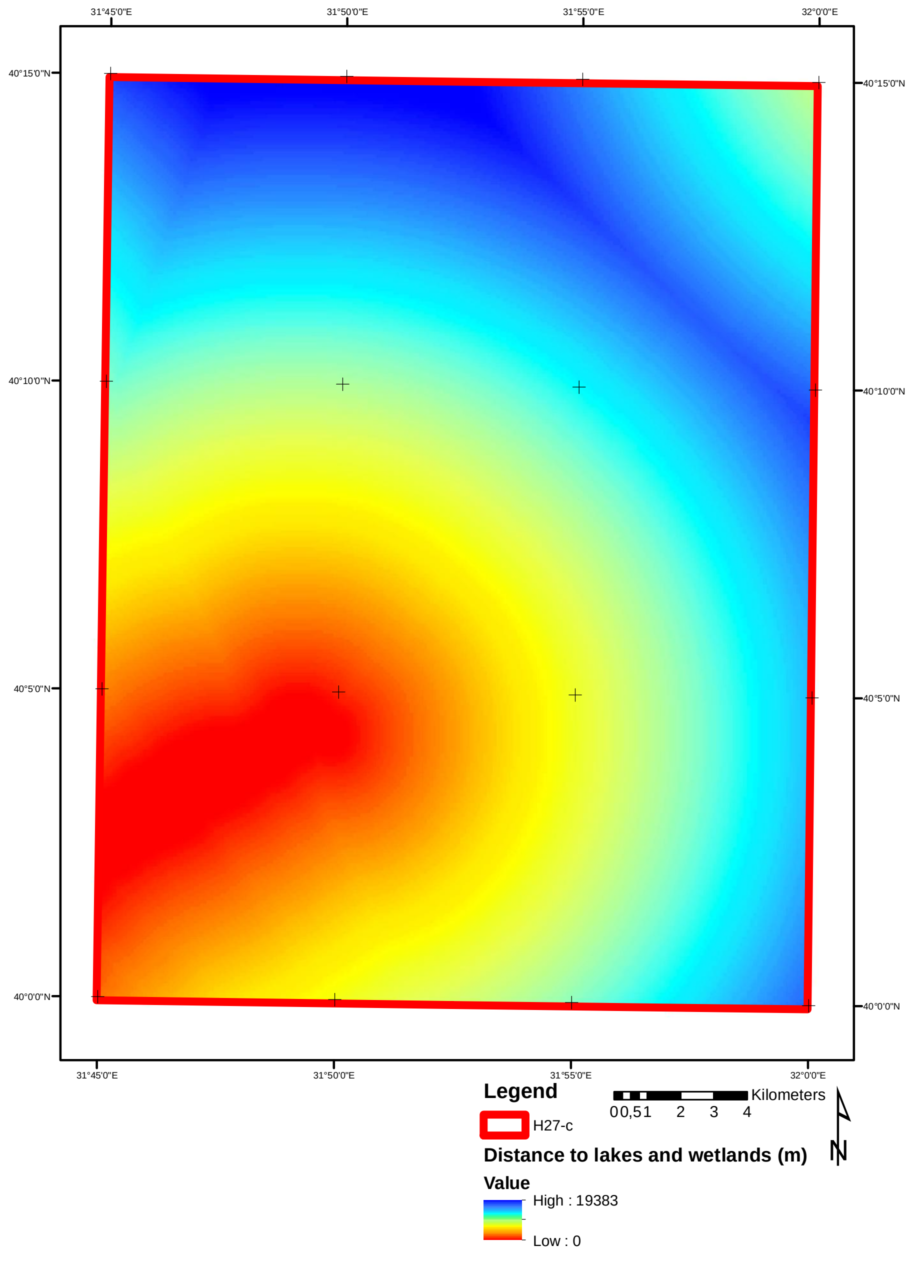


Figure 3.5. Distance to lakes and wetlands map

When the generation of distance map is completed, the suitability map shown in Figure 3.6 is produced according to the already defined fuzzy set membership function for distance to lakes and wetlands criterion presented in Table 2.2.

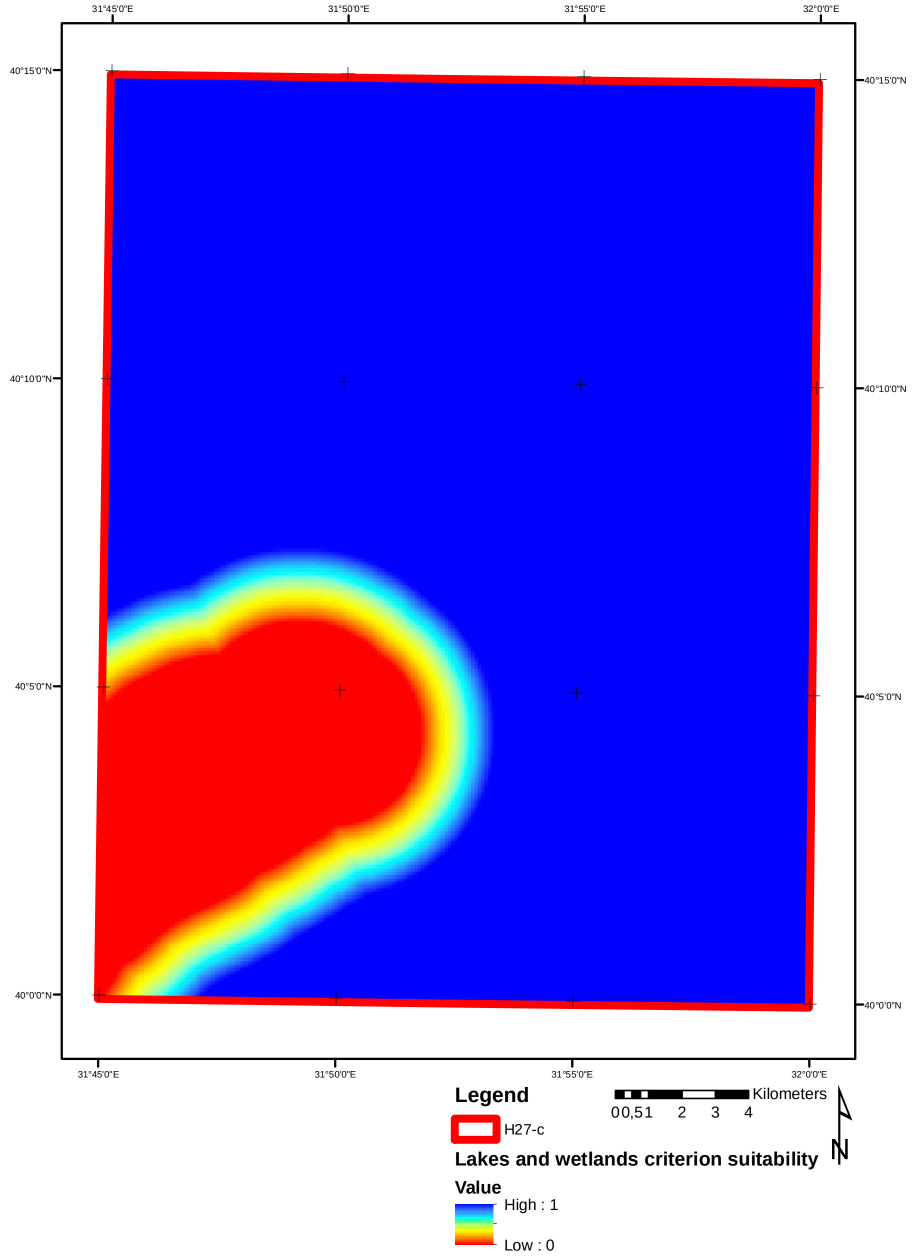


Figure 3.6. Suitability map according to fuzzy membership function for distance to lakes and wetlands criterion

The rivers are derived from USGS's 30-meter resolution Earthexplorer SRTM digital elevation model (DEM) which is given in Figure 3.7. By using spatial analyst hydrology tools, in the first step fill operation is applied to DEM and produced surface raster data is used as an input for flow direction calculation. Later on obtained flow direction raster is used to obtain flow accumulation raster. Afterwards from the produced flow accumulation raster, values greater than 2500 is selected by the help of algebraic map operation. And then from flow accumulation raster and flow direction raster, stream orders are calculated with Shreve method of stream ordering by magnitude, introduced by Shreve in 1967. In this method links without tributaries are assigned a magnitude or order of one. Magnitudes or orders are added as moved towards downslope. At the intersection of two links, their orders are added and assigned to the downslope link. Finally, using the produced stream order raster and flow direction raster as inputs in the stream to feature tool river layer used in this study is prepared and presented in Figure 3.8.

