FINDING THE MOST SUITABLE IRRIGATION DAMS FOR HYDROPOWER DEVELOPMENT BY USING GIS TOOLS

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ABSTRACT

FINDING THE MOST SUITABLE IRRIGATION DAMS FOR HYDROPOWER DEVELOPMENT BY USING GIS TOOLS

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This thesis aims to find the most suitable irrigation dams for hydropower development in Turkey to provide clean energy from an available resource by assessing on technical, spatial, and environmental criteria. The selected dams are arranged based on their suitability scores into three categories (high, medium and low) using a multi-criteria fuzzy logic tool that calculates the score separately for each criterion and then aggregates them into an overall suitability score. Six criteria are assessed: normal water level, reservoir storage capacity, dam purpose, years in operation, nearest substation distance and environment impact assessment requirement. The criterion of nearest substation distance was used to ensure that the benefits of potential power are consistent with the cost of grid connection. A methodology for finding best grid connection path is presented based on a multi-criteria geographic information system (GIS) spatial analyst to achieve the least cost, lowest power losses and lowest environmental impact. Two dams are chosen as case studies, Karadere and Karaçomak. For these dams, technical and spatial criteria are evaluated and the potential power and economic benefits are estimated. A least cost path methodology is applied to find the best grid connection path for each of those dams to their nearest substations.

Keywords: Hydropower, Grid Connection, Fuzzy logic, GIS.

ÖZ

HİDROELEKTRİK ENERJİ ÜRETİMİ İÇİN EN UYGUN TARIMSAL SULAMA BARAJLARININ CBS YÖNTEMİ İLE BULUNMASI

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Bu tezde, Türkiye'de hidroelektrik gelişimi için en uygun sulama barajların bulunması hedeflenmiştir. Teknik, mekansal ve çevresel kriterleri değerlendirerek mevcut sulama barajlarından temiz enerji temin edilmesi amaçlanmıştır. Seçilen barajlar daha sonra uygunluk endekslerine göre üç kategoriye ayrılmıştır: yüksek, orta ve düşük. Her kriterinin uygunluğunun ayrı ayrı hesaplayan ve daha sonra bunları Genel Uygunluk Endeksine göre bir araya getiren bulanık mantık aracı kullanılmıştır. Altı kriter değerlendirilmiştir: rezervuar ortalama su düşüm yüksekliği, rezervuar hacmi, barajın amacı, baraj yaşı, en yakın trafo merkezine mesafesi ve çevre etki değerlendirme için enerji nakil hattı mesafesi. En iyi şebeke bağlantı yolunu bulmak için en düşük maliyet, en düşük güç kaybı ve en az çevresel etkisini elde etmek için çok kriterli CBS mekansal analiz yöntemi sunulmuştur. Örnek çalışma için iki baraj seçildi: Karadere ve Karaçomak. Bu barajlar için teknik ve mekansal kriterler değerlendirilmiş, ayrıca potansiyel güç ve ekonomik faydalar tahmin edilmiştir. Ek olarak, bu barajların her biri için en yakın trafo merkezine en iyi şebeke bağlantı yolunu bulmak için en uygun güzergah metodolojisi uygulanmıştır.

Anahtar Kelimeleri: Hidroelektrik, Şebeke bağlantısı, Bulanık mantık, CBS.

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GIS	Geographic Information System
Mha	Million Hectares
DSI	General Directorate of State Hydraulic Works of Turkey (Devlet Su İşleri)
ESRI	Environmental Systems Research Institute
WGS	World Geodetic System
NWL	Normal Water Level (Head)
PDF	Portable Document Format
KMZ	Keyhole Markup language Zipped
TEİAŞ	Turkey Electricity Transmission Corporation (Türkiye Elektrik İletim Anonim Şirketi)
ICOLD	International Committee on Large Dams
EIA	Environmental Impact Assessment
Q50	(above || under the median)
TCX	Garmin's Training Center for XML (Extended Markup Language) Data
IDW	Inverse Distance Weighted
DNA	Deoxyribonucleic Acid
MENR	Ministry of Energy and Natural Resources of Turkey
OECD	Organization for Economic Co-operation and Development
ESHA	European Small Hydropower Association
IFC	International Financial Corporation
FAO	Food and Agriculture Organization
I	Irrigation Purpose Dam
IM	Irrigation and Municipal Purpose Dam
IF	Irrigation and Flood Control Purpose Dam
IFM	Irrigation, Flood Control and Municipal Purpose Dam
CCS	Clay Core Sand-Gravel Fill
CCR	Clay Core Rock Fill
RCC	Roller Compacted Concrete

CFR	Concrete Faced Rock Fill
HE	Homogeneous Earth Fill
CFS	Concrete Faced Sand-Gravel
CG	Concrete Gravity

CHAPTER 1

INTRODUCTION

In Turkey, it is expected that there will be an increase in demand for electricity due to economic growth. According to the European environment Agency Report 2017 of changes in Turkey land cover for years 2006 to 2012 [1], the types of land use that increased are residential, industrial and water bodies, which proves the increase in electricity demand, at the same time increasing the possibility of exploiting water bodies' increase represented by irrigation dams in hydropower generation. The laws in recent years succeeded in promoting the utilization of renewable energy for electricity generation [2]. It is estimated that installing a small hydropower plants to 45 municipal water supply dams will generate 173GW/year without effecting the environment [3]. But, what about 751 irrigation dam or other purposes other than hydropower in operation in Turkey. Sure if they are also used for this aim, the 173GW/year will increase at least by a factor of 3. In light of this, the aim is finding the most suitable irrigation dams for a hydropower development by using geodatabase query, fuzzy logic and a Multi-criteria GIS spatial analyst tools, also connecting these potential new hydropower dams to the existing electricity grid by finding the best path (shortest, least risk, least cost and least environment impact route) according to the criteria for grid connection. The use of GIS spatial analyst tools can help in performing analyses on spatial data, and can provide answers to spatial questions such as “How steep is this location?” and “What is the distance between these two locations?”. It's also provides answers to more complex spatial questions such as “Which is the nearest facility for a particular location?” and “What is the least costly path between two locations?” [4]. There have been many studies based on different criteria in Germany, Turkey, and Switzerland that have successfully identified a number of potential sites for small hydropower production [5][6][7], and several studies have successfully evaluated a number of existing paths based on potential path or evaluated the criteria for power lines routing for grid connection in turkey and Spain [8][9].

Unlike these studies, this study is an integrated solution; a holistic strategy within the modern GIS tools was created to achieve the study goals by combining spatial criteria and technical criteria and then applied spatial analysis tools to find the best irrigation dams to develop hydropower and ranked them according to the degree of suitableness using the fuzzy scoring logic for the multi-criteria which include technical, spatial, environment and risk criteria. A second phase of spatial analysis was applied by finding the best path to link the energy produced from those dams to the existing electricity grid also for the same multi-criteria to ensure the compatibility of the potential generated power with all these criteria and to avoid unbalanced results as in some energy projects where the cost of grid connection exceeded the benefits of generated power [10]. Siphon turbines have been proposed for hydropower development without tampering the irrigation dams' body.

1.1. Background

In Turkey economic growth and an increase in population bring more electricity and irrigation water demand. The population expected reach 91 million in 2030 with an annual growth rate of 1% [11]. As seen from Figure 1 most of the water is consumed through irrigation. Turkey has 25.85 Mha (million hectares) irrigable area (4.3 Mha is currently being irrigated) and 106.6 km^3 per year total available water resources, most of the irrigation systems (96%) are depend on dams [12]. According to that and by the fact of 711 existing dams irrigation and multipurpose dams in Turkey until 2018 (Figure 2), which could be used to install hydropower plants and collect the highest amount of energy from these dams to avoid the cost of constructing new hydroelectric dams [13] or thermal power plants, which have a negative impact on the environment [6]. Previous researches in Germany [5], Turkey [6], and Switzerland [7] were succeeded in finding appropriate dams for the development of hydropower. Prior research has shown that hydropower can be produced from 43 domestic water dams in Turkey, where the expected power is 173 GW/year [3]. Based on values of 106.6 km^3/year of water resources for irrigation and by using a hydropower calculator to estimate the potential power [14], it should be possible to collect around 500 GW/year of power by choosing the best from existing 711 irrigation dams for hydropower development with the lowest investment cost by finding the best connection path to the current power grid in accordance with the same technical criteria that succeeded to achieve the highest energy in addition to spatial criteria of best grid connection to about 692 existing power substation in Turkey (Figure 3).

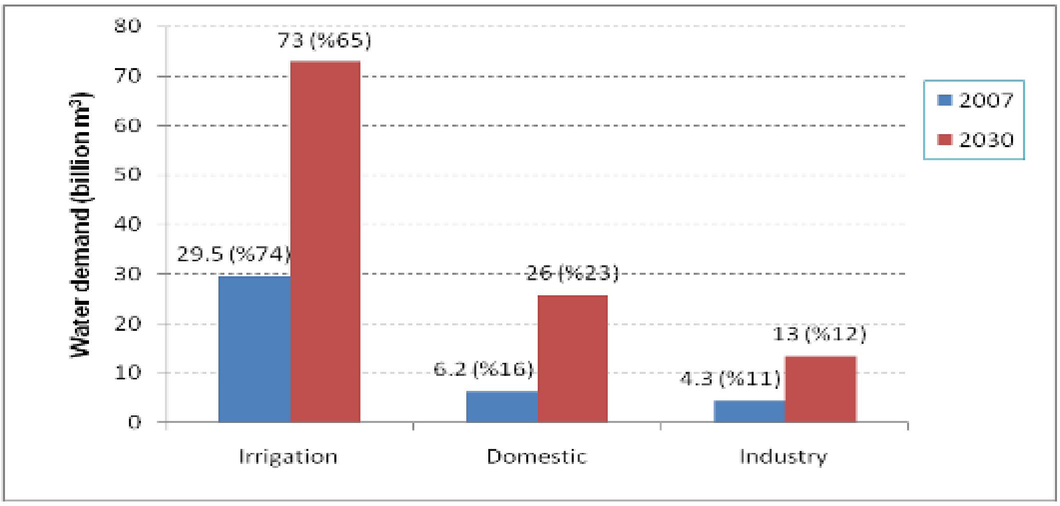


Figure 1 Water demand in Turkey by sector, for 2007 and 2030, by Turkish Water Works Directorate (DSI)