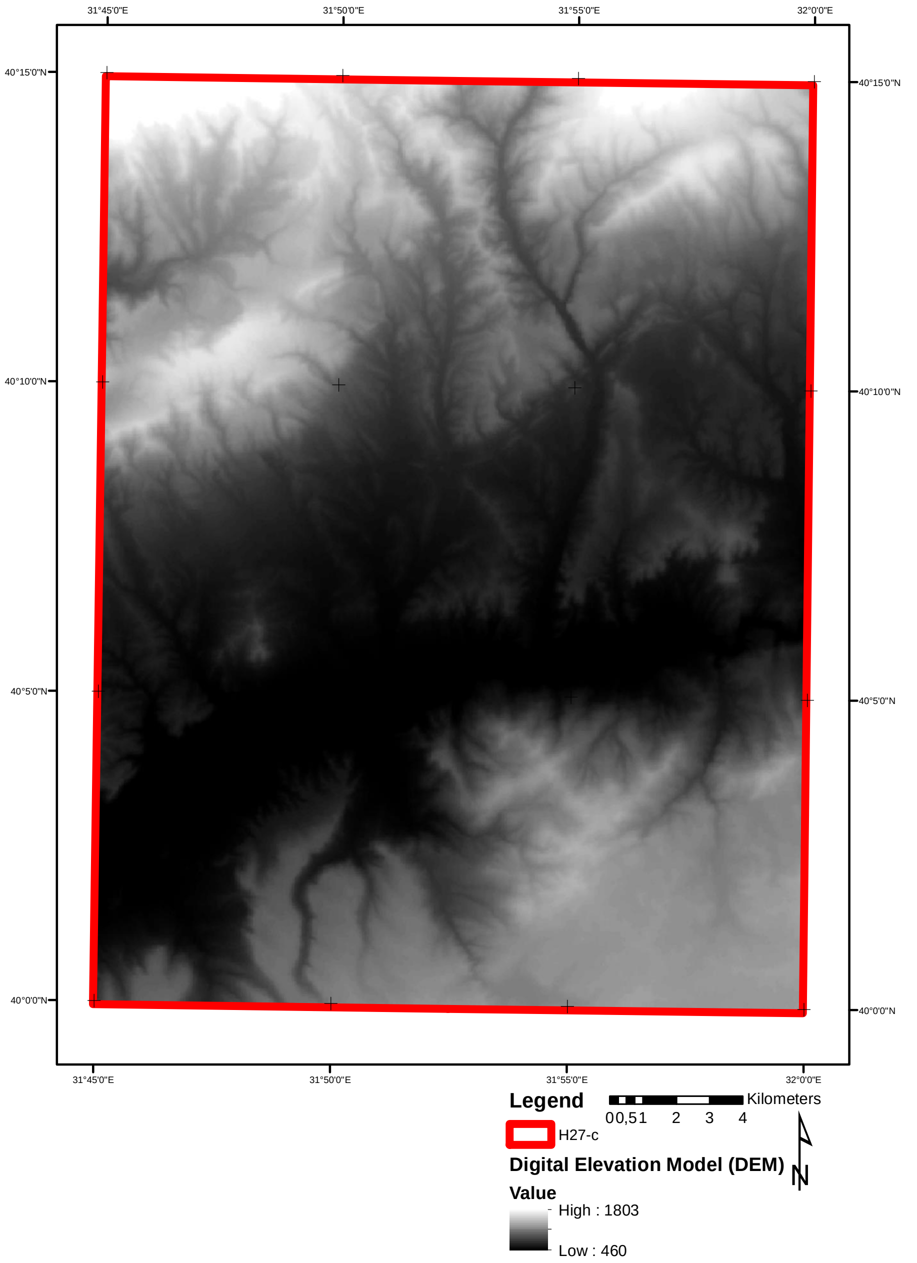


Figure 3.7. Digital elevation model of the study area

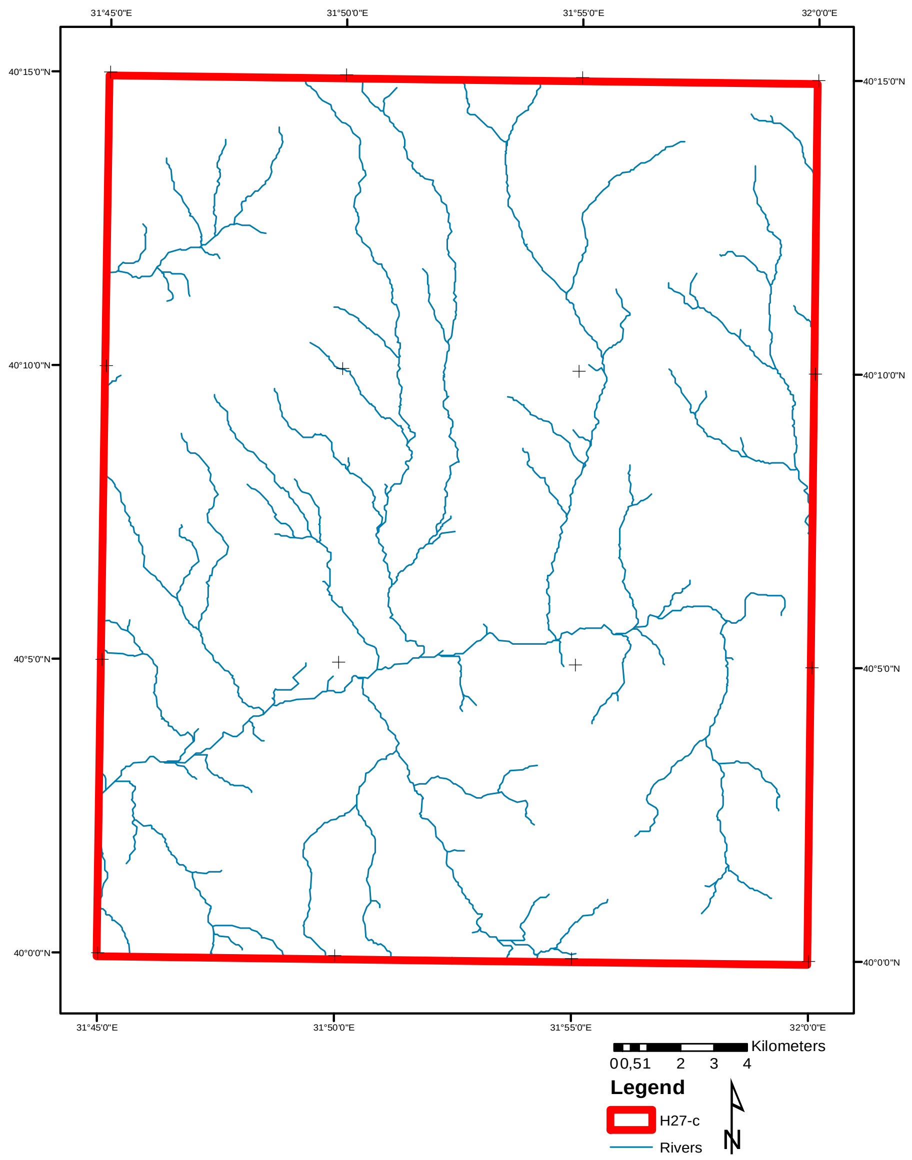


Figure 3.8. Rivers in the study area

By using the rivers map derived from digital elevation model (DEM), distance to rivers map is produced by the help of Euclidean distance tool with 100-meter raster cell size (Figure 3.9).

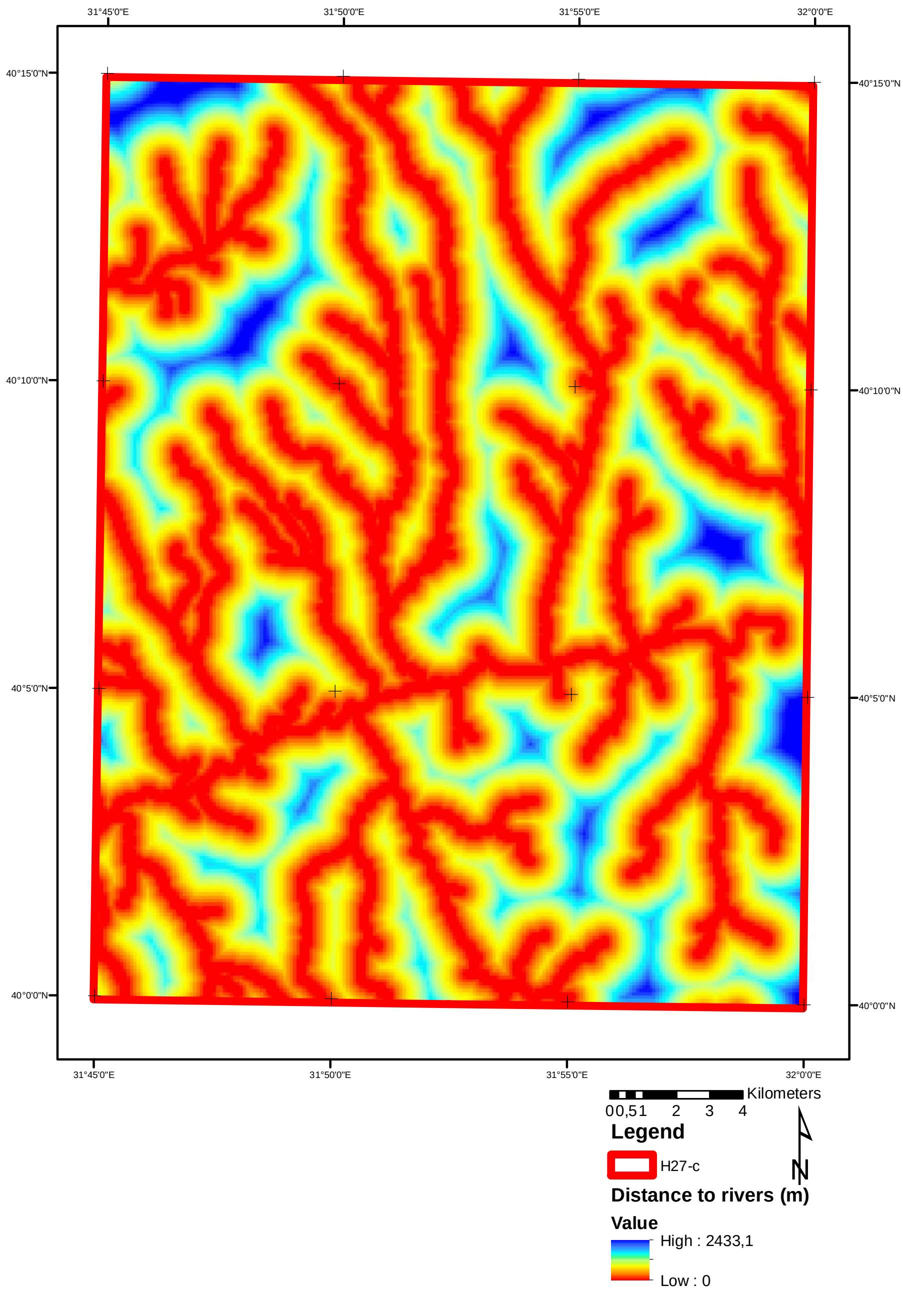


Figure 3.9 Distance to rivers map

Later on, in accordance with the pre-defined fuzzy set membership function for distance to rivers criterion given in Table 2.2, the suitability map shown in Figure 3.10 is generated.

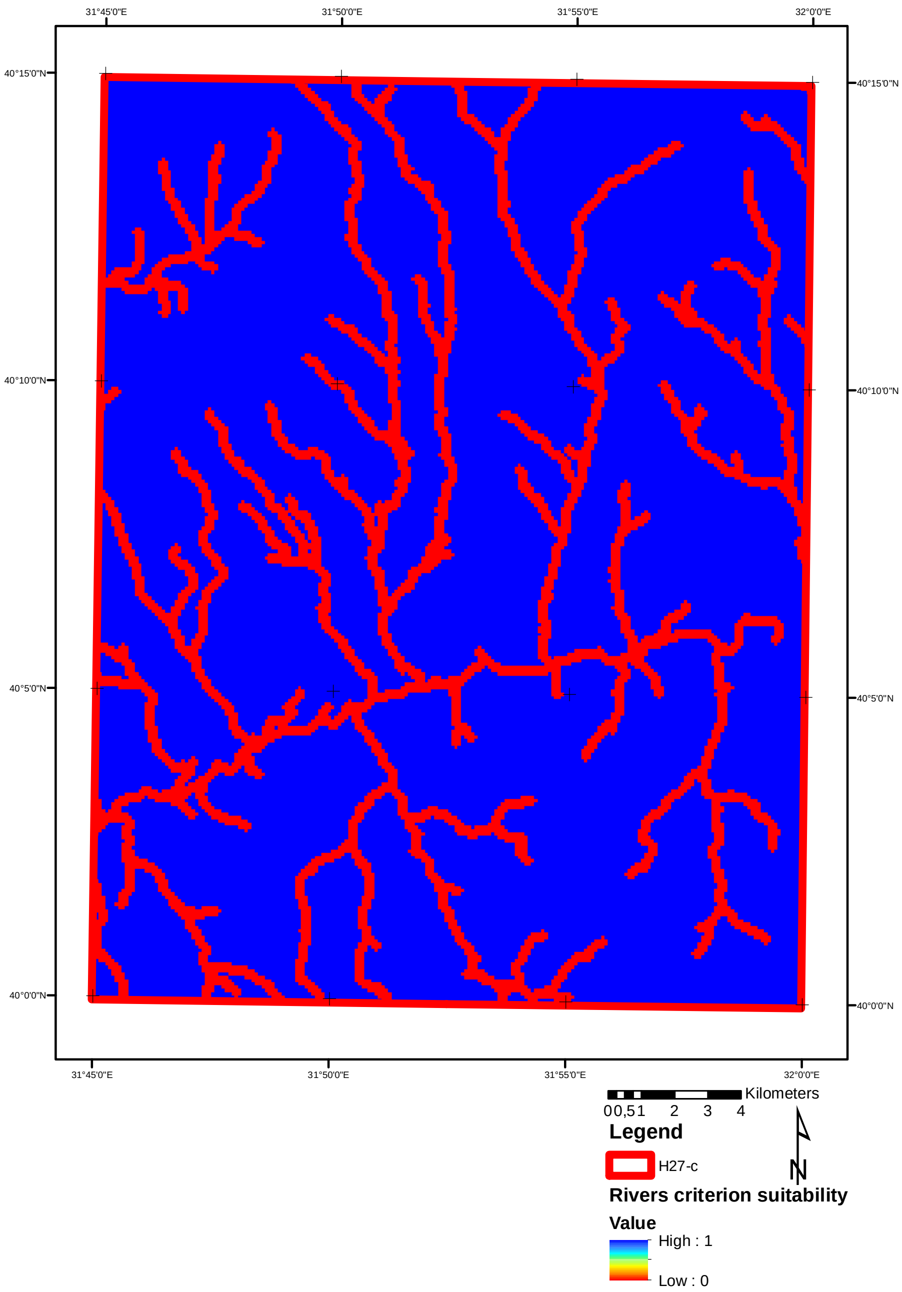


Figure 3.10. Suitability map according to fuzzy membership function for distance to rivers criterion

Last environmental and regulatory criterion is natural protection zones and forest areas. Natural protection zones and forest areas are combined together from the Republic of Turkey Ministry of Agriculture and Forestry data and presented in Figure 3.11. As mentioned before, to avoid data loss or incorrect cell value calculation towards the edges of the study area before the generation of distance map sufficient amount of data outside the red framed study area, are also evaluated.

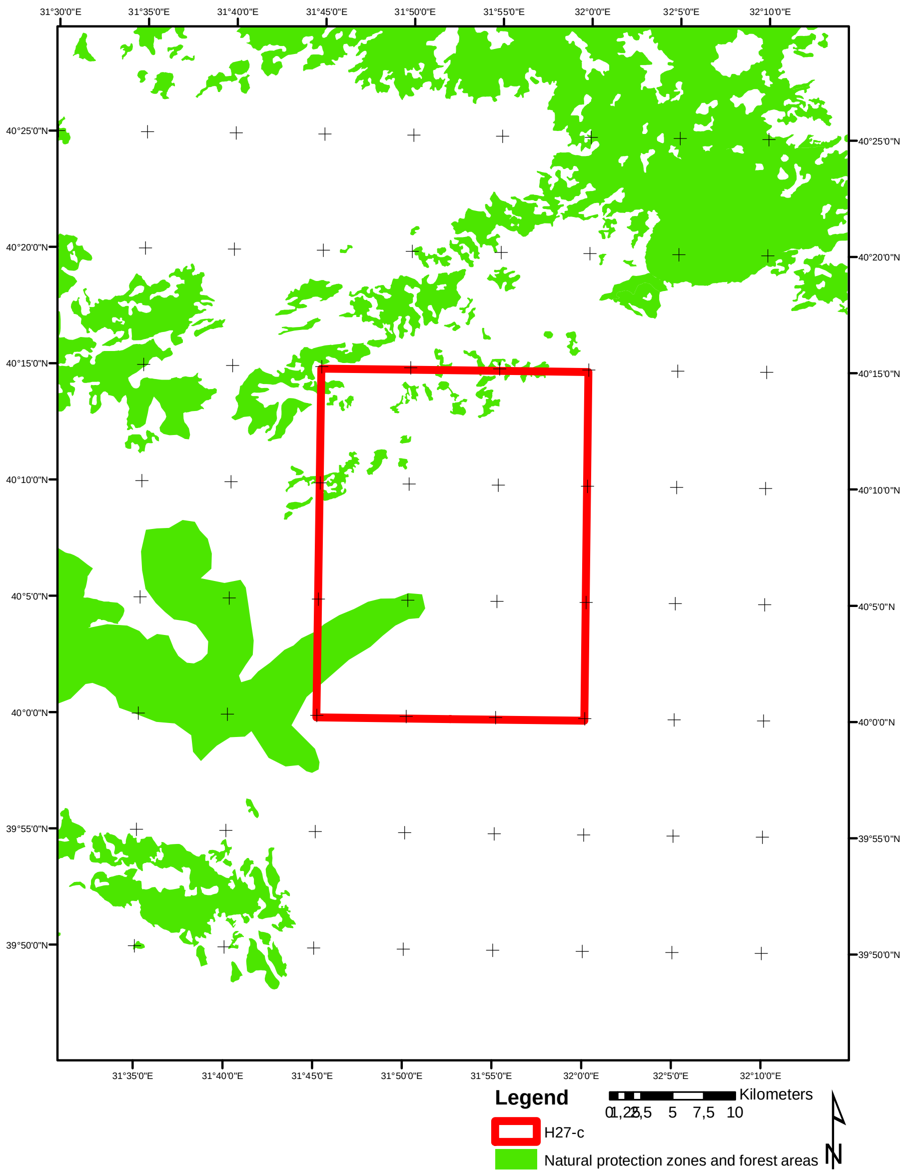


Figure 3.11. Natural protection zones and forest areas around the study area

Conversion of the natural protection zones and forest areas vector data to distance raster data with 100-meter cell sized is made by the help of Euclidean distance spatial analyst tool (Figure 3.12).