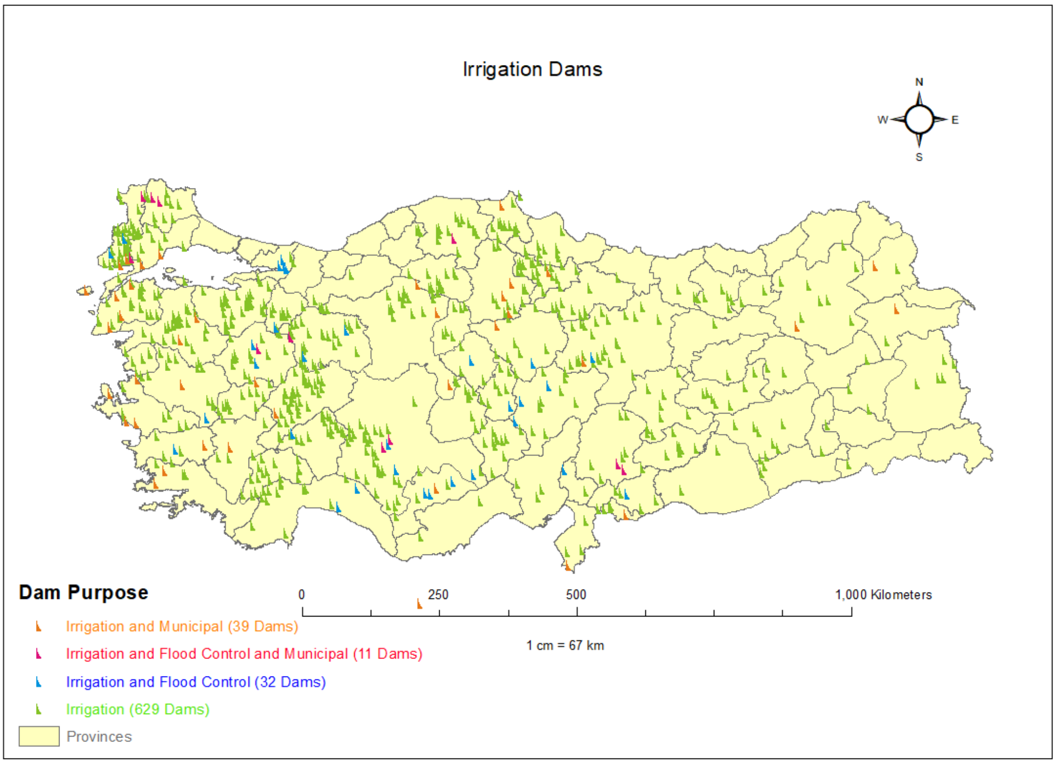


Figure 2 Distribution of 711 irrigation dams over 81 provinces in Turkey in 2018

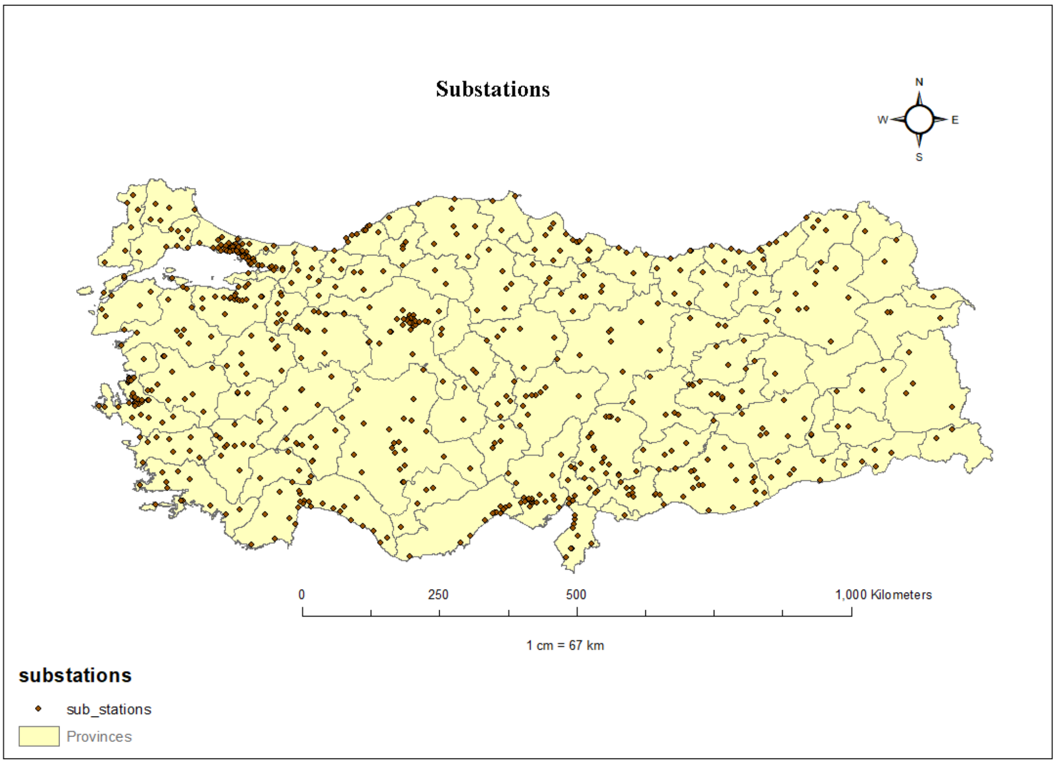


Figure 3 Distribution of 692 substations over 81 provinces in Turkey in 2018

1.2. Objectives

This thesis aims to assemble a large power capacity from several of the most suitable irrigation or multipurpose dams to gain the maximum benefits by investigation on the best dams for hydropower development with best grid connection to nearest substations based on least cost, least power losses, lowest risks and lowest environmental impact.

1.3. Organization of the Thesis

This thesis contains six chapters, in which the steps and the methodology used to reach the objective of the thesis are explained and discussed.

Chapter 1 highlights the objectives of the thesis and describes previous studies. An introduction is given to the availability of potential hydroelectric resources in Turkey, as represented by the presence of irrigation dams and the availability of substations for the electricity transmission grid.

Chapter 2 describes the preparation of the geographical database, the determination of spatial and technical criteria for both dams and substations, and the use of database queries to filter the dams and substations and to choose the best of them, based on the specified criteria.

Chapter 3 explains the use of multi-criteria fuzzy logic to classify the selected dams according to their suitability, in terms of meeting the specified technical and spatial criteria.

Chapter 4 presents the steps and methodology involved in the multi-criteria GIS spatial analyst use to find the best grid connection paths between dams and their nearest substations, within a maximum distance of 40 km.

Chapter 5 discusses the selection of two dams with high and medium suitability scores as case studies: Karadere and Karaçomak. The technical and spatial aspects of these dams are discussed, the potential power is calculated and the methodology used to find the best path to their nearest substations for grid connection is explained.

Finally, Chapter 6 presents the conclusion of the thesis, a discussion, and recommendations for future studies.

CHAPTER 2

TECHNICAL AND SPATIAL CRITERIA USED TO SELECT THE MOST SUITABLE DAMS AND POWER SUBSTATIONS

2.1. Building the Geographical Database

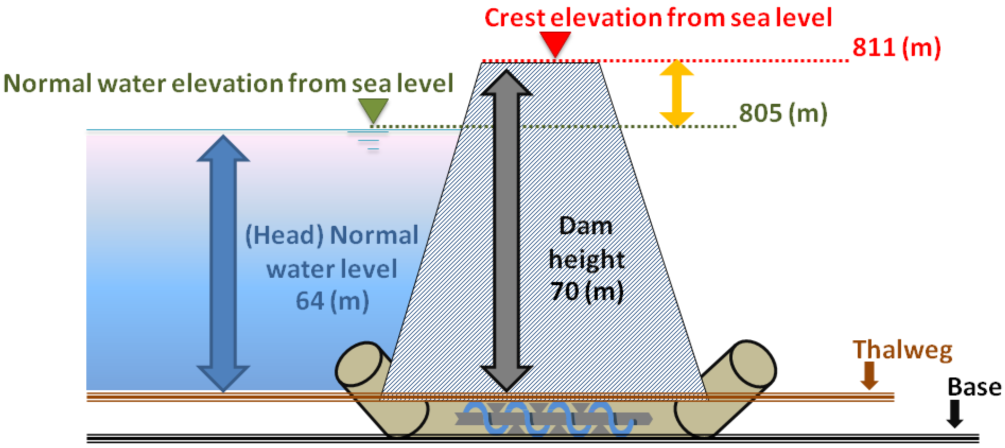
In order to reach the goal of finding the best irrigation dams for hydropower development with best grid connection, it must be dealt with the data and locations of 751 dams (which are not already used as hydropower dams) as well as the data and locations of 692 substations (power transmission and distribution substations), in addition to the general data of Turkey map and its 81 provinces, also the spatial reference images of the areas between the selected dams and nearest power substations and their components for finding the best grid connection path. For this reason, a geodatabase was first build using Environmental Systems Research Institute (ESRI) ArcGIS-ArcCataloge softwear to apply a database query and a multi-criteria spatial analyst and to save the resulting data. In this geodatabase the following initial objects have been created:

Dams table (point feature class): The data table of 751 dams (which are already not hydropower dams). For each dam in this table the following fields were included; dam name, start operation year, river, province, purpose, dam body type, reservoir capacity in cubic hectare, base height (dam height from the base) in meter, dam height from the thalweg (river bed) in meter, normal water elevation above the sea level in meter, dam crest elevation above sea level in meter, full spillway in m^3/s, dam (longitude X, latitude Y and elevation Z) geographic coordinates, normal water level in meter (head or normal water height from thalweg) and irrigated area in squire hectare.

Equation (1) was derived to calculate normal water level (NWL) field values (Figure 4), using *Add Field* and *Field Calculator* tools, where:

NWL = [dam height – [crest elevation at sea level – normal water elevation at sea level]] (1)

Dam name	Dam height (m)	Crest elevation from sea level (m)	Normal water elevation from sea level (m)	Head or NWL (m)
KARADERE	70	811	805	64



Head = Dam height - [Crest elevation from sea level - Normal water elevation from sea level]
64 = 70 - [811 - 805]

Figure 4 Calculation of normal water level from thalweg (head) for Karadere Dam

The dams table data were obtained from the Dams of Turkey guide provided by the Turkish Water Works Directorate (DSI) [15], the coordinates of the dams were included by the dam information available through Barajlar Uygulaması v1.4 online application provided by DSI [16]. Information and data on the status of some of the dams were also updated via the verification and matching of information from various news and informatics resources, including the Hurriyet website, DSI website and Google Earth.

Substations table (point feature class): The data table of 692 substations. For each substation in this table, the following fields were included; substation name, substation region directorate, substation institute, operational status, voltage level in kV and substation (longitude X, latitude Y and elevation Z) geographic coordinates.

The substations table data and coordinates (Trafo Merkezleri ve Tarife Bölgeleri Listesi) [17], were downloaded in form of portable document format (PDF) and keyhole markup language zipped (KMZ) files from the website of the Directorate of Environmental Protection of Turkish Electricity Works Corporation (TEİAŞ).

Turkey provinces map (polygons feature class): The map of provinces in Turkey using the World Geodetic System (WGS) 1984 Lambert Conformal Conic geographical coordinate system.

The coordinates for the dams and substations were also verified and corrected by dropping them onto the satellite image and map in the Google Earth Pro application and Google Maps. The locations of the dams and substations on the spatial reference satellite image and map were viewed and corrected if any deviation was detected.

2.2. Determination of Criteria

After the creation of the geodatabase to allow query filtering, the technical and spatial criteria were defined. These criteria were used to find suitable dams and substations and to exclude those that did not completely meet the criteria. An integrated strategy based on GIS tools was created to achieve the goals of the study by combining geographical (spatial) and non-geographical (technical) criteria. Spatial analysis tools were then applied to find the best irrigation dams for hydropower development and the best power substations to connect with them. Based on this, the following criteria were set.

2.2.1. Dams Criteria for Best Hydropower Generation (Technical Criteria)

Modern hydropower turbines can turn most of the available energy into electricity, while the best fuel power plants are less effective. Water turbines convert water pressure into mechanical energy, which is used to operate an electricity generator. The electrical power available from the water pressure depends on the product of the pressure head and discharge water. The pressure head is proportional to the height of the dam. For irrigation dams, the discharge water is proportional to the irrigated area, which itself depends on the reservoir capacity [18]. This is expressed in Equation (2).

$$P = \gamma \times Q \times (H - \Delta H) \times \eta \quad (2)$$

Where γ is the specific weight of the water, Q is the discharge (m3/s), H is the head (m), ΔH is the hydraulic head loss (m), and η is the sum of the turbine and generator efficiency [3]. Based on this, the technical criteria of dam base height and reservoir capacity were set; other criteria included dam years in operation and dam purpose.

Dam height and reservoir capacity: The International Committee on Large Dams (ICOLD) has identified large dams as being those with a height of more than 15 m from the base and a reservoir capacity larger than 3 cubic hectares [19]. Higher heads will decrease the construction and equipment costs of hydropower generation [20], while higher reservoir capacities will provide the continuous, reliable discharge needed for hydropower generation. Hence, when filtering the dams to choose the best for installation of a hydropower plant, the conditions of height >= 15 m and reservoir capacity >= 3 hm3 were applied.

Dam years in operation: Dams do not last forever; they require regular maintenance and have a finite lifespan. Across the world, many dams were built during the 1930–70s, a period of intensive dam construction, and these have an expected life of 50–100 years. Due to inadequate maintenance, and/or for environmental or operational reasons such as sediment accumulation over the anticipated life of the reservoir, some of these dams will fail or be removed [21]. Over 450 dams have been removed in the United States alone, and these have been reasonably old (average age 87 years at removal) [22]. For this reason, dams with (years in operation < =80) were chosen in this study. As a result of database query filtering based on all criteria, the oldest dam chosen had been in operation for 60 years, meaning that at least 20 more years of life could be expected before removal.

Dam purpose: Globally, irrigation dams are most suitable for hydropower development [18]; they often have a strong, continuous flow of water, since they are established for the purpose of irrigating large areas of land near rivers which provide a good water supply encourage agriculture. In addition, the simple design of irrigation dams allows for the modifications required to install various power turbines (Figure 5). For example, a siphon intake turbine can be installed; this is an elegant solution that does not need to pierce the dam body, and the design of the crests of irrigation dams near the water surface makes it easy to install with a generating efficiency of about 95%. There are examples of such turbines with installed power of up to 11 MW and heads of up to 30.5 meters, and they can be located either at the top of the dam or on the downstream side (Figure 6). If the dam already has a bottom outlet, this will offer the possibility of installing another type of power turbine (Figure 7) [18].

Figure 5 Simple design of an irrigation dam (Koyunbaba Dam)

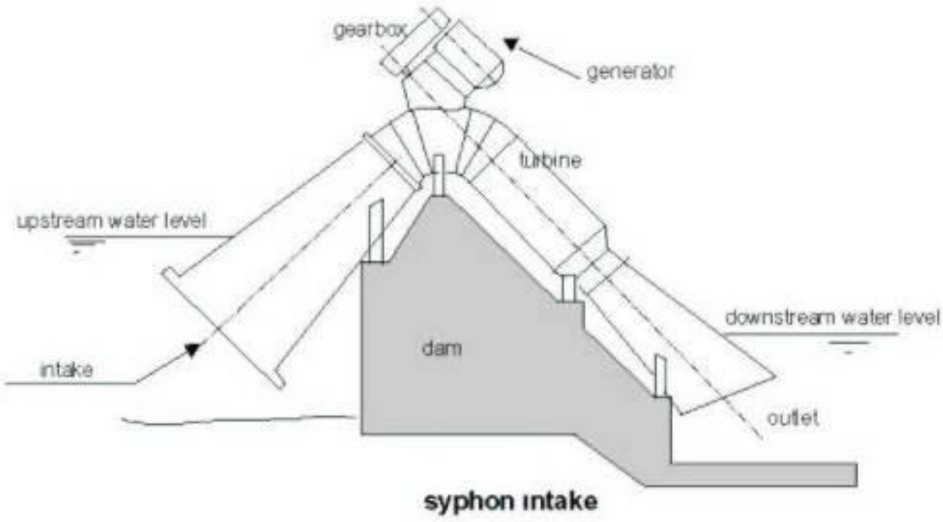


Figure 6 Siphon Intake turbine

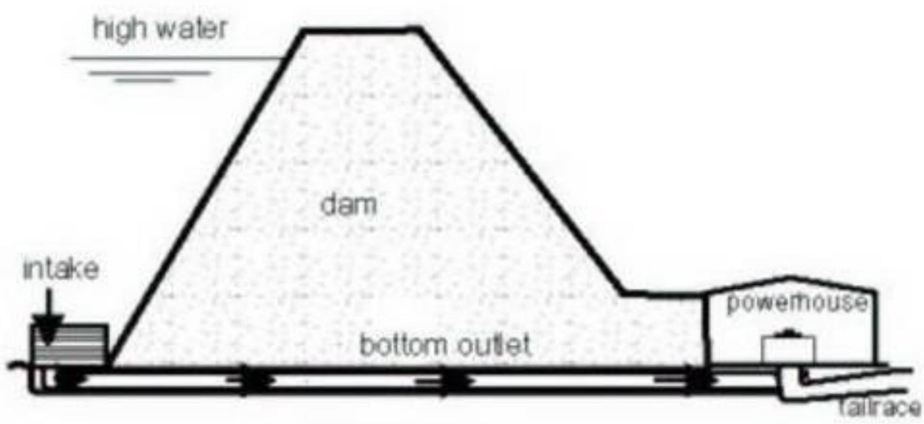


Figure 7 Base intake turbine

In addition, it can be observed from Figure 1 that the largest demand for water is from irrigation dams. Approximately 96% of the irrigation systems in Turkey are based on dams [12]. Most other types of dams are already used for hydropower or are planned for hydropower development [3], or do not have a large, stable water discharge like irrigation dams [18]. Thus, in the database query related to the purpose of the dam, only irrigation dams or irrigation dams with other purposes I (irrigation), IM (irrigation and municipal), IF (irrigation and flood control) and IFM (irrigation, flood control and municipal) were selected, meaning that municipal or flood control dams that were not used for irrigation were excluded.

Result: As a result of applying database query filtering to all 751 dams based on the above criteria, using the *Select by Attributes* tool in ArcMap, the number of dams was reduced to 273. This means that 478 dams did not meet the criteria (height >=15 m, reservoir capacity >= 3 hm3, dam years in operation <= 80 and irrigation purposes) and were excluded.

2.2.2. Substations Criteria for Electrical Power Transmission (Technical Criteria)

Consumers receive electrical energy after the processes of generation, transmission, and distribution. Before the generated energy is transmitted via the grid, step-up transformers are used to increase the voltage, in order to reduce energy losses in the lines. The generated electricity is transmitted to a grid connection point (step-up substation), where electricity is converted to the voltage of the transmission network (Figure 8) [23]. Step-up substations are used for long-distance electricity transmission, and the voltages for long distance transmission range from 155 to 765 kV [24].

Typically, renewable energy projects use step-up transformers to collect the output from turbines and route it to a transmission substation, where the voltage can be stepped up again to enable the efficient onward transmission of power via a land-based transmission system. It has been shown that by increasing the array system voltage, it is possible to transport a greater amount of power along a cable with the same cross-sectional area. The most significant benefit in transferring to a higher voltage is that less array cabling is required, and this can result in substantial capital costs savings, in terms of both the purchase and installation of cables [25].

Power plant transformers are used to step up the power produced by the hydroelectric generator, which is generally at between 0.415 and 11 kV, to a level which matches the substation transmission system voltage, typically between 12 and 420 kV. Transformers for micro hydro applications are normally 12 kV class, while those for small hydropower projects of approximately 3 to 5 MW are generally 36 kV class. A generator transformer for large units may be up to 420 kV class. From 145 kV class and upwards, transformers are available with two or more values of basic insulation. The choice of the lower value of insulation is made on the assumption that the equipment is adequately protected against surges. Power plant step-up transformers for small hydropower applications are liable to be subjected to high temporary overvoltage due to load rejection, and a higher voltage must therefore be used [26].

In Turkey, electricity generated by thermal, hydro and natural gas power plants is injected to the interconnected system via 154 kV or 380 kV power transmission lines, and is transferred to the closest substations through auto transformers at a voltage level of 154 kV. It is then reduced to 34.5 kV, 31.5 kV and 15 kV at substations and transmitted to the consumption points. Distribution transformers are used to decrease the voltage level from 34.5 kV to 400 V, and the final consumers such as factories, offices, commercial institutions and homes can use this electrical energy at this voltage level (Figure 8) [27].

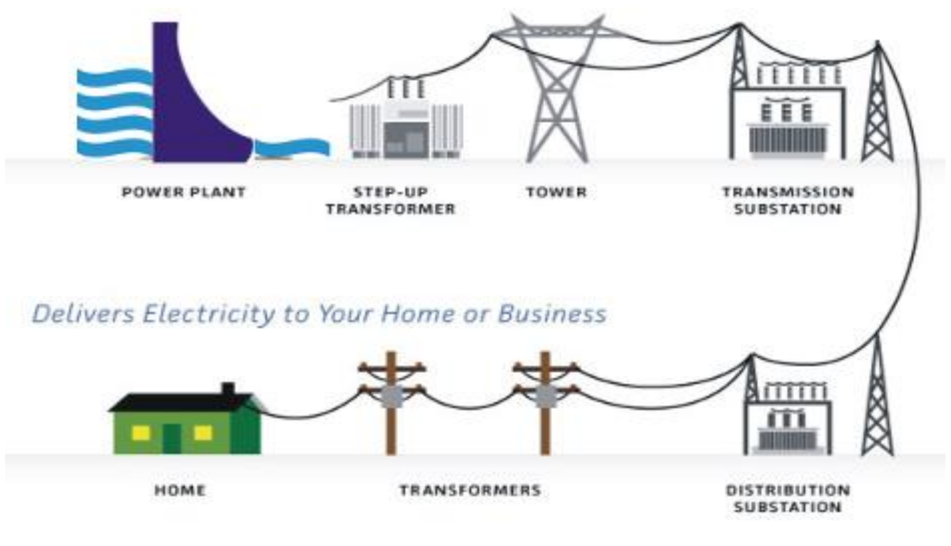


Figure 8 Generation, transmission and distribution grid

Result: Based on the above, step-up transmission substations of 154 kV and higher were selected, while substations that were under construction were excluded. As a result of applying database query filtering to all 692 substations using the *Select by Attributes* tool in ArcMap, the number of substations was reduced to 658, meaning that 34 substations which did not meet the criteria of voltage >= 154 kV and in-operation status were excluded.