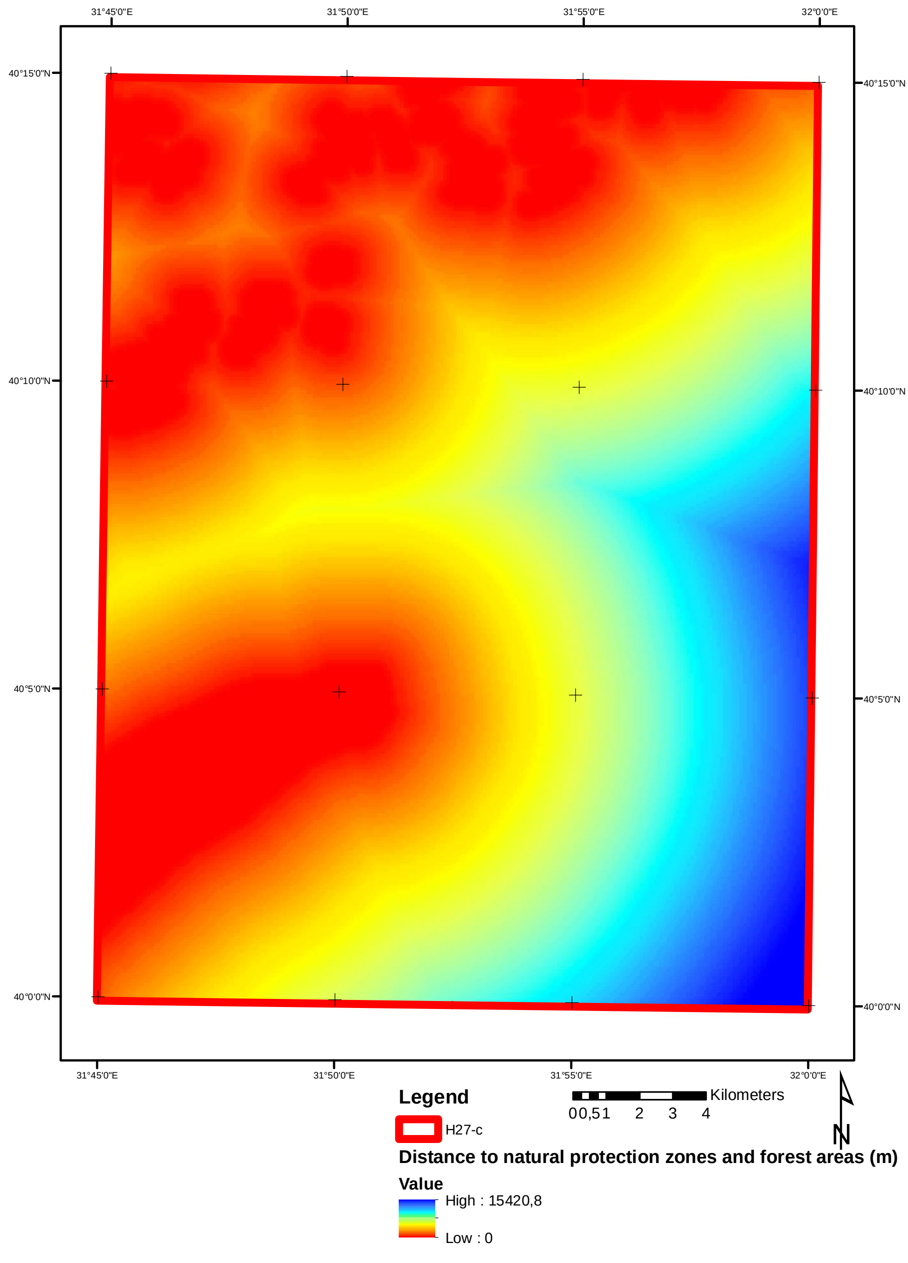


Figure 3.12. Distance to natural protection zones and forest areas map

After the distance map is produced, the suitability map given in Figure 3.13 is generated in accordance with the previously defined fuzzy set membership function for distance to natural protection zones and forest areas criterion presented in Table 2.2.

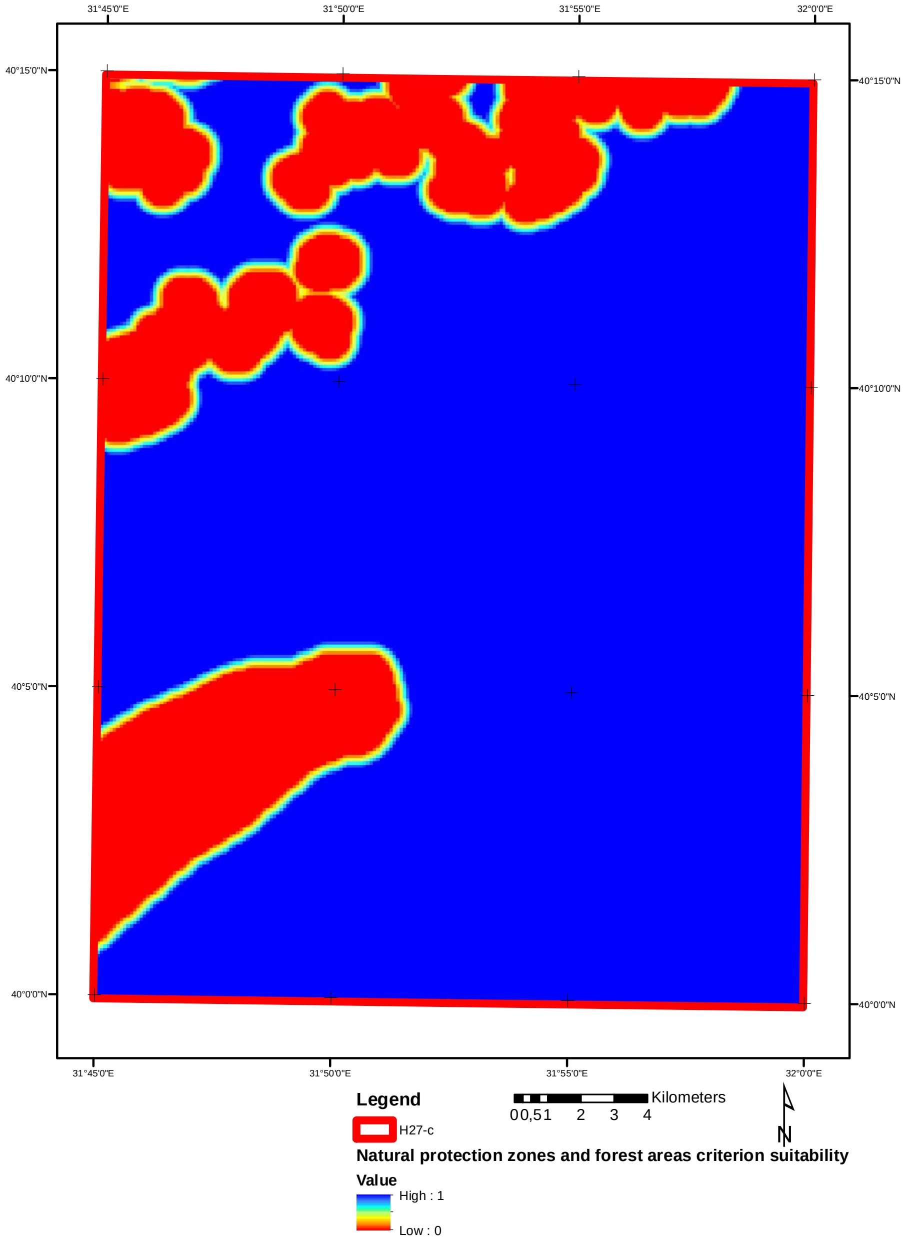


Figure 3.13. Suitability map according to fuzzy membership function for distance to natural protection zones and forest areas criterion

After suitability maps for all environmental and regulatory objectives are completed, suitability maps for each economic and technical feasibility criterion are produced in accordance with the fuzzy sets membership functions.

Slope which is identified as the most important economic and technical feasibility criterion are derived from USGS's 30-meter resolution Earthexplorer SRTM digital elevation model (DEM) which is given in Figure 3.7. By using the slope calculation tool, which is the sub-tab of the surface calculation among the spatial analyst tools, percent slopes for the whole study area is calculated and given in Figure 3.14.

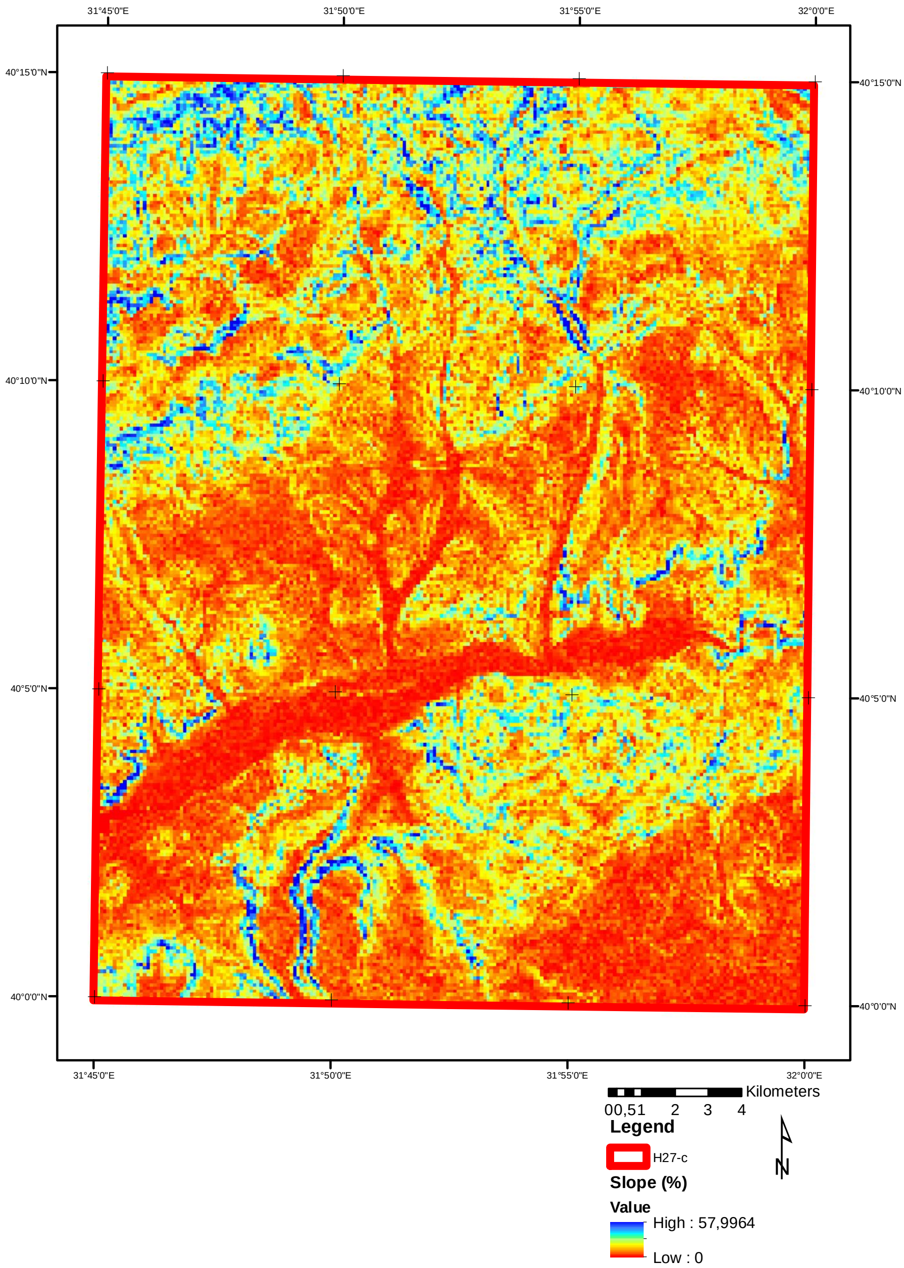


Figure 3.14. Slope percentage map

After the generation of slope percentage map, the suitability map shown in Figure 3.15 is produced with respect to predefined fuzzy set membership function for slope percentages criterion presented in Table 2.3.