2.2.3. Maximum Distance to Nearest Substation (Spatial Criteria)

Turkey consider as medium-area country with a population density proportional to the total area. It has 81 provinces that are approximately similar in area and a large number of cities and villages that are close to each other. Most residential communities are therefore close together and connected to the national electricity grid, meaning that the grid covers the entire country and there is no location that is very far from the grid. This can be seen from the map of grid transmission and distribution substations, which show 692 substations, distributed over 81 provinces (Figure 3). With a total area of 783,562 km^2, this means an average of one substation for each 34 km^2, as calculated using Equation (3).

$$\text{Average distance between substations} = \sqrt{[\text{Total area / Number of substations}]} \qquad (3)$$

Based on this, connecting the potential hydropower produced from the selected dams of this study to the transmission grid is a good option. In remote areas, the construction of new transmission lines can incur considerable planning hurdles and costs, and it is easier and more economical to locate a hydropower scheme that is closer to the loads or existing transmission lines [23]. In this case, the grid will transfer the power and then distribute it optimally, rather than direct distribution via an isolated grid that can create cost or instability problems related to capacity and demand [28]. The issue of grid connection distance is one of the most important issues that must be considered when planning power generation [29]. Many projects have encountered problems from power production that is disproportionate to the distance to the grid or cost of the grid [10].

The grid connection distance mainly depends on the amount of power produced and the load voltage of the transmission lines. For example, a 160 km distance at 345 kV carrying 1000 MW of power may experience losses of 4.2% [30], where when the power produced is greater, the economic feasibility of sending them to long distance will be greater. Also when the qualitative resistance of the transmission wire is smaller, the loss of power during the distance will be smaller, and then the possible distance will be greater. At the same time the qualitative resistance increases, when the power transferred increases then losses during the unit of distance increases. And the qualitative resistance decreases when the load voltage capacity increases then losses during the unit of distance decreases.

Based on this, there is a term known as (break-even distance), which is the distance that if exceeded, the grid connection becomes economically inefficient either because of the increased cost of grid connection above the value of power produced or because of the loss of power due to the qualitative resistance of the transmission wire [31]. Mainly for small hydropower the maximum transmission loss should not exceed 4.5 percent of the received energy [10]. For short distances lines (less than about 80 km) the capacitance and leakage resistance to the earth are usually neglected [32]. Studies determined the break-even grid connection distance (nearest substation) for a small hydropower and or micro renewable energy at 45 km to 50 km [33] [34]. The resources also indicate that hydropower projects with a capacity of more than 100 kW can be connected to the grid [28].

Since the criteria for substations and power transmission were set to ensure the best transfer of produced power with lowest loss within the distance unit, as well as through the selection of technical criteria for irrigation dams which can achieve the highest production of hydropower including the dam height and reservoir capacity with considering the irrigated areas and compared with the dams of other studies whose potential power has been already calculated, the estimated potential power that can be produced from the selected dams in this study ranges from 100 kW to 10 MW or above. Such estimates can be attributed to small and medium hydroelectric power according to most hydropower definitions [28], which can be generated from small or medium-flow rivers. Such energy is economically feasible to connect to the grid.

The maximum grid connection distance (break-even distance) between the selected dams and their nearest substations was therefore set to 40 km, in order to avoid exceeding power losses of 4.5% (Figure 9) and to take into account the average distance of 35 km between substations in Turkey, as indicated in Equation (3).

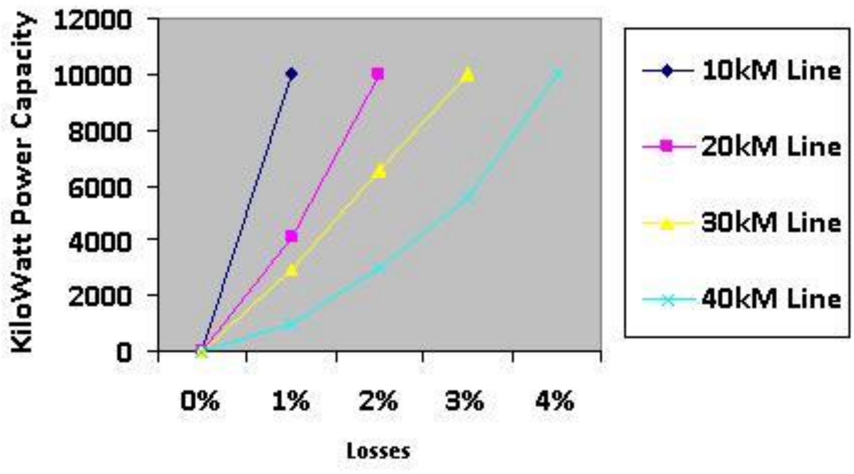


Figure 9 Losses Percentage of losses from hydropower (100–10000 kW) via 154 kV transmission lines over distance of 10, 20, 30 and 40 km

Result: After applying spatial analyst to the geodatabase of dams and substations using ArcMap *Select by Location* tool, all dams without a substation within a distance of 40 km were excluded. Thus, the number of dams was reduced to 265, as eight dams without a substation within 40 km were excluded.

A 'near table' was then created using the spatial analyst tool *Create Near Table*. This table identifies the nearest substation for each dam and calculates the straight-line distance to that substation. As a result, 265 dams with 183 nearest substations within 40 km were obtained; it should be noted that some substations were near to more than one dam.

2.3. Geodatabase Filtering of Criteria and Spatial Analyst Results

By applying geodatabase queries based on the technical criteria for the dams and substations and the spatial criterion of nearest substation distance using ArcGIS spatial analyst tools *Select by Attribute*, *Select by Location* and *Create Near Table*, and joining the records of nearest substations from the substations table to the selected dams table using *Join and Relate* tool in ArcMap, the following results were obtained (Figure 10):

- The most suitable 265 irrigation dams for hydropower development were identified.

- A total of 183 nearest substations located within 40 km of the selected 265 dams were selected by assigning the nearest substation to each candidate dam, some of these substations were near to more than one dam.

- The straight-line distance was calculated from each candidate dam to its nearest substation.

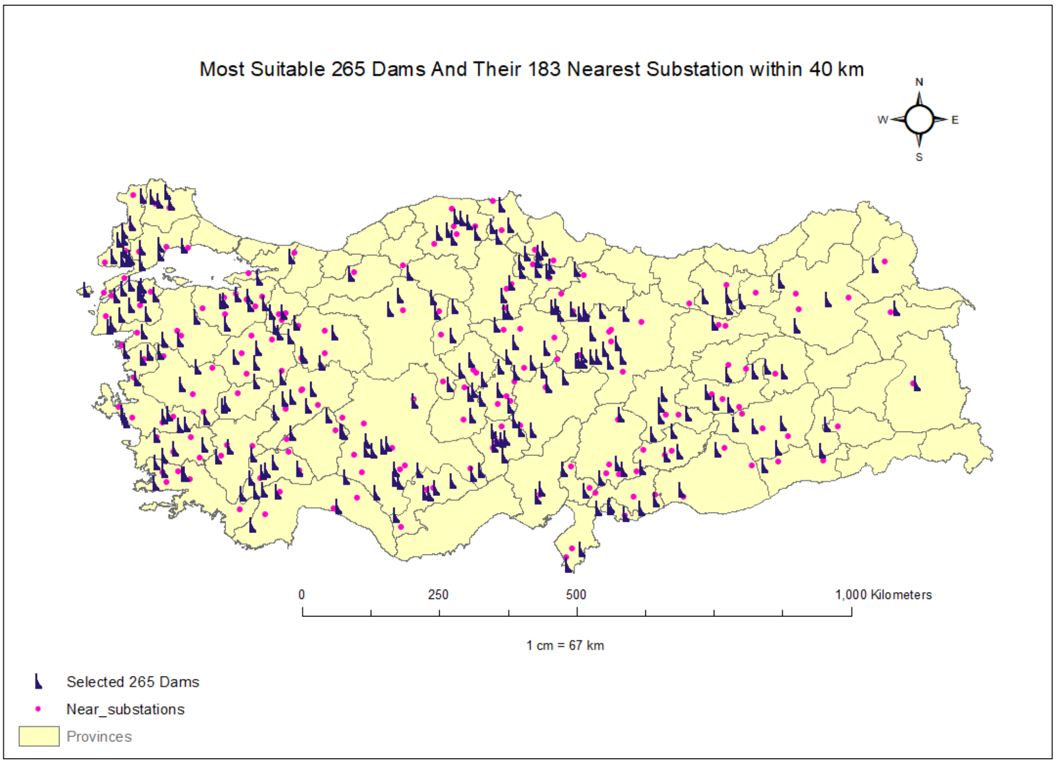


Figure 10 The selected 265 dams and nearest 183 substations (within 40 km)

For the selected 265 dams, in order to recognizing the differences between criteria data preferences, statistical indicators were calculated.

Statistics for the criterion of dams base height: The dam which has the maximum base height of the selected dams is (Burgaz Zeyti) has 115 m base height which considered a high preference for hydropower development. Burgaz Zeyti Dam has good values in its preferences of the other criteria. It should be noted that there is no clear relationship between the base height of the dams and their other criteria, except for the normal water level, since this depends on the height of the dams (Table 1). The average base height for the selected dams was 48 m, and most of the selected 265 dams had base heights of between 20 and 70 m (Figure 11).

Table 1 Comparison in base height criterion preference of the selected 265 dams with their other criteria statistical indicators

Dam base height (m)	Value / Preferences	Reservoir capacity (hm^3)	Years in operation	Irrigated Area (hm^2)	Normal Water Level (m)	Near substation distance (km)
15	Min / Low	55.2	2	77	10	26.8
46	Median / Mid	18.9	11	5128	28	20.1
115	Max / High	33	5	3009	81.5	11.9

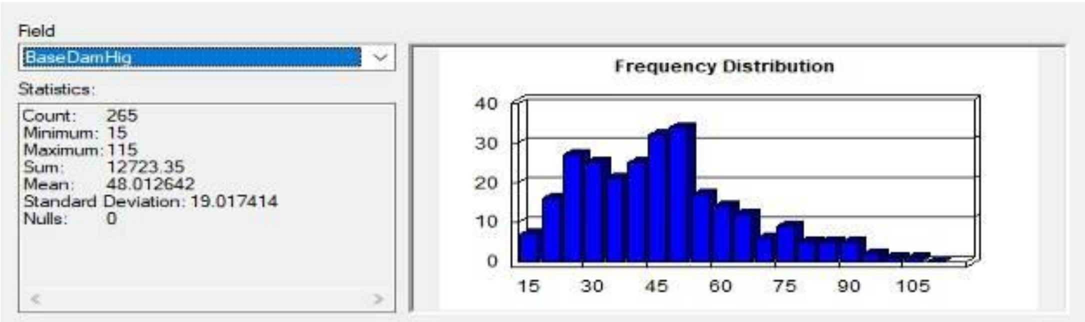


Figure 11 Statistics for the criterion of base height for the selected 265 dams

Statistics for the criterion of dams reservoir capacity: The dam which has the maximum reservoir capacity of the selected dams is (Kartalkaya) has 717.7 hm^3 reservoir capacity which considered a high preference for hydropower development. Kartalkaya Dam has a medium values in its preferences of the other criteria. It should be noted that there is a relationship between the dams reservoir capacity and their other criteria, except the near substation distance because it's a spatial criterion which is not related with dams technical criteria (Table 2). The average reservoir capacity for the selected dams is 43 hm^3 and most of the selected 265 dams have a reservoir capacity between 3 to 90 hm^3 as shown in Figure 12.

Table 2 Comparison in reservoir capacity criterion preference of the selected 265 dams with their other criteria statistical indicators

Reservoir capacity (hm^3)	Value / Preferences	Dam base height (m)	Years in operation	Irrigated Area (hm^2)	Normal Water Level (m)	Near substation distance (km)
3	Min / Low	25.5	31	450	15	7.2
18.5	Median / Mid	44	5	2045	26.5	15.4
717.7	Max / High	57	38	20000	49	12.5

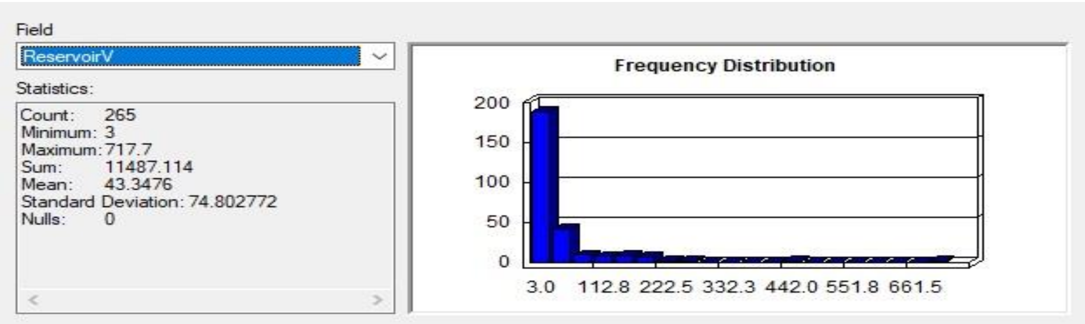


Figure 12 Statistics for the criterion of reservoir capacity for the selected 265 dams

Statistics for the criterion of dams nearest substation distance: The shortest grid connection distance between the selected dams and nearest substations is (Kocadere) has 720 m nearest substations distance which considered a high preference for grid connection. However Kocadere Dam has low values for its other technical criteria preferences. There is no relation between the nearest substation distance of the selected dams and their other criteria, since this is a spatial criterion that is not related to the technical aspects of the dams (Table 3). The average distance to the nearest substation for the selected dams was 17.29 km, and the selected 265 dams had a normal distribution around the average value (mean) for this criterion (Figure 13).

Table 3 Comparison in nearest substation distance criterion preference of the selected 265 dams with their other criteria statistical indicators

Near substation distance (km)	Value / Preferences	Dam base height (m)	Years in operation	Irrigated Area (hm^2)	Normal Water Level (m)	Reservoir capacity (hm^3)
0.72	Min / High	23.75	37	381	13.7	3.71
16.55	Median / Mid	89	22	3123	68	31.4
38.20	Max / Low	36	60	5438	31	30.9

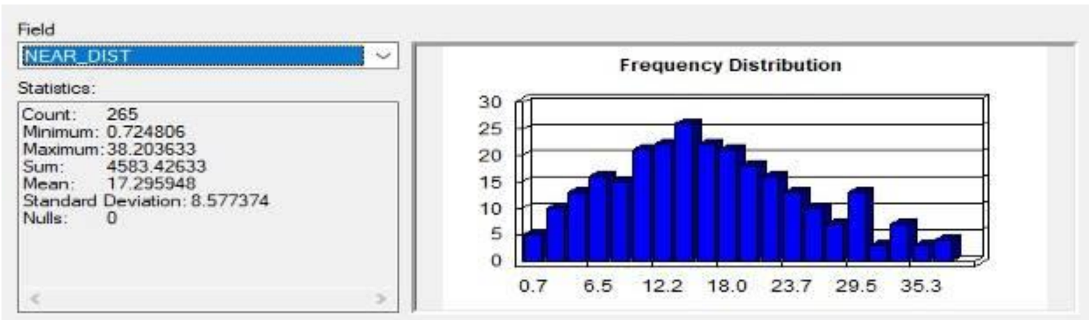


Figure 13 Statistics for the nearest substation distance criterion for the selected 265 dams

Statistics for the criterion of dams years in operation: The dam which has the minimum years in operation of the selected dams is (Ardıl) has one year in operation, which is considered a high preference factor in encouraging hydropower development, as it indicates that around 79 more years of operation are possible. Ardıl Dam has normal values for its other technical criteria and a good value for the nearest substation distance. There is no relationship between years in operation for the dams and their other criteria (Table 4).The average value for the years in operation of the selected dams was 22 years, and most of the selected 265 dams were built after 1980 (Figure 14).

Table 4 Comparison in years in operation criterion preference of the selected 265 dams with their other criteria statistical indicators

Years in operation	Value / Preferences	Dam base height (m)	Reservoir capacity (hm^3)	Irrigated Area (hm^2)	Normal Water Level (m)	Near substation distance (km)
1	Min / High	54	10.97	2126	44	12.73
20	Median / Mid	97	79.4	7872	84	13.82
60	Max / Low	36	30.9	5438	31	38.2

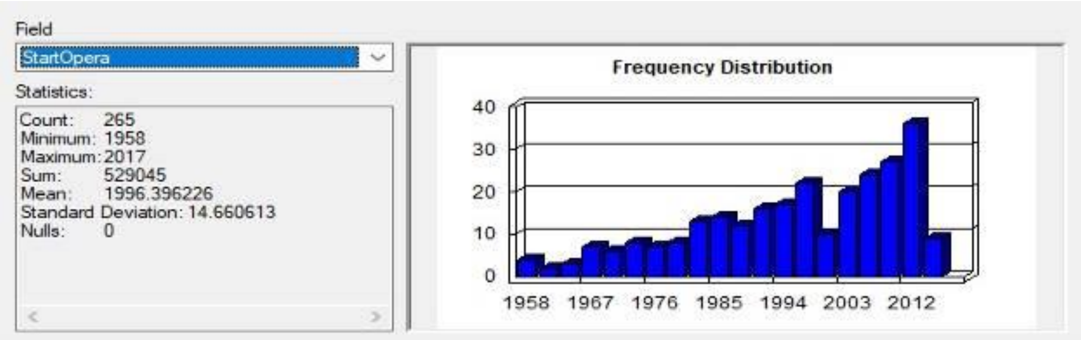


Figure 14 Statistics for the criterion of years in operation for the selected 265 dams

Statistics for the criterion of dams irrigated areas: The dam which has the maximum irrigated area of the selected dams is (Apa) has 97015 hm^2 irrigated area which considered a high preference for providing water supply for hydropower development. Apa Dam has low values for its other criteria preferences although it has a high value for reservoir capacity. The irrigated area is strongly related to reservoir capacity, since a high reservoir capacity means good availability of water for irrigation (Table 5). The average value for the irrigated area for the selected dams was 4913 hm^2, and around 200 of the selected 265 dams had irrigated areas of less than 10,000 hm^2 (Figure 15).

Table 5 Comparison in dams irrigated areas criterion preference of the selected 265 dams with their other criteria statistical indicators

Irrigated Area (hm^2)	Value / Preferences	Dam base height (m)	Years in operation	Reservoir capacity (hm^3)	Normal Water Level (m)	Near substation distance (km)
53	Min / Low	34.5	26	4.96	22	19.64
2062	Median / Mid	35.5	45	8.56	36.5	25.78
97015	Max / High	30.8	56	171.6	26.8	19.76

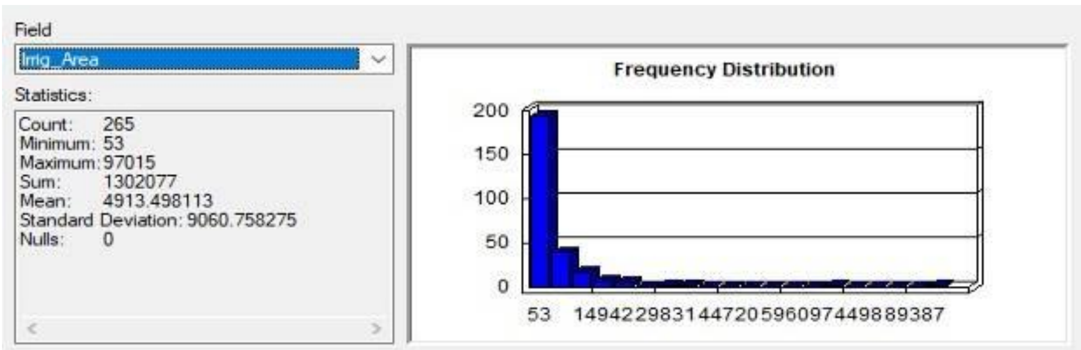


Figure 15 Statistics for the irrigated area criterion for the selected 265 dams

Statistics for the criterion of dams normal water level (Head): The dam which has the maximum normal water level of the selected dams is (Aktaş) has 98 m normal water level which considered a high preference for providing water pressure for hydropower generation. Aktaş Dam has good values for its other criteria preferences. There is no clear relationship between the dams normal water level and their other criteria, (except for the base height, since the water level depends on the height of the dam) (Table 6). The average value of the normal water level for the selected dams was 36 m, and most of the selected 265 dams had a normal water level of between 10 and 60 m (Figure 16).

Table 6 Comparison in reservoir capacity criterion preference of the selected 265 dams with their other criteria statistical indicators

Normal Water Level (m)	Value / Preferences	Dam base height (m)	Years in operation	Irrigated Area (hm^2)	Reservoir capacity (hm^3)	Near substation distance (km)
10	Min / Low	15	2	77	55.2	26.87
33.5	Median / Mid	49	5	2313	23.67	13.02
98	Max / High	105.5	1	1580	43.79	9.92

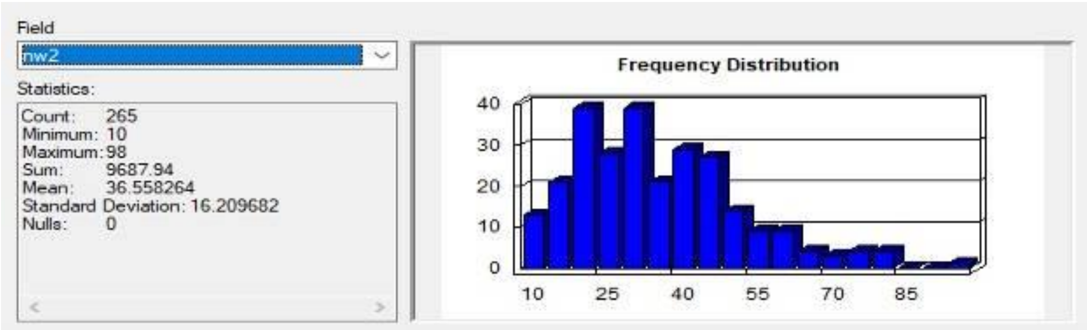


Figure 16 Statistics for the normal water level criterion for the selected 265 dams

Statistics for the criterion of dams purposes: High preference dams are those which are only used for irrigation purpose. There are 201 dams only for irrigation from the 265 selected dams, and the other 64 are used for both irrigation and other purposes (Table 7). Thus, most of the selected 265 dams are used only for irrigation purposes, and these are the main focus of this study (Figure 17).