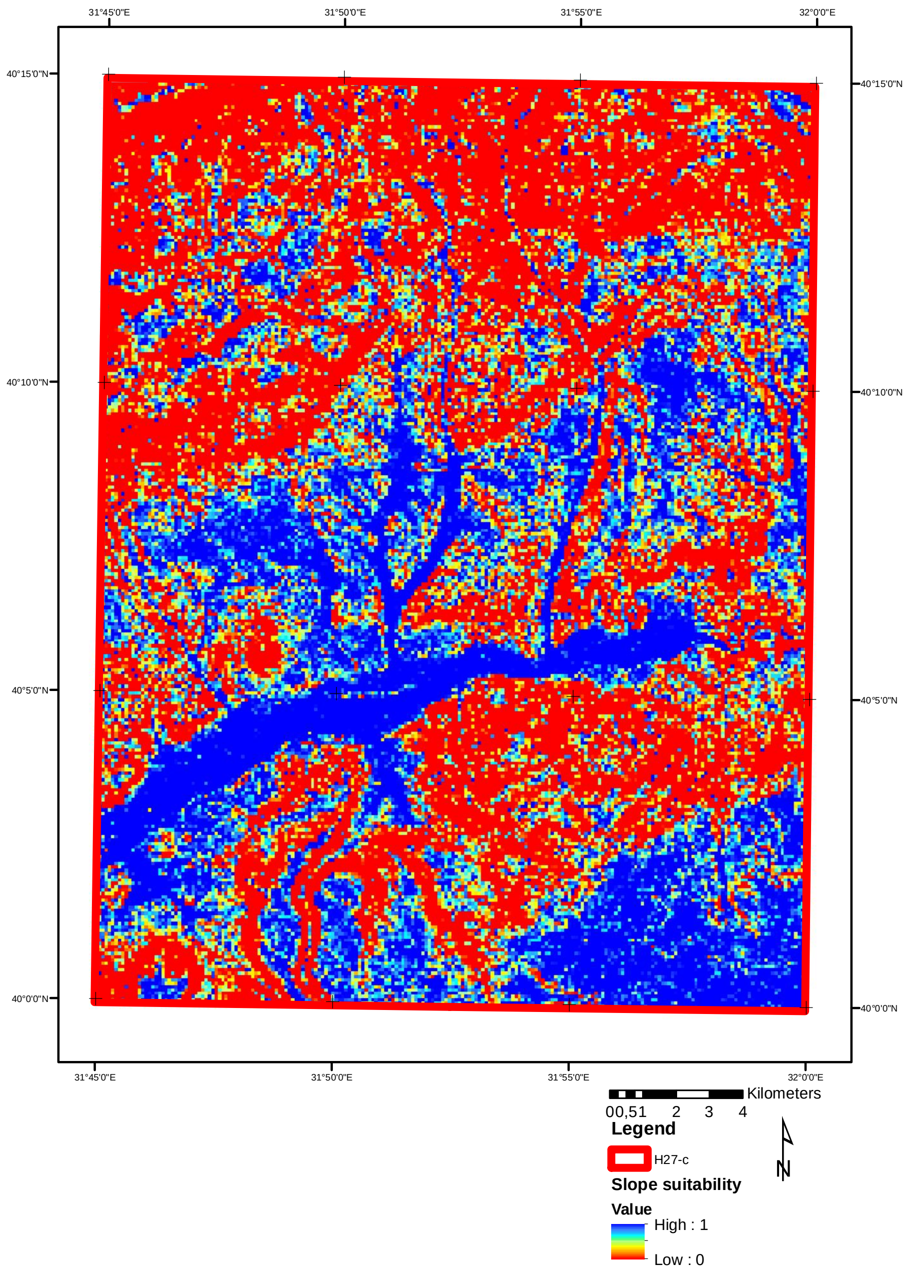


Figure 3.15. Suitability map according to fuzzy membership function for slope percentages criterion

Second economic and technical feasibility criterion is distance to transmission lines. Transmission lines vector data obtained from Başkent Electricity Distribution Inc. and presented in Figure 3.16. As previously mentioned, to avoid data loss or incorrect cell value calculation towards the edges of the study area before the generation of distance map sufficient amount of data outside the red framed study area, are also taken into account.

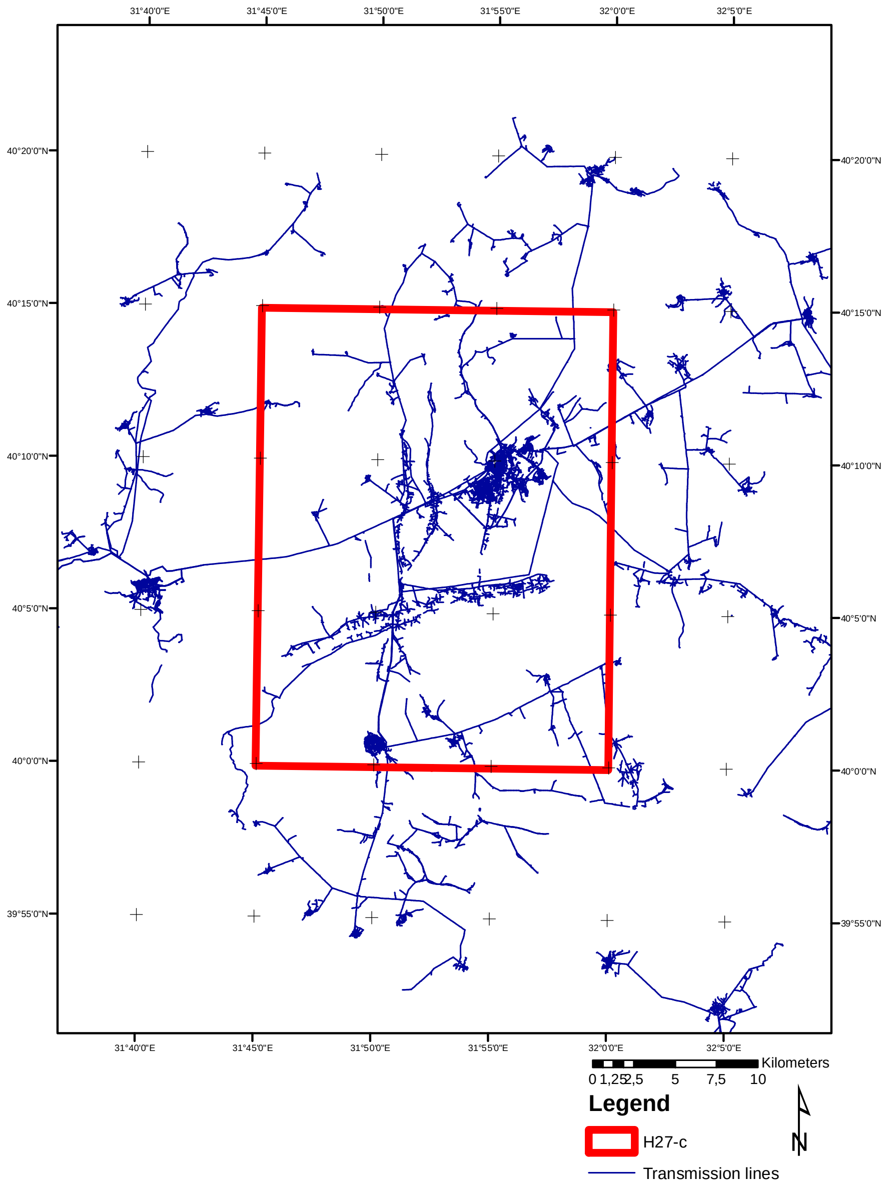


Figure 3.16. Transmission lines around the study area

The transmission lines vector data conversion to distance raster data with 100-meter cell sized is performed by the help of Euclidean distance spatial analyst tool and produced distance map is presented in Figure 3.17.

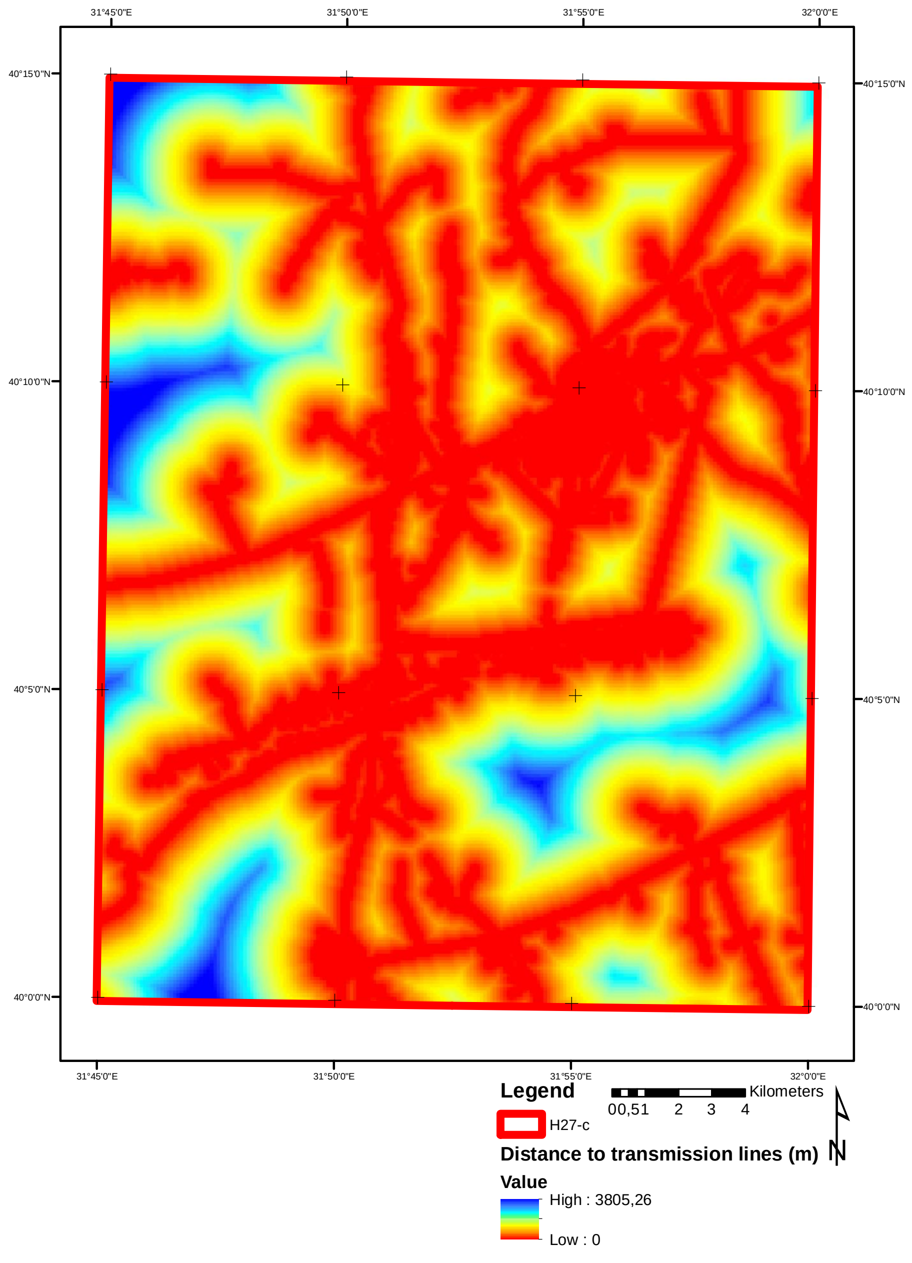


Figure 3.17. Distance to transmission lines map

Later on the distance to transmission lines map is generated, the suitability map given in Figure 3.18 is calculated according to the already defined fuzzy set membership function for distance to transmission lines criterion presented in Table 2.3.

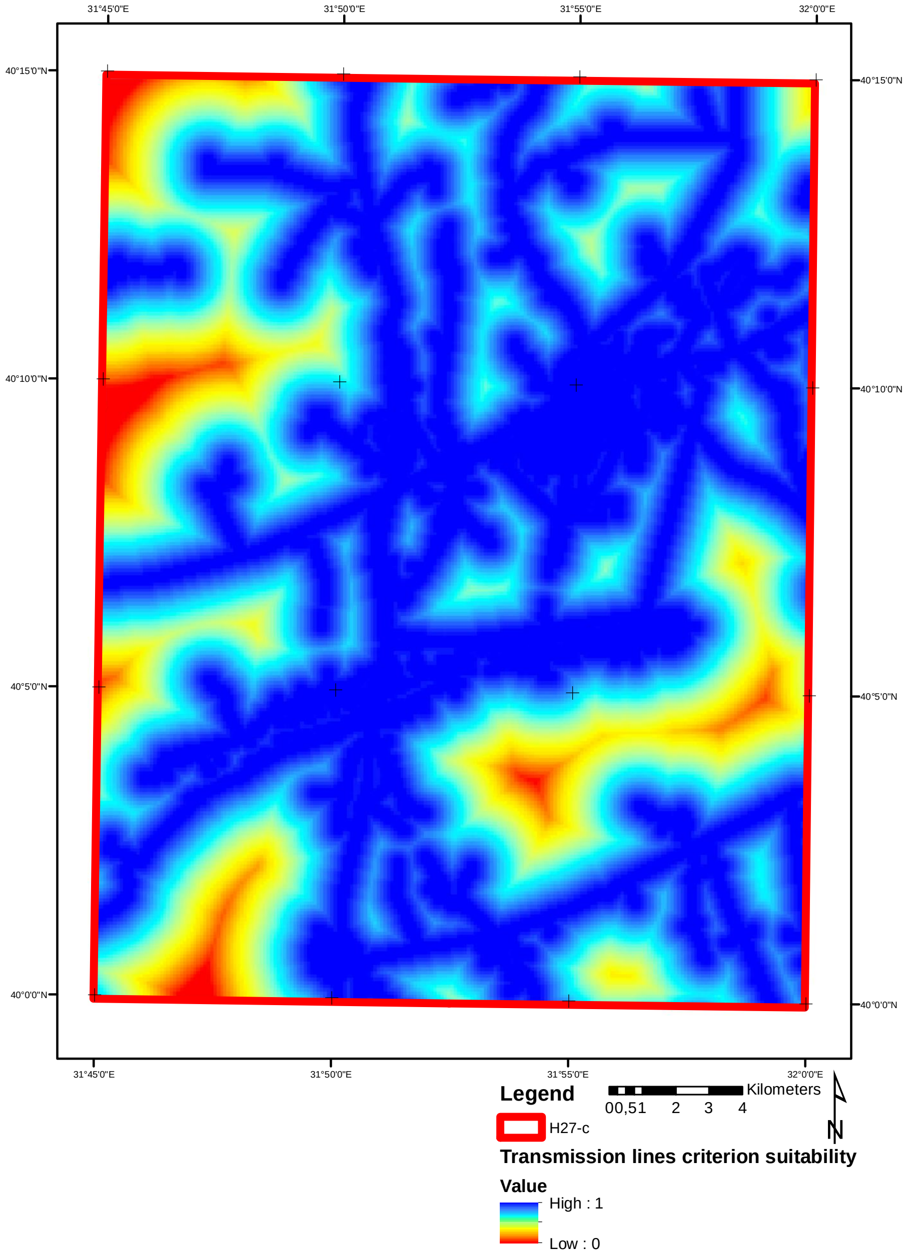


Figure 3.18. Suitability map according to fuzzy membership function for distance to transmission lines criterion

Next economic and technical feasibility criterion is distance to settlement areas. Data used for distance to settlement areas feasibility calculations are derived from the Republic of Turkey Ministry of Agriculture and Forestry database and presented in Figure 3.19 below. With similar manner, data outside of the red framed study area are also considered during calculations.