Table 7 Comparison in dams purposes criterion preferences of the selected 265 dams

Dam purpose	Value / Preferences	Number of dams
Irrigation, Flood control and Municipal	Triple / Low	10
Irrigation and Flood control	Dual / Mid	21
Irrigation and Municipal	Dual / Mid	33
Irrigation	Single / High	201

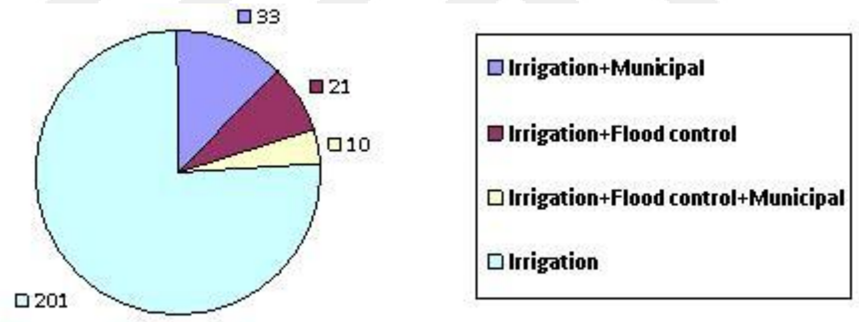


Figure 17 Statistics for the dams purpose criterion of the selected 265 dams

CHAPTER 3

USE OF MULTI-CRITERIA FUZZY LOGIC FOR DAMS SUITABILITY SCORING

3.1. Introduction

After the technical and spatial criteria were applied, 265 irrigation dams were identified that were suitable for hydropower development, within the maximum of 40 km distance from the nearest substation for connection to the power grid. Although all of these dams are suitable for hydropower development, it is important to determine which are most suitable. The implementing agencies and beneficiaries aim to choose dams that meet the criteria to the fullest extent (i.e. highest power production, least cost and environmental damage, and shortest grid connection), especially in view of the variation in the preference of the criteria for the selected dams, as shown by the results for the of the statistical indicators for the selected dams criteria. The degree of suitability of each dam in terms of meeting all the required criteria needs to be calculated, and the dams should then be sorted according to their suitability score, allowing for classification within suitability ranges which allowes the selection of the most suitable dams for the on-site tests for hydropower development or using spatial analyst for best grid connection.

3.2. Multi-Criteria Decision Making with Fuzzy Logic

Multi-criteria fuzzy logic is one of the most important ways to evaluate options to achieve objectives based on a set of compatible or conflicting criteria [35]. There have been many studies evaluated options using fuzzy logic, such as evaluating the risk of hydropower run of river type projects based on multiple environmental criteria in Turkey [36], or finding the best sites for developing solar energy in Vietnam [37], or using fuzzy logic tools to evaluate low-head hydropower technologies at the outlet of wastewater treatment plants [38].

Multi-criteria fuzzy logic depends on calculating the impact of each criterion to serve the desired objective within available options. For example, if there is a decision maker which wants to find a job to achieve the goals of making money and fun at the same time and there were two job options, the first job profitable but boring and the second profitable and enjoyable. Therefore, the choice will be on the second job because it meets the criteria of profit and pleasure. In this study research, options are dams and the objective is the ability of these dams to achieve the highest proportion of all criteria. Fuzzy logic translates each criterion into a continuous variable that takes a value between zero and one ($0<=x<=1$) called suitability degree or membership degree, which reflux the actual values within the maximum and minimum values of the original criterion [39].

3.2.1. Determination of Criteria

The criteria chosen to calculate the suitability of each dam are spatial criterion which is the distance to the nearest substation and the environmental criterion which is environmental impact assessment (EIA) requirements and technical criteria such as the capacity of the reservoir, the normal water level, the purpose of the dam and the number of years in operation (Figure 18).

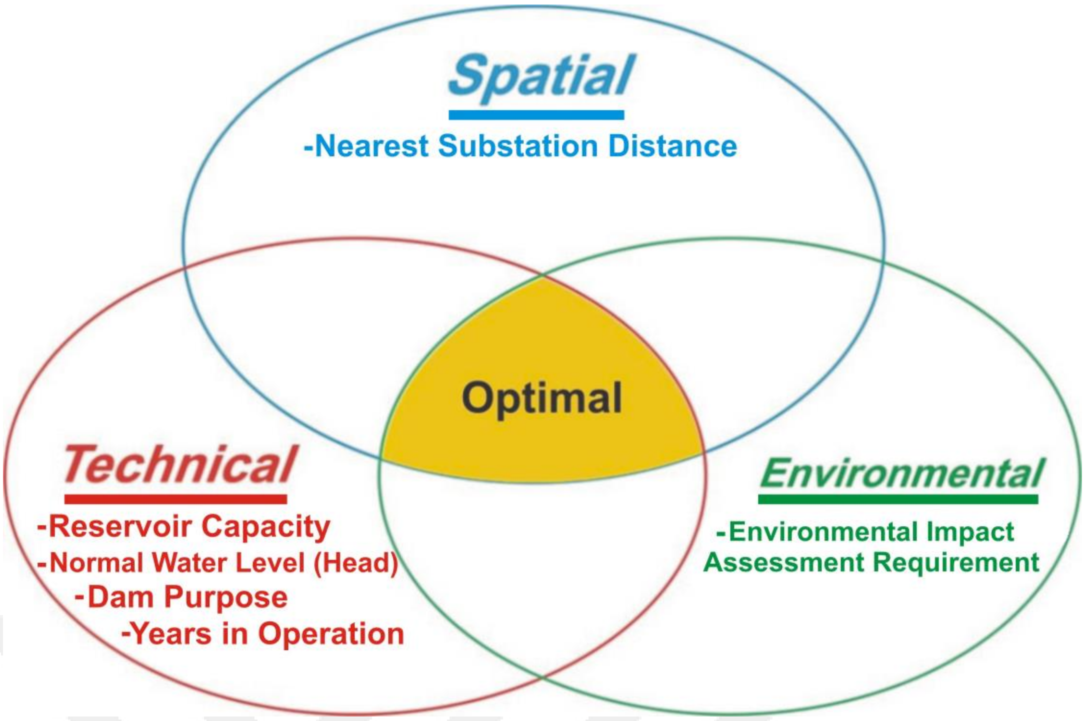


Figure 18 Evaluation criteria for scoring the suitability of dams

Nearest substation distance criterion: This is the distance from the body of the dam to the nearest substation. Construction of a new transmission line is costly and may be complicated, since it involves obtaining appropriate permits and may also require the acquisition of land [40]. The distance to the nearest substation and the suitability degree have an inverse linear relationship [41]; when the distance to the nearest substation decreases, the suitability degree increases, due to the decrease in costs and increase in power efficiency. The minimum and maximum distances between the selected dams and their nearest substations are 0.7 and 38.2 km, respectively (Figure 19).

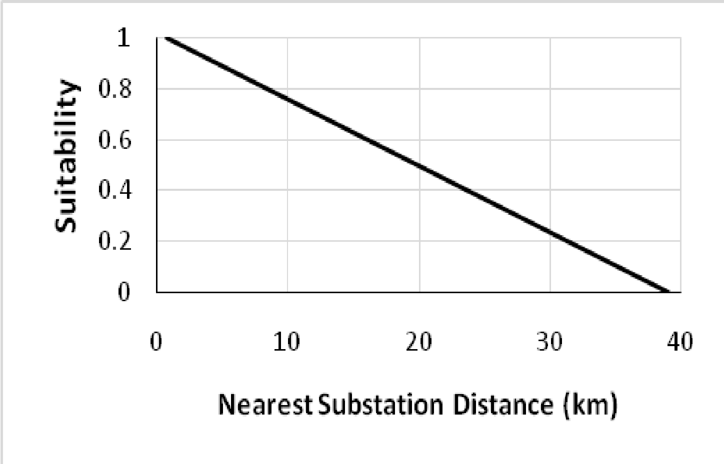


Figure 19 Suitability function for nearest substation distance criterion

Environmental impact assessment requirement criterion: According to the EIA regulations in Turkey, which were enacted in the official gazette on November 25th, 2014, any grid connection distance greater than 15 km is considered to have a negative environmental impact, and EIA regulations must applied; if the grid connection is less than 15 km, an EIA assessment is not required. There will therefore be a threshold point at a distance of 15 km, where any distance less than this will give a suitability degree of one (i.e. a low environmental impact), and a distance equal to or greater than this will give a value of zero (i.e. a negative environmental impact) [42] (Figure 20).

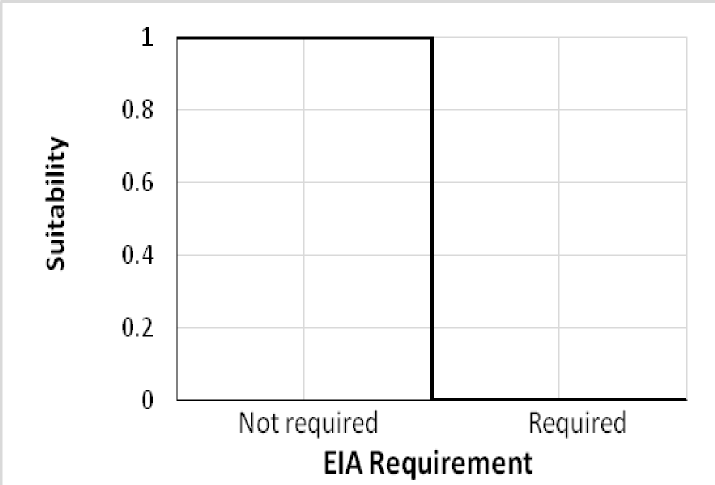


Figure 20 Suitability function for EIA requirement criterion

Reservoir capacity criterion: It includes the active storage (full with water) and dead storage (sedimentation part) capacity of reservoir [43]. Higher reservoir capacities will provide continuous reliable discharge for hydropower generation. Where the maximum reservoir capacity of the selected dams is 717.7 hm^3 (high suitability) and the minimum reservoir capacity is 3 hm^3 (low suitability).

Normal water level (Head) criterion: Is the water height from the thalweg (river bed), or it is the diffirence between the normal pool elevation (water surface level) at the top of active storage and the minimum pool elevation at top of the dead storage (thalweg) (Figure 21). Higher heads will decrease the construction and equipment costs of hydropower generation [20]. In this respect, higher heads represent preferable site conditions and they have higher scores.

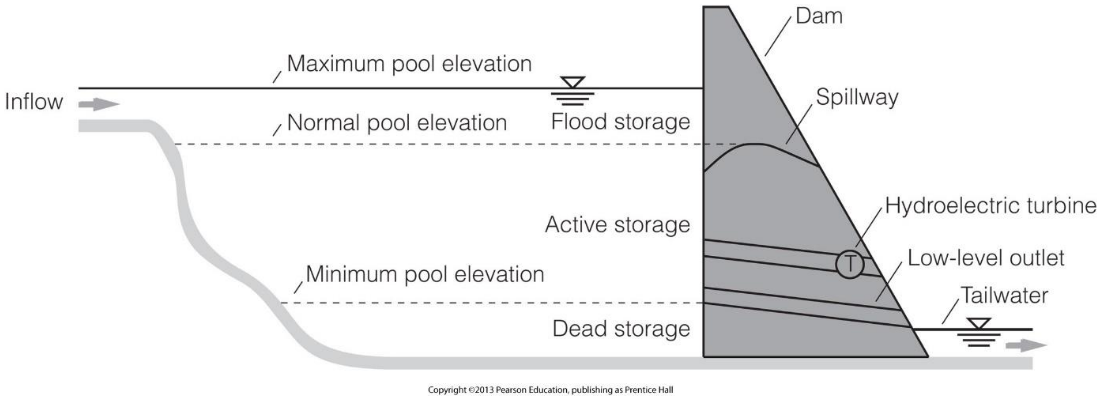


Figure 21 Reservoir storage zones (adapted from [43])

The normal water level was already calculated for all the dams from the geodatabase ArcCatalog *Filed Calculator* by based on equation (1) (Figure 4). The normal water level represent the head height if the water outlet at the bottom of the dam's active storage (Figure 21).

For reservoir capacity and the normal water level, the suitability degree was calculated by Q50 method (above || under the median) which give each criterion a suitability degree (membership) between 1 and 0 [41], where the upper half of the criterion data values were gave 0.5 or more suitability degree according to the original criterion value that exceed the median value, and the lower half of the criterion data values were gave less than 0.5 suitability degree according to the original criterion value that less than the median value which is 18.5 hm^3 for the reservoir capacity and 33.5 m for the normal water level (Figures 22 and 23).

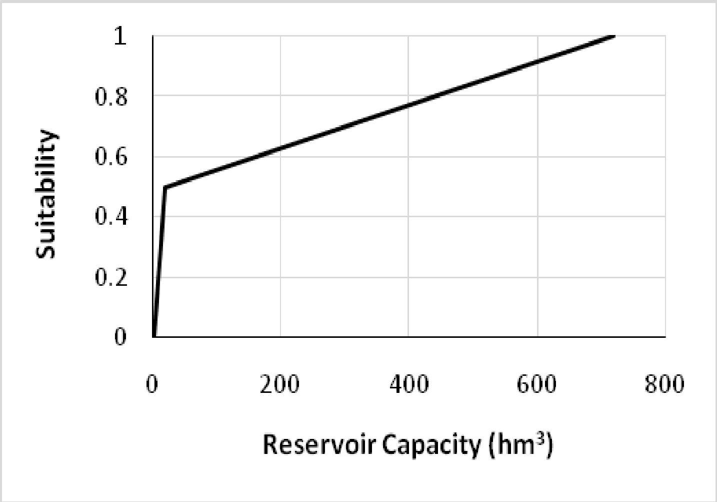


Figure 22 Suitability function for the reservoir capacity criterion

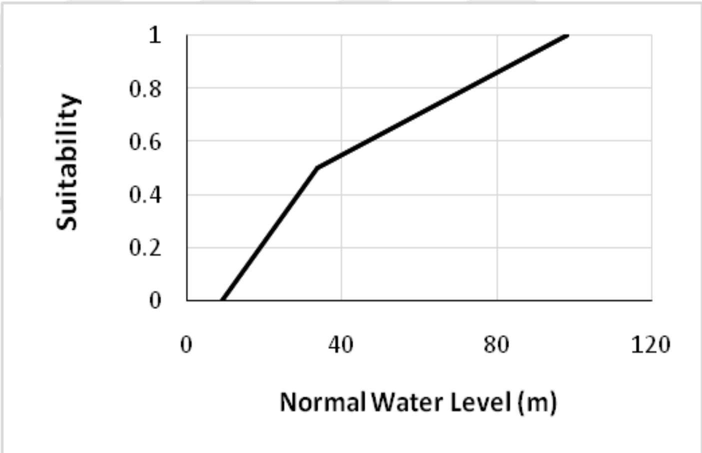


Figure 23 Suitability function for the normal water level (head) criterion

Dam purpose criterion: Under the scope of this study, purposes of dams cover (irrigation), (irrigation and municipal), (irrigation and flood control) and (irrigation, flood control and municipal). If the dam has a single purpose, it has the highest score. Because single purpose dams have fewer constraints compared to multipurpose dams. The suitability degree was determined as follows (Figure 24):

- If the dam is used for irrigation purpose only (single purpose), then the suitability degree of this criterion is 1.

- If the dam is used for irrigation and municipal or irrigation and flood control purposes (dual purposes), then the suitability degree of this criterion is 0.66.

- If the dam is used for irrigation, municipal and flood control purposes (triple purposes), then the suitability degree of this criterion is 0.33.

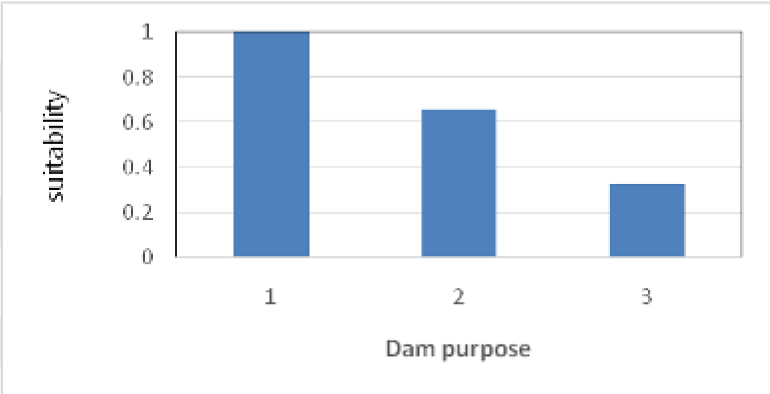


Figure 24 Suitability function for dams purpose criterion

Dam years in operation criterion: This reflects the age of the dam, and is an especially important parameter in regard to the sedimentation status of the reservoir. It also has an inverse linear relationship with the suitability degree, since as the age of the dam (years in operation) increases, the number of possible future years of operation decreases and the suitability degree decreases within the range of the selected dams ages which is from 1 to 60 years (Figure 25).

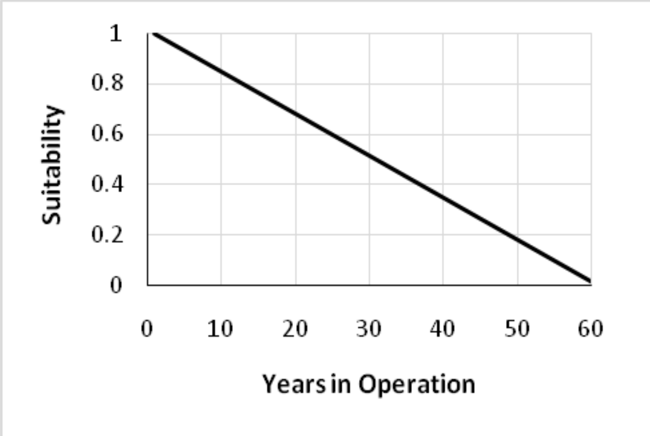


Figure 25 Suitability function for the years in operation criterion

3.2.2. Fuzzy Logic Methodology for Suitability Scoring

Fuzzy logic assumes that a weight is given to each criterion according to its importance. This is done by mathematical methods or based on expert opinion [45]. It is also possible to give the same weight to all participating criteria, if the aim is to offset the weakness of one criterion with the strengths of the other criteria, or when all criteria are equally important [45]. The criteria have been given equal weights in order to achieve the highest suitability from all criteria equally; it is then easy to change these weights and obtain other results in the future [46]. Weight control is considered a variable option that is influenced by temporal conditions, spatial conditions, restrictions and instruction.

The suitability degree was computed for each dam based on all the criteria. The suitability degree (score) for each dam could be aggregated in many different ways, such as a linear method of aggregation based on multiplication of the set of weights by the degrees of suitability memberships [45], as shown in Equation (4).

$$S\,(D_i) = \sum W_j * C_{ij} \qquad i=1,2,...,n \qquad j=1,2,\ldots,r \tag{4}$$

Where i is the dam number, j is the criterion number, n=265 is the total selected dams, r=6 is the total number of the criteria, W_j is the weight of the criterion j, C_{ij} is the suitability degree of the criterion j for the dam i and S (D_i) is the suitability score of the dam i.

3.3. Results of Suitability Scoring

When the suitability scores for all of the dams were obtained, they were arranged in a table, where the lowest suitability score is 0.27 (27%), and the highest suitability score which is Aktaş Dam was obtained 0.87 (87%) suitability score, so the dams have been classified according to theirs suitability score as follows (Figure 26):

- High suitability class: 21 dams had a suitability score of between 75% and 87%, and these are listed and shown in Appendix A.

- Medium suitability class: 149 dams had a suitability score of between 50% and 74.99%, and these are listed and shown in Appendix B.

- Low suitability class: 95 dams had a suitability score of between 27% and 49.99%, and these are listed shown in Appendix C.

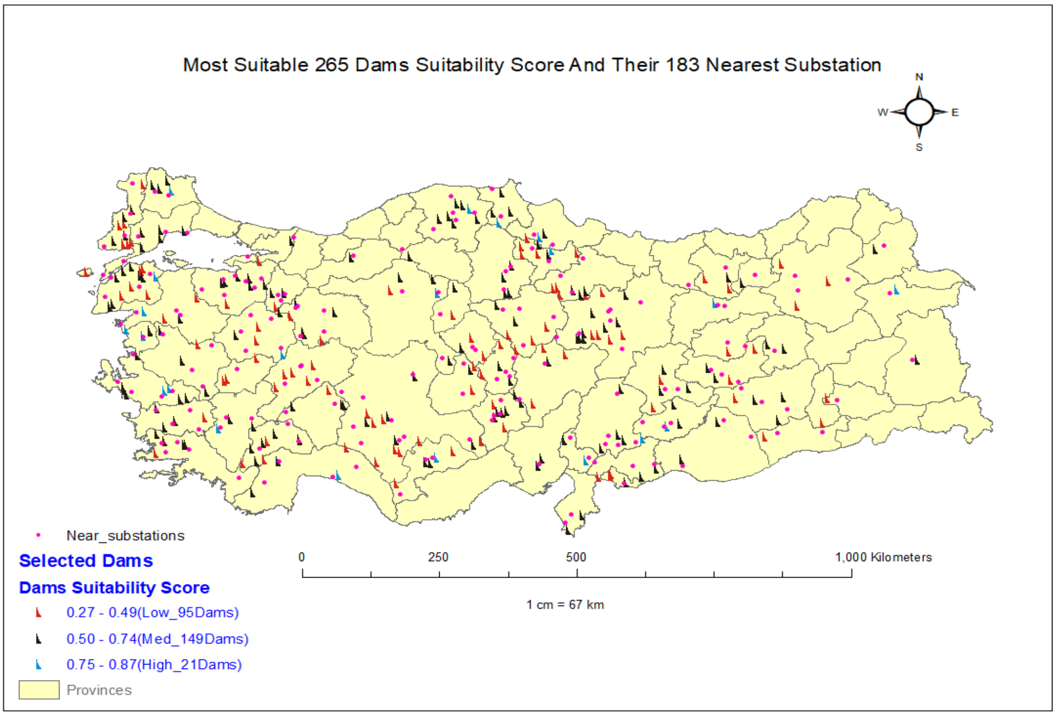


Figure 26 Distribution of the 265 dams with their suitability class and their 183 nearest substations

As explained before, all the selected dams are suitable to develop a hydropower because these dams have been selected according to criteria that ensure reaching the suitable hydropower generation condition, although the low level class has a low suitability score, it's can be used to develop a hydropower, where some dams in this class reach a 454 hm^3 reservoir capacity or 55.1 m normal water level or 79015 hm^2 irrigated area or 14.5 km near substation distance, which consider a suitable condition for hydropower development.