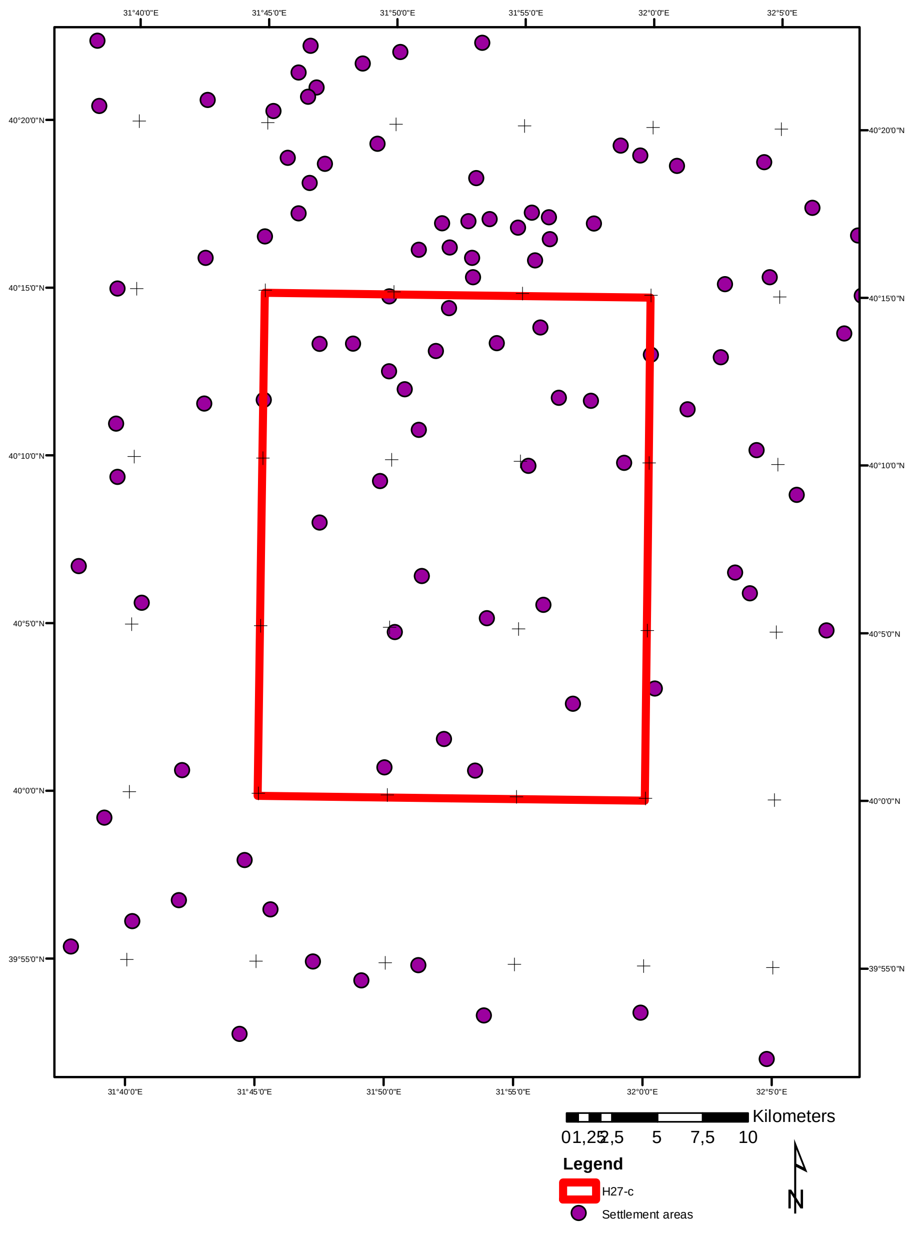


Figure 3.19. Settlement areas around the study area

By using the settlement areas vector data, distance to settlement areas raster map is produced with 100-meter raster cell size (Figure 3.20).

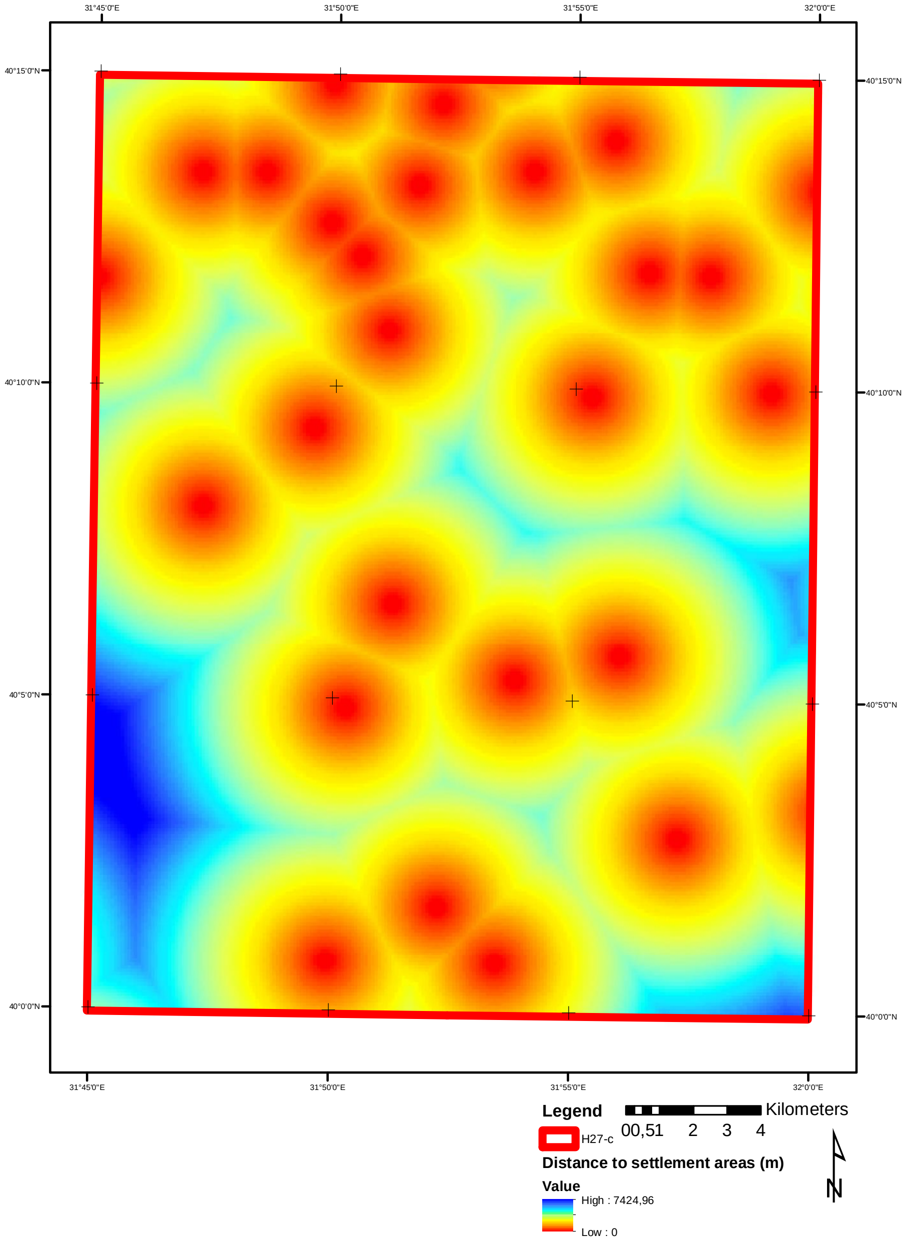


Figure 3.20. Distance to settlement areas map

After the distance to settlement areas map production is completed, the suitability map given in Figure 3.21 is generated based on the defined fuzzy set membership function for distance to settlement areas criterion presented in Table 2.3.

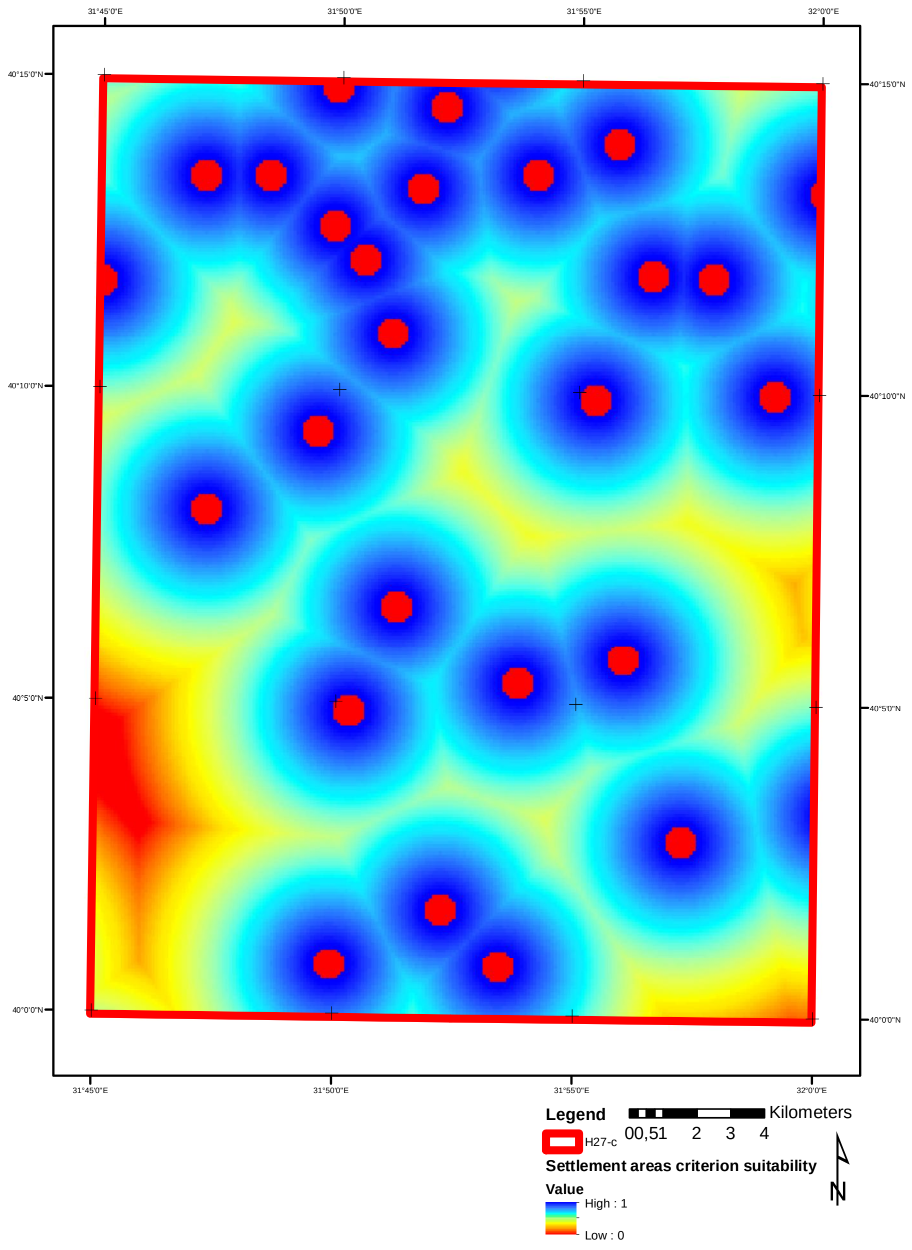


Figure 3.21. Suitability map according to fuzzy membership function for distance to settlement areas criterion

Last economic and technical feasibility criterion is distance to roads. Data used for distance to roads feasibility calculations are derived from the General Directorate of Maps and presented in Figure 3.22 below. Similar to previous applications, data outside of the red framed study area are also taken into account during calculations.

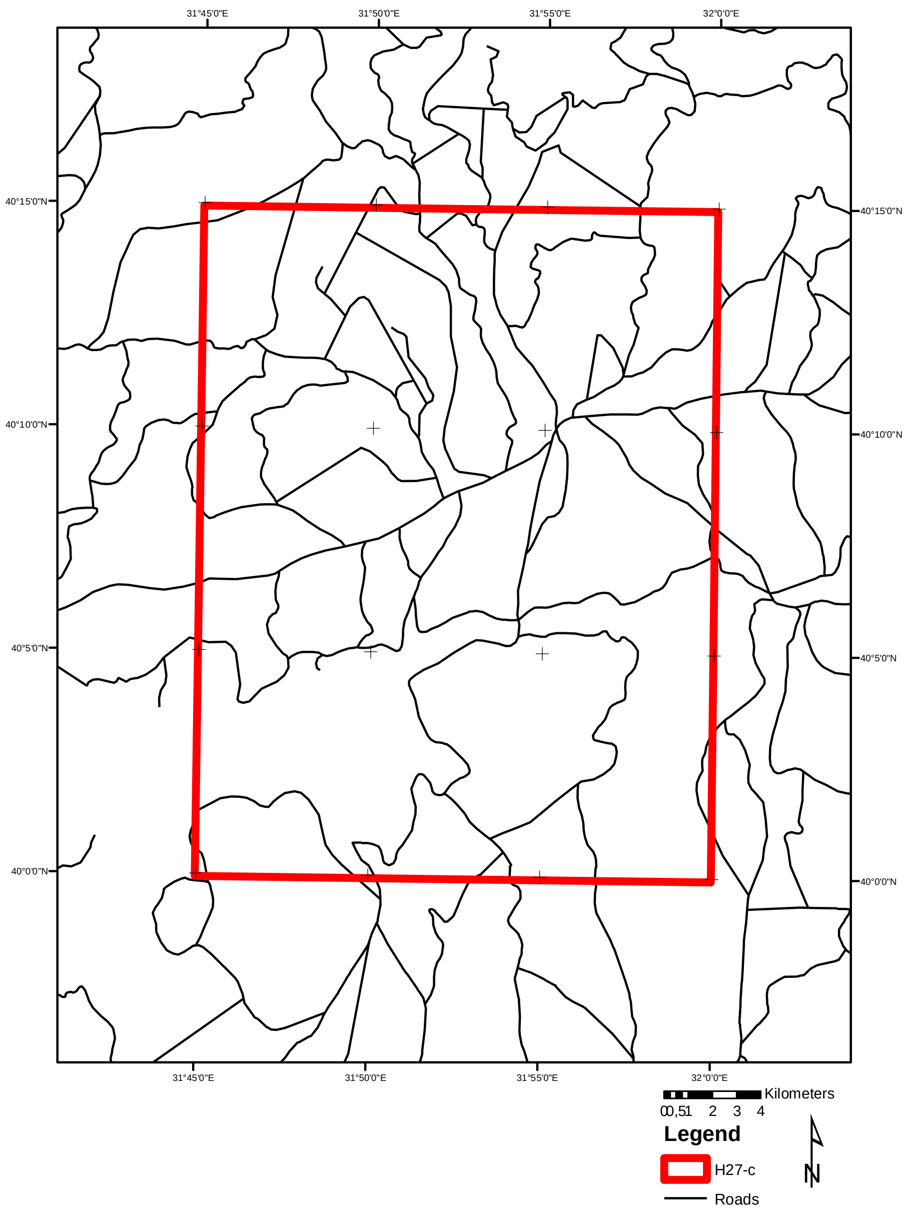


Figure 3.22. Roads around the study area

The roads vector data conversion to distance to roads raster data with 100-meter cell sized is performed by the help of Euclidean distance spatial analyst tool and generated distance to roads map is shown in Figure 3.23.

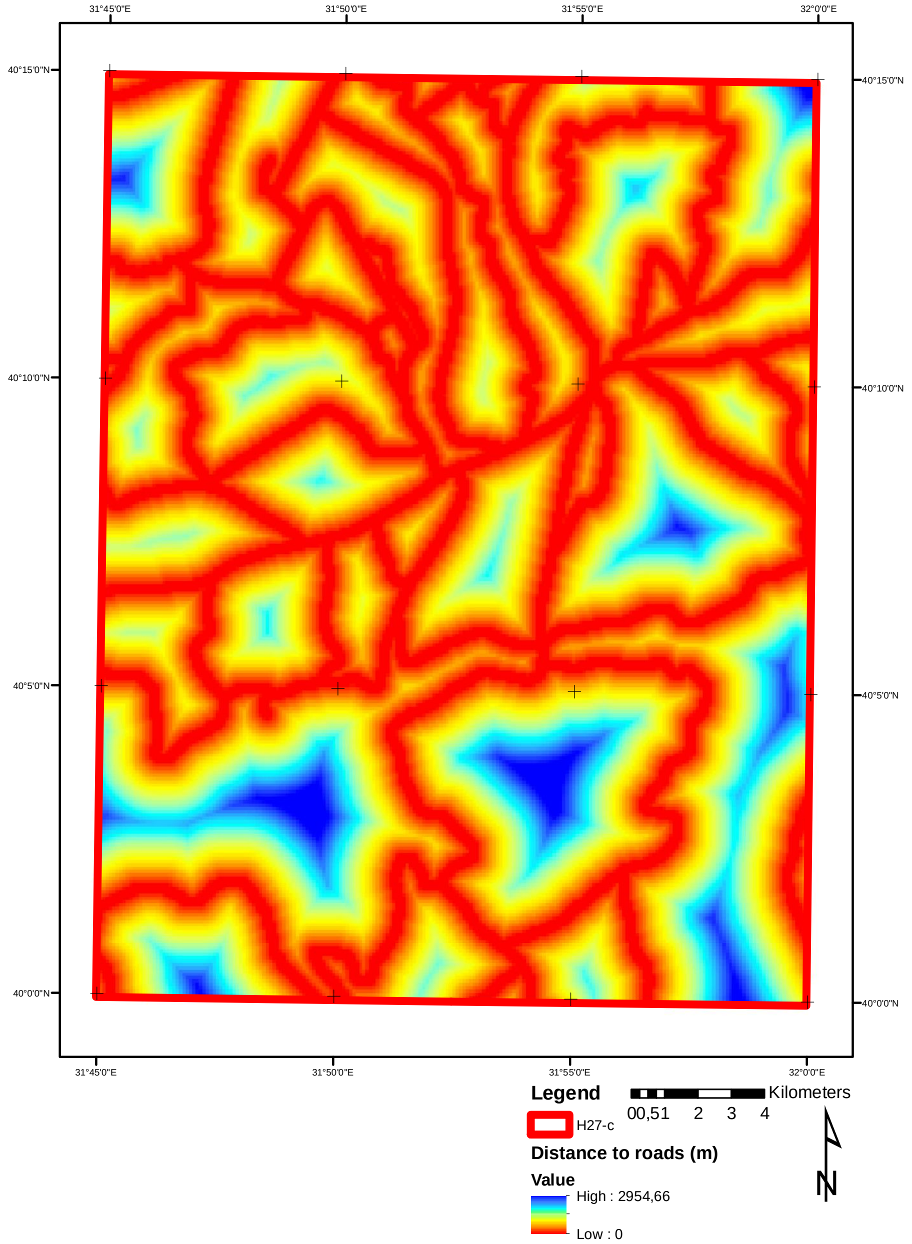


Figure 3.23. Distance to roads map

Later on the distance to roads map preparation is finished, the suitability map given in Figure 3.24 is produced according to the predefined fuzzy set membership function for distance to roads criterion presented in Table 2.3.

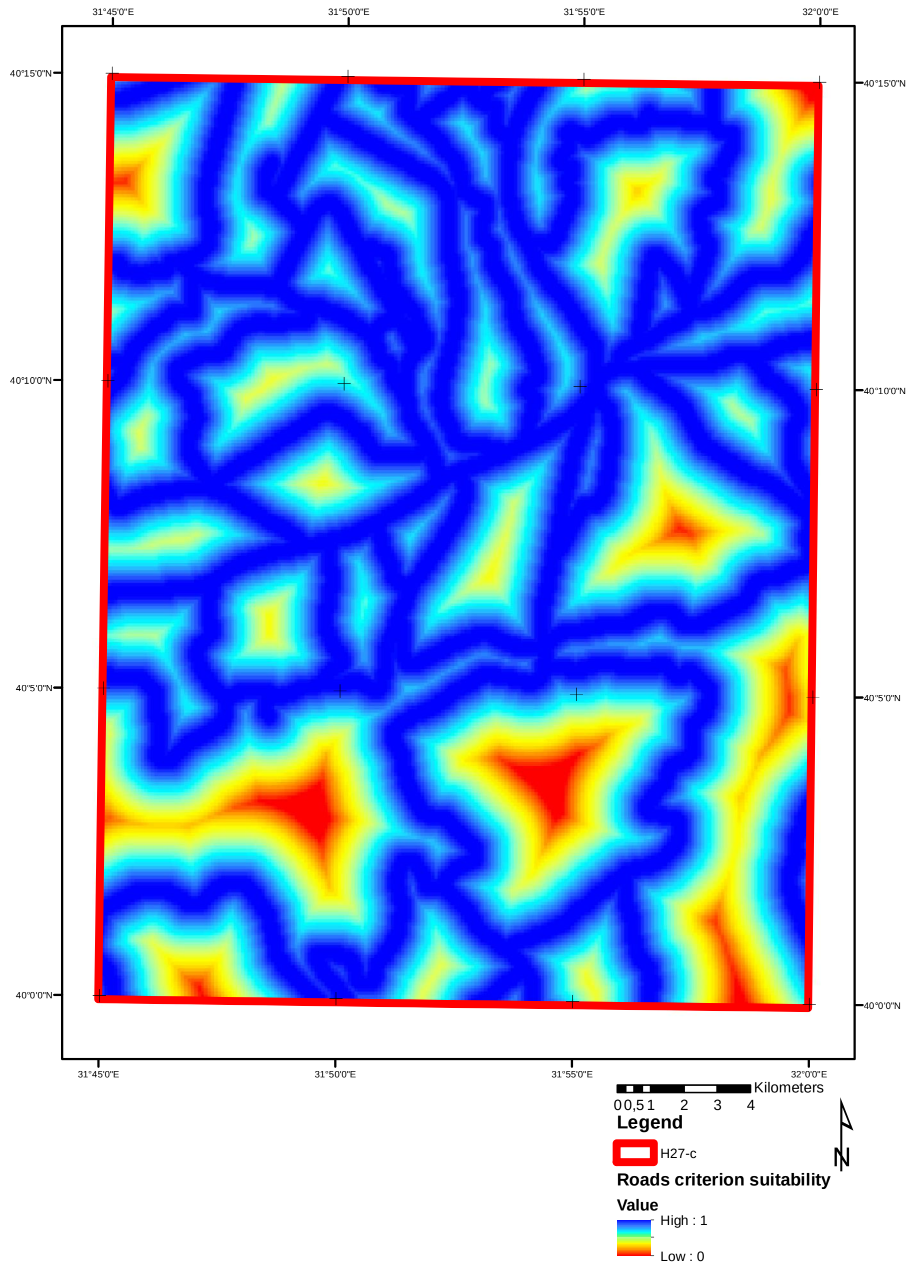


Figure 3.24. Suitability map according to fuzzy membership function for distance to roads criterion

After all these suitability maps are generated. MCDA4ArcMap software extension is used for quantifier guided OWA calculations to obtain overall performance by multi criteria aggregation. Previously defined weights, which are derived by the aid of AHP, were used during OWA aggregation operations. ñAllò linguistic quantifier is preferred for the OWA operations by supposing that the meeting "all" of the environmental and regulatory objectives and economic and technical feasibility criteria is a reasonable expectation. By this way cells which are not satisfying the decision makersô preferences for any of the criteria is masked as a result of this OWA multi criteria aggregation operation while calculating the overall potentials based on environmental and regulatory objectives and also economic and technical feasibility criteria. By using the weights given in Figure 2.3 within the OWA operations overall potential map based on environmental and regulatory objectives is produced and presented in Figure 3.25. In overall potential map based on environmental and regulatory objectives blue areas are representing the most suitable areas, red areas are showing the least suitable areas and white areas are identified as constrained or unsuitable areas in terms of environmental and regulatory objectives (Figure 3.25).

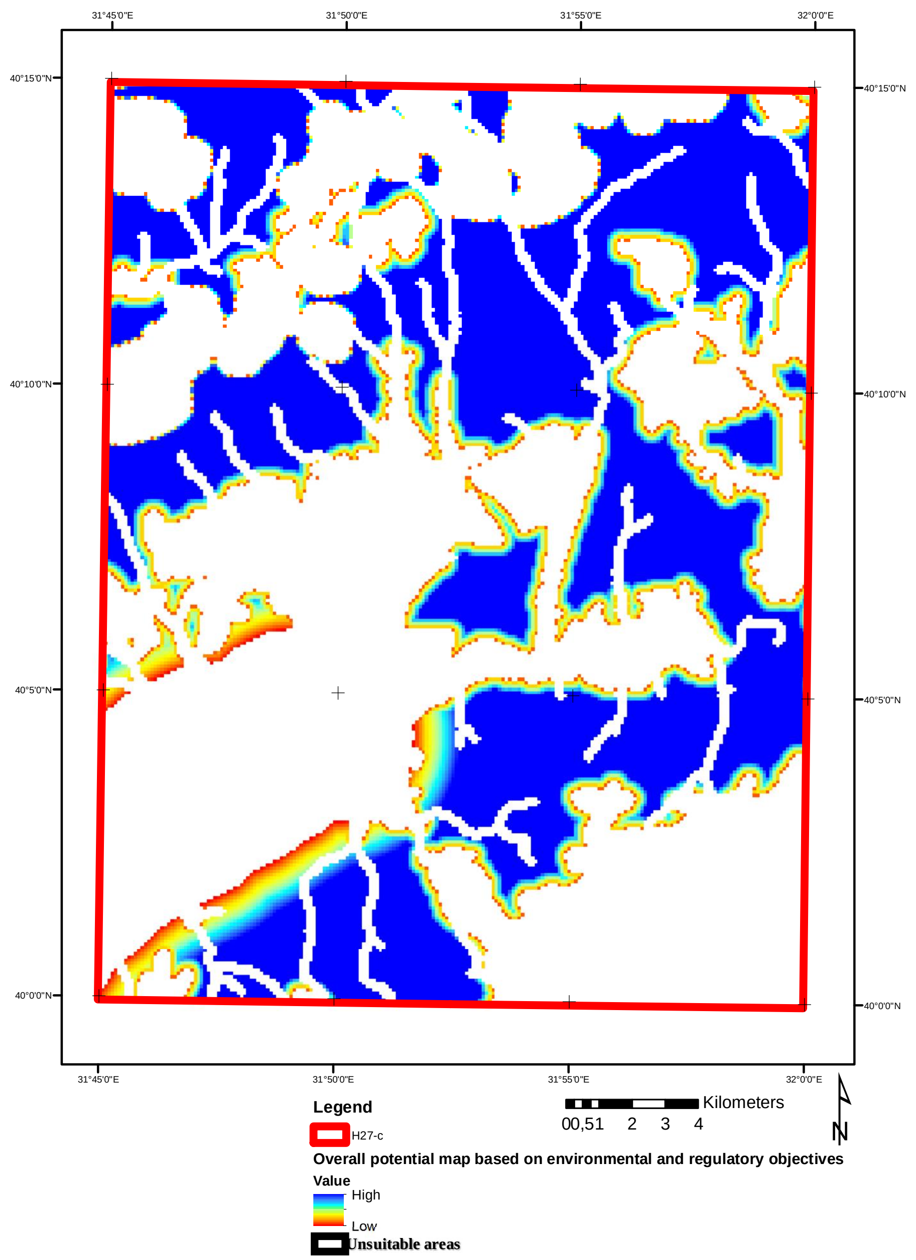


Figure 3.25. Overall potential based on environmental and regulatory objectives

Similarly, by the help of the weights given in Figure 2.4 within the OWA operations overall potential map based on economic and technical feasibility criteria is generated and shown in Figure 3.26. In overall potential map based on economic and technical feasibility criteria blue areas are representing the most suitable areas, red areas are showing the least suitable areas and white areas are identified as economically and technically unfeasible or unsuitable areas (Figure 3.26).

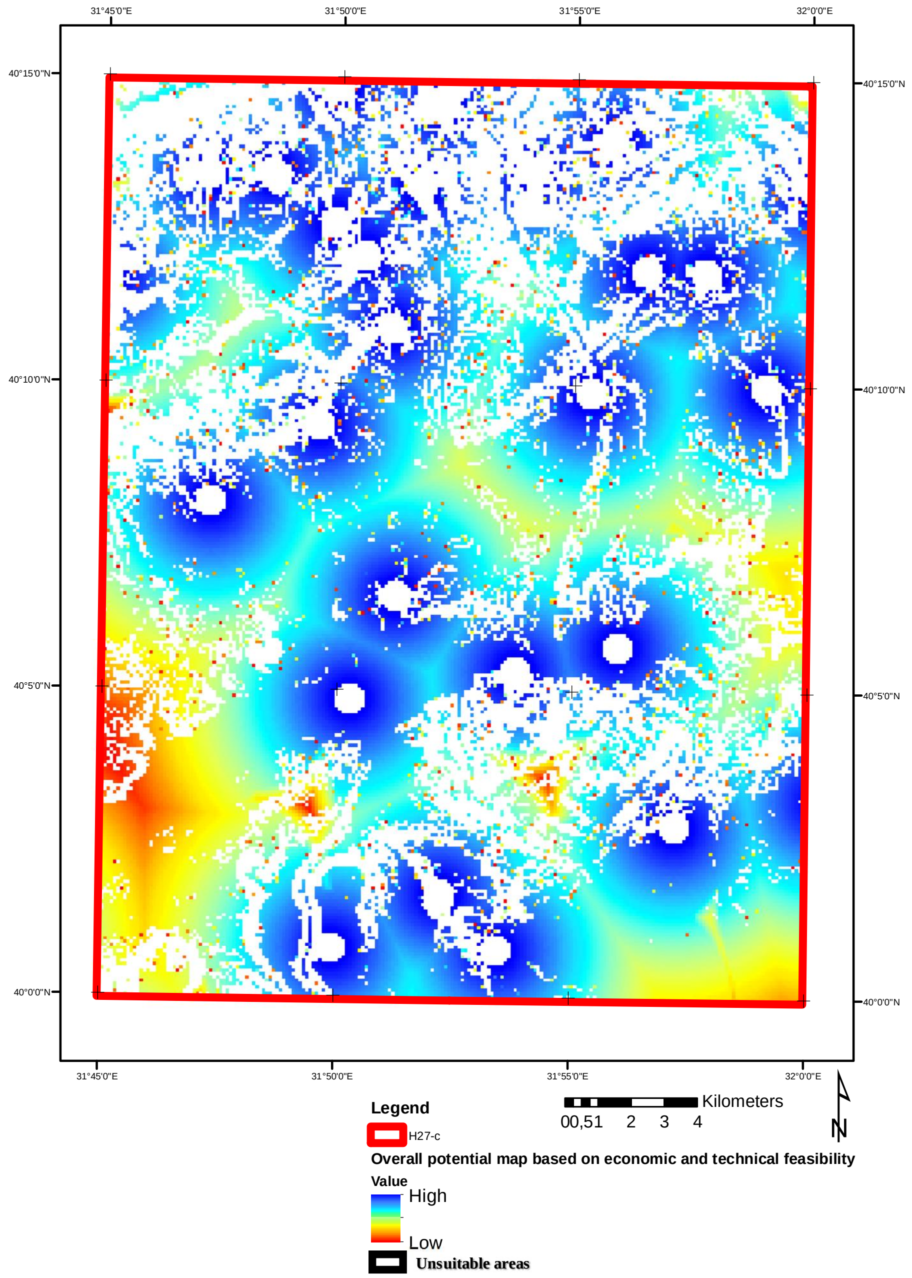


Figure 3.26. Overall potential map based on economic and technical feasibility

After overall potential maps based on environmental-regulatory objectives and economic-technical feasibility, to select priority sites overall potential is calculated in accordance with the specified rules and categorization of the study area for suitability to solar PV plant installations introduced in Table 2.8. To compute categorization map simple algebraic map operations are performed by raster calculation tool in ArcGIS software. The final map of the study area categorization for suitability to solar PV plant installations produced by following these explained steps and produced map is given in Figure 3.27.

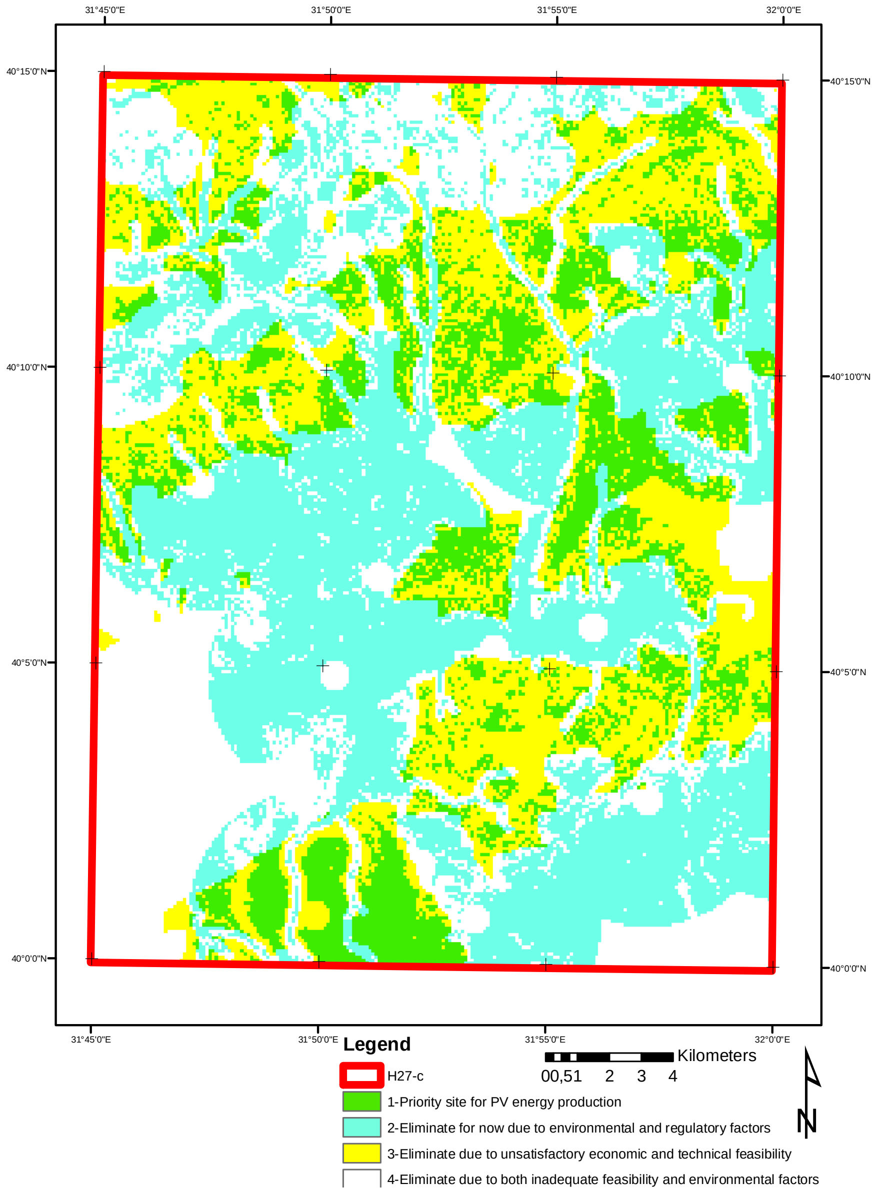


Figure 3.27. The study area categorization for suitability to solar PV plant installations

Finally, for identifying the superior areas in terms of efficiency and production potential within the determined priority PV sites, solar radiation distribution (Figure 3.28) along potential solar PV power plant areas are revealed in Figure 3.29.

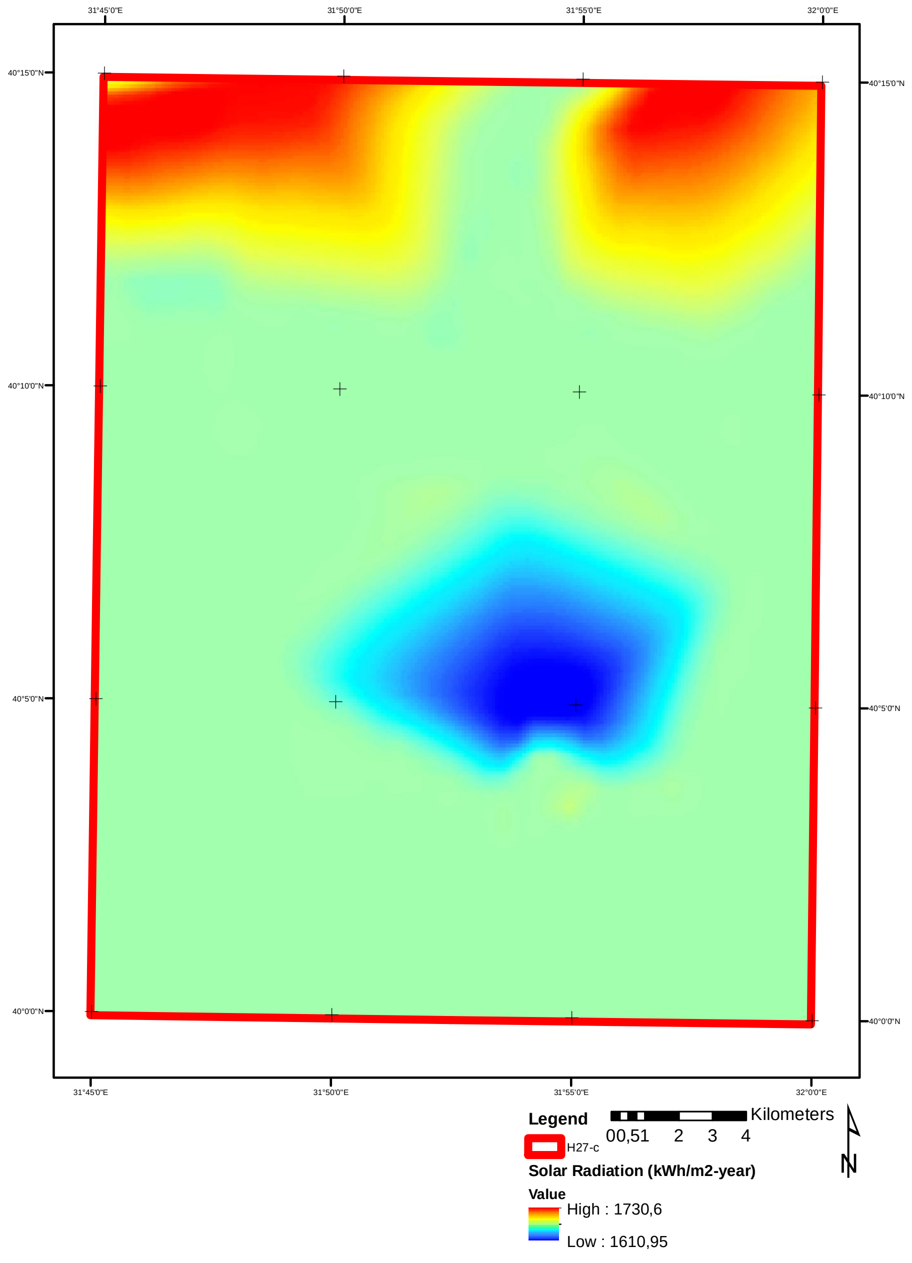


Figure 3.28. Solar radiation map

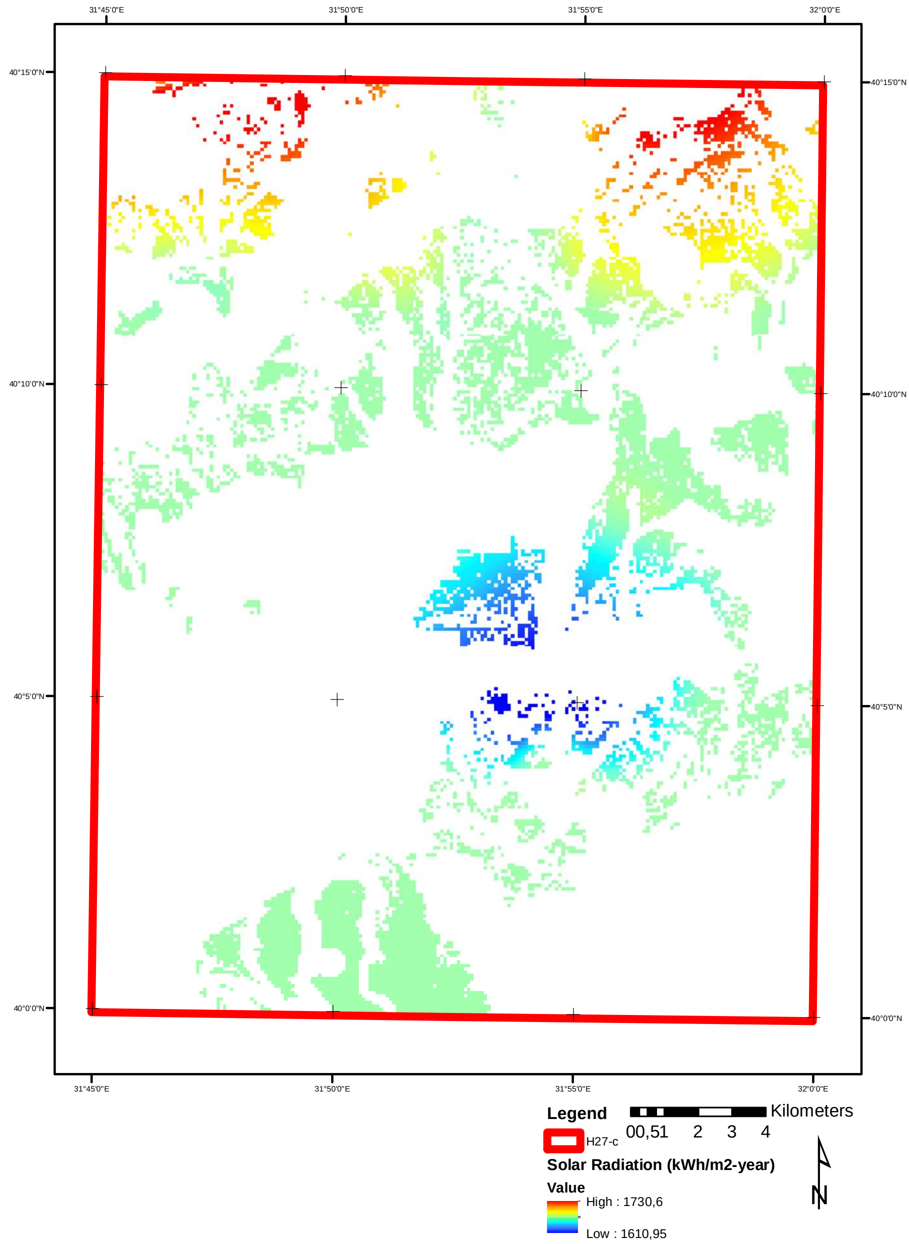


Figure 3.29. Solar radiation distribution map along the potential solar PV plant areas

CHAPTER 4

RESULTS AND DISCUSSIONS

Conventional energy sources have negative impacts on the environment and are not enough to compensate the energy needs of our country. For this reason, solar energy systems are very important in closing this energy deficit of our country. In this context, various regulations, investments, supports and incentives are present in our country.

In addition to these, the solar energy potential of our country is high. However, the proper selection of the sites where these systems will be installed is important in order to obtain effective results by establishing these facilities in areas that are less harmful to the environment, more efficient with regards to energy production and easy in terms of taking permission. Therefore, the development of a methodology in this regard will help the investors, developers, policy makers and authority by facilitating the selection of sites for solar energy systems.

Since solar energy systems are an energy type with a high cost of investment, the selection of the best areas is the most important step in this context and it is very significant for the development of this sector. Moreover, the determination of suitable sites with early manner can raise the development together with saving a remarkable amount of time and money.

Within the concept of this study, hybrid AHP and FuzzyOWA methodology has been proposed to select the appropriate site for the installation of solar PV power plants and the outcomes obtained from the implementation of this proposed methodology on a study area in H27-c sheet located within Beypazarı district of Ankara is presented in Figure 3.29. H27-c sheet was chosen as the study area because it contains almost all the criteria used in previous studies and is an area where all these criteria can be tested.

Various maps with different scales were used in this study. Since the maps obtained from the governmental institutions were used in this study, map scales of the institutions were the limiting factor for the study. In order to obtain more accurate results, the maps should have higher resolution. But in this study, it was aimed to reach the most accurate results by obtaining the most sensitive maps available prepared by the governmental institutions. However, as the resolution of the maps produced by government agencies increases in the future, more and more accurate results can be obtained. Since, one-hectare area is needed both for ground mounted PV plant having 0.5 MW capacity and solar tracker PV plant with 1MW capacity, in order to obtain this 10000 m^2 area and to evaluate every single cell of the map as a possible PV plant site, raster cell size in this study was selected as 100*100 metres. The minimum area required for the solar PV power plant was effective in determining the scale of this study.

The criteria used in the multi criteria site selection vary according to the study area and depending on the criteria used the results also vary. Therefore, one of the most important things in the site selection is to determine the criteria in a way that reflects the area properly and realistically.

Environmental and regulatory objectives and economic and technical criteria associated with solar PV power plants are determined through a comprehensive examination of literature, interviews and Turkish laws, legislation and regulations.

As a result of this detailed examination, environmental and regulatory objectives are identified as; distance to agricultural areas, rivers, natural protection zones and forest areas, lakes and wetlands. In addition to that, economic and technical criteria are determined as; solar radiation amount, slope percentage, distance to transmission lines, distance to roads and distance to settlement areas.

Unlike this study in some other similar studies, distance to airports, aspect, sunshine duration, distance to faults are used as criteria. However, in this study, these criteria were not used for some reasons which will be explained in detail. Since an airport does not exist within 3000 meters of the study area, according to related circular this criterion has not been taken into consideration in the study. Aspect and sunshine duration are used as criteria in some of the previous studies. However, since these criteria were used in preparing the solar radiation map obtained from the relevant ministry, these two criteria were not taken into account to avoid the repeated use of the criteria. Similar to these negligible criteria, distance to fault criterion is also not taken into account in this study since the distance to fault criterion is considered during project stage of the panel carrier systems based on the information gathered from the interview conducted with International Solar Energy Society (ISES) – Turkey division (GÜNDER). Furthermore, the solar radiation criterion, which is considered as the most important criterion by almost all previous studies, has also been used separately in this study to avoid shadowing the effects of other criteria.

Moreover, the distance to the settlement areas was determined as the least important criterion in this study due to the absence of a large settlement area. In addition to that, there are settlement areas scattered in the study area consisting of a few small buildings. All of these small settlement areas have been included in calculations even if it is represented with low weight, to simulate the study area realistically and to investigate the settlement areas criterion in our evaluations like in literature. Since there is no official map showing the boundaries of these small settlements and they are represented by point data in the existing governmental maps due to being small settlements, it was not considered objectionable to use this data as point data. However, it was considered that it would be more appropriate to use settlement area boundaries instead of point data for the study areas containing larger settlements.

After criteria identification is completed, fuzzy set membership functions are defined (Table 2.2; Table 2.3) by the aid of previous studies, conducted interviews and present laws, legislations and regulations. According to defined membership functions suitability maps based on each criterion are prepared.

It is hard to make a generalization about, which criteria are more important or making criteria ranking for the establishment of a solar PV power plant. However, prioritization of the criteria might be more reasonable and useful for decision makers. Since criteria and also their importance may vary depending on the site considered. To illustrate this context, if the site investigated is a flat area or close to flat area then slope criterion becomes unimportant compared to others. Since almost all the area is flat, slope criterion could barely affect the result. On the other hand, normally in areas having a variant slope, this slope criterion is accepted as an important factor since slope directly affects the construction cost. To overcome this problem the AHP method is used to identify the importance weights of the criteria considered in this study. Since the AHP methodology is dealing with subjective, vague and imprecise data by checking the consistency of the decision maker's evaluations this method is chosen to identify the criteria weights in this study.

Pairwise comparison of each criterion is conducted according to Saaty's nine-point continuous scale (Table 2.4) and these comparisons recorded into comparison matrix presented in Figure 2.3 and Figure 2.4. Since four criteria is present in both environmental-regulatory objectives and economic-technical feasibility criteria random index (RI) is taken as 0,9 from Table 2.5 and consistency ratios for environmental-regulatory objectives and economic-technical feasibility criteria are obtained respectively as 0,0115 and 0,0040. Both CR of 0,0115 and 0,0040 are less than 0,1, thus reasonable level of consistency has been reached by the decision makers evaluation. Moreover, from the AHP calculations given in Figure 2.3, weights for Natural Protection Zones and Forest Areas, Rivers, Lakes and Wetlands and Agricultural Areas are determined respectively as 0,4673, 0,2772, 0,1601 and 0,0954. In addition to that, from the AHP calculations given in Figure 2.4, weights for Slope, Distance to Transmission lines, Distance to Roads and Distance to Settlement areas are calculated respectively as 0,5132, 0,2751, 0,1376 and 0,0741.

Afterward calculated weights are used for overall potential map preparation. In order to simulate real life decision making conditions that is not crisp and includes fuzziness fuzzy logic is selected. Therefore to calculate overall potential maps for environmental-regulatory objectives and economic-technical feasibility criteria Fuzzy OWA operation with linguistic quantifier “all” is used together with previously calculated weights from AHP. Study area examined as 100 m by 100 m pixels and each pixel is evaluated as a potential alternative solar PV power plant area. From the proposed hybrid AHP-Fuzzy OWA methodology overall potential maps for environmental-regulatory objectives and economic-technical feasibility criteria are calculated separately and results are given in Figures 3.25 and 3.26. Compatible with “all” linguistic quantifier selection as seen in these figures, each pixels having a membership degree of zero within any of the suitability maps, are also received zero membership degree value in the resultant overall potential maps in Figure 3.25 and Figure 3.26. After overall potential maps based on environmental-regulatory objectives and economic-technical feasibility, priority sites are determined in accordance with the specified decision rules and categorization for suitability to solar PV plant installations defined in Table 2.8. As a result of this operation priority sites are determined and shown by green color in Figure 3.27. Consequently sites with an overall economic-technical and environmental-regulatory satisfaction degree of 0.5 or greater is characterized as priority sites for PV energy production and this priority sites are covering 89690000 m^2 area which corresponds to 15 % of the study area. Since one-hectare area is needed both for ground mounted PV plant having 0.5 MW capacity and solar tracker PV plant with 1MW capacity, ground mounted PV plant with 4484.5 MW capacity and solar tracker PV plant with 8969 MW capacity can be established in the selected priority sites. Moreover, 34% of the study area categorized as the areas need to be eliminated for now due to environmental and regulatory factors but could be reconsidered later after the remedial actions are applied or present status of the area have changed. Additionally, 21 % of the study area characterized as the areas need to be eliminated due to unsatisfactory economic and technical feasibility. Lastly, 30 % of the study area categorized as the areas need to be eliminated because of both inadequate feasibility and environmental factors, these areas could also be considered as environmental, regulatory, economic and technical constrained areas.

Finally, for identifying the superior areas with respect to efficiency and production potential within the determined priority PV sites, solar radiation distribution along potential solar PV power plant areas are shown in Figure 3.29 as a resultant map of this study.

CHAPTER 5

CONCLUSION

Site selection plays a vital role along the whole lifetime of the solar PV power plant project. Therefore in this study, GIS-based MCDM methodology with a new hybrid approach composed the mixture of AHP-Fuzzy OWA with linguistic quantifier “all” is proposed and implemented to select priority sites for the solar PV power plant.

The selection of suitable areas for solar energy systems depends directly on the number of related factors, criteria or objectives.

The comprehensive criteria within the subject of environmental, economic, technical and regulatory offers reasonable selection results for solar PV power plants.

In the light of derived information, it is concluded that 15 % of the H27-c sheet selected as the study area is suitable for solar PV power plant installation. In the selected priority sites, ground mounted PV plant with 4484.5 MW capacity and solar tracker PV plant with 8969 MW capacity can be established.

It is decided that this proposed hybrid methodology could be an applicable methodology for solar PV power plant site selection.

With this proposed methodology real-life situations, which is not having sharply defined boundaries and contains fuzziness, could be simulated and this methodology could also be applied for subjective, vague and imprecise data by controlling the consistency of the decision maker’s evaluations.

This proposed methodology might be an advantageous tool for the determination of national strategies about solar energy and for the determination of spatial plans considering environmental protection while using solar energy.

With the methodology developed as a result of this study, the investments in solar PV power plants will be enhanced and job opportunities will be created as well as sustainable development of the country will be ensured.

This methodology allows the decision-maker's choices to be included in the site selection and this provides the flexibility to the process.

Proposed methodology in this study could readily be modified according to the additional environmental, economic, technical or regulatory criteria for different sites and could be used as a beneficial tool to select priority sites as long as related criteria are carefully determined and required data is gained.

Performance of proposed methodology could be verified by applying the same methodology to other solar PV plant site selection studies with making some minor modifications due to site specific criteria.

Although site selection studies are carried out for renewable energy sources in our country, a study using different methodologies for the selection of solar PV power plant area with this detail has not been found in the current literature. Within the scope of this study, almost all the criteria used in the literature on this subject have been taken into consideration and two different methodologies have been used together to strengthen each other.

The comparison of the proposed AHP-Fuzzy OWA integrated methodology with other MCDM methods with using the same criteria for the same area with respect to its advantages and disadvantages deserves further research as an extension of this present study.

Implementation of proposed methodology to other renewables namely wind, geothermal, hydropower, biomass or wave might be the topic of the further studies if related regulations and literature are carefully examined and criteria or membership functions are revised with respect to determined requirements.

Since, between criteria values and site suitability only linearly increasing or decreasing relationship can be defined, linear membership functions are used in this study. However, if the criteria change in subsequent studies, if there is a nonlinear relationship between criterion values and field suitability, using nonlinear functions can be considered in future studies.

In addition to these, economic analysis can be the subject of further studies as an extension of this study.

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