The medium suitability class is good for hydropower development, it's has not a very much low level of its criteria values, also some dams in this class reach a 717 hm^3 reservoir capacity or 84 m water level or 73690 hm^2 irrigated area or 0.7 km nearest substation distance, so it's has good dams to select from them for installing a hydropower plant.

The most suitable dams for hydropower development are those in the high suitability class they have a (10.9–220.5 hm^3) reservoir capacity, (36–98 m) water level, (1580–31918 hm^2) irrigated area and a (2.1–14 km) nearest substation distance. All the dams in this level are good and benefit able for hydropower generation with suitable grid connection distance.

CHAPTER 4

METHODOLOGY FOR FINDING BEST GRID CONNECTION PATH USING GIS MULTI-CRITERIA SPATIAL ANALYST TOOLS

4.1. Introduction

It is possible now to select any dam from the suitability scoring table of best 265 irrigation dams for hydropower development to find the best grid connection path to its nearest power transmission substation using the multi-criteria GIS spatial analyst tools or to make the manual technical tests at the dam location. For integrated solution, first the technical and spatial criteria that ensure finding the most suitable irrigation dams and power substations for generating and transmission electric power have been selected, then the dams were sorted according to their suitability of meeting all the criteria. In this section how to find the best grid connection path for power lines between the selected dams and theirs nearest power transmission substations were discussed, again according to multi-criteria which ensure the shortest path with least cost, least environment impact, avoids obstacles and in a suitable land use. The dams and substations have been selected before based on the criterion of 40 km nearest substation distance as maximum, so the distance of the derived best grid connection path between any dam and its nearest substation will be in the range of (0.7–38.2 km), which ensured the compatibility between the generated power and grid connection distance.

4.2. Multi-Criteria Spatial Analyst

GIS has good capabilities to deal with spatial problems, it can therefore be used to support spatial decision-making. Solving problem of spatial multiple complex criteria without GIS analysis and its spatial perception tools would be arithmetically difficult, if not impossible [47]. GIS multi-criteria spatial analyst is the most modern effective way to evaluate spatial options to achieve objectives within a set of compatible or conflicting spatial criteria [48]. It can be noted here that there were researches that have been able to evaluate spatial options using multi-criteria GIS spatial analyst, such as a GIS-assisted optimal Baghdad metro route selection based on multi-criteria decision making [49], or multi-criteria spatial analysis of land accessibility for seismic operations [50].

Multi-criteria GIS spatial analysis depends on calculating the impact of each spatial criterion in order to reach the desired objectives based on the available spatial options. In this study, the options are the potential routes for power line in the area between a dam and its nearest substation, and the objective is to find the best path in order to maximize the acceptance based on all the spatial criteria. Prior studies have used multi-criteria GIS spatial analysis to evaluate the paths of existing power lines in Turkey [8], and to optimize the routing of power lines in Spain [9].

The criteria which were chosen to find the best grid connection path are the measurable continues phenomenon spatial criteria's including (shortest distance, suitable elevation, least slope, near to roads, near to existing power lines) which related to the cost of establish and maintenance of new power lines, and the attributed spatial criteria's which are land cover criteria including (avoids or exclude some public and private property, avoid natural reserves, avoid large water surfaces, land use preferences) which related to the lands deduction costs, EIA requirement, and natural and artificial obstacles.

4.3. Methodology for Finding Best Grid Connection Path

To find the path with the least cost (the best path) [51], GIS multi-criteria spatial analysis starts by translating each spatial criterion from the extent of the study area (in this case, a rectangular area including the dam and the nearest substation) into a visible raster layer, where each cell in this layer represents a variable with a spatial value proportional to its criterion compatibility degree [48], [52]. This raster layer is then reclassified using a common scale for all the other criteria layers [53]. This reflects their actual spatial values and provided the ability to combine with the other criteria layers and enable weights to be given for each criterion by the decision maker or mathematical methods [54]. This will produce a new visual layer called the suitability layer or cost layer [55]. The value at any location (one raster cell) in this layer represents the cumulative cost or the suitability degree of that location, based on all the spatial criteria (Figure 27).

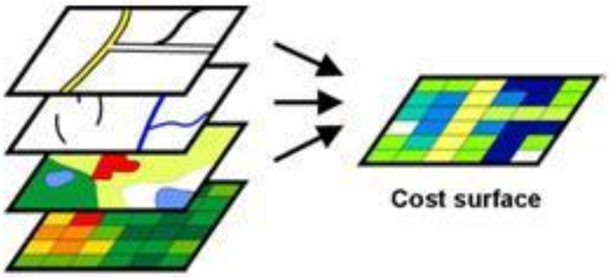


Figure 27 Reclassification of the criteria and cost raster layers

4.3.1. Evaluation of Shortest Distance Criterion

The GIS spatial analyzer is always seeks to approximate the best path to the Euclidean direct distance, this is basis on the fact of costs are always related to distance. But the spatial nature of some regulations related with directing power lines leads to a compromise between a straight line (Euclidean distance) from one point to another and the deviation of the path (least cost path) to avoid costly terrain, obstacles or other regulations criteria. In a study [56], the power line path was determined using Euclidean distance and spatial distance between the starting and the destination points, multiple layers were examined using the weighted criteria method to reach the optimal path selection, the path was compared with the Euclidean distance and showed that the spatial distance was better than the Euclidean distance method.

In this study case, when the grid connection distance decreases, the distance criterion suitability degree increases by decreasing the costs of establishing new power lines and increasing the efficiency of power transmission within the maximum and minimum grid connection distances range which are between (0.7–38.2 km) between the selected dams and their nearest substations, also the negative environmental impact decreases.

4.3.2. Evaluation of Elevation and Slope Criteria

For the criteria of suitable elevation and the least slope, Turkey consider as a varied terrain country, with plains, undulating areas and steep mountainous areas, elevations ranging from zero meters in coastal areas to 5200 meters elevations in mountain peaks (Figure 28). The slope directly affects the suitability and cost of installation and maintenance of the power transmission lines. Naturally, the power lines in the flat terrain are less expensive and more suitable.

Figure 28 Elevation map of Turkey

In a study [8], there are different decision makers who have different professional backgrounds on the power transmission line, one of them is an expert engineer in power lines design, where gave attention to the importance of terrain in the design of power transmission lines. For power towers, there are some technical regulations on the degree of slope because it is difficult to build transmission line towers on a high sloping surface. According to regulation of the power transmission line of the Turkish Electricity Company TEİAŞ (2004), the degree of slope, which is more than 30%, is unsuitable for design. Also areas with a slope greater than 40 % are prone to landslides, where landslides is a problem for power transmission towers because power tower locations must have a stable base because the landslides of the towers causes huge losses on the line.

There are also terrain-based costs including accessibility, where it requires additional costs for the transportation, installation and maintenance of equipment to cross rough terrain. Non-flat terrain also requires higher towers and more tower units. high elevation increases the likelihood of ice where it requires more expensive towers to support the mechanical stress and additional costs of electrical protection equipment, such as lightning arresters, because the increases of lightning probability. Also, the threat of wind speed on the towers is partly linked to the elevation [9].

Thus, the criterion of terrain slope is very important. In GIS, the quality of the results depends on the accuracy of the data; remote sensing techniques have played an important role in giving easy access to high-resolution data. In this study, to fit the extent of the area between any dam and its nearest substation, satellite imagery with spatial references was downloaded using the SASPlanet application and Google Earth Pro. The latter is the world's most famous satellite imagery viewer, and offers instant access to a tremendous amount of high-resolution satellite imagery. Most of this high-resolution database is filled with QuickBird images provided by DigitalGlobe. This application also enables users not only to preview satellite images, but also to obtain brief information about the scene, such as the date of acquisition, an elevation histogram, the cloud cover, nadir angle and target azimuth. Satellite imagery was used as a basis for determining the work extent and cell size for all other layers of criteria used to generate the best grid connection path, where GIS is usually use a base map or a base layer for serialized spatial analyses [57]. The elevation data for the coordinates of the work extent for each selected dam area were downloaded in Excel format, using the cells coordinates of the satellite imagery base map and the software TCX Convertor (Garmin's Training Center for Data).

In ArcCatalog for each selected dam to find the best path, a new subgeodatabase was created and it was gave the same name of the dam. In this subgeodatabase, the elevation data table of the area between the dam and its nearest substation and the satellite imagery of this extent area were imported, the feature classes of selected dam and its nearest substation were also imported from the original geodatabase of all dams and substations, all those subgeodatabase components have been projected on the polygons of turkey map feature class using WGS 1984 Lambert Conformal Conic coordinate system.

From the new subgeodatabase of the selected dam, the Excel spreadsheet of elevation data was imported into ArcMap to create the elevation raster layer using the inverse distance weighted *(IDW*) interpolation tool in spatial analyst tools box, where *IDW* interpolation calculates a value for each cell in the output raster layer from the values of the data points, with closer points given more influence and distant points less influence [58], *IDW* can be used to estimate elevation, precipitation, temperature, chemical dispersion, or other spatial persistence phenomena. So users can create surfaces from sample sites without having to visit each site in the study area, saving time and effort [59].

Then by using the *Slope* tool in the surface spatial analyst tools box the slope raster layer was created, where each cell in this layer represents the slope of its position. By using the surface spatial analyst in ArcGIS users can create many surface layers like hill shade, slope, contour, and aspect [59]. Then by reclassified the slope layer in a common scale from 1 to 9 with the other reclassified criteria's by giving the low values to the low slope cells (low cost), the slope suitability degree of that position to create a power line was represented.

4.3.3. Evaluation of Near to Roads and Current Power Lines Criteria

For the criteria of near to roads and near to existing power lines, Turkey covered by a wide roads network (Figure 29), and also large power grid connections (Figure 30), reach 68203 km of power transmission lines (as reported by TEİAŞ in 2019). Distance to roads and existing power lines directly affects the suitability and cost of installation and maintenance of the power transmission lines.

In a study [8], there are different decision makers who have different professional backgrounds in power transmission line, one of them is an expert technician in power lines works in the maintenance service, where attaches importance to the criterion of access to the new power transmission lines, according to his preferences near to current power lines makes the new power lines maintenance easier.

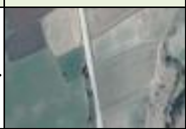
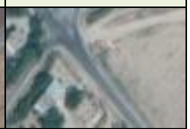
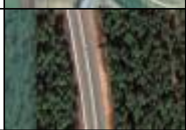
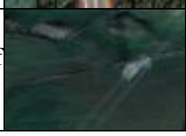
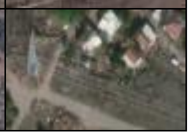
Figure 29 Detailed map of roads in Turkey

Figure 30 Map of power transmission lines in Turkey

The accessibility requires additional costs for the transportation, installation and maintenance of equipment to cross areas far from roads. Accessibility costs analysis is important in urban planning and land use management [60]. There are also land use based costs related with near to existing power lines, where it requires additional costs for the confiscation or rent lands for new power lines, while the passage of the new line along with the current lines does not require these additional costs.

In view of this, it's important to calculate the distance from roads and the distance from existing power lines. Note that any type of roads (highways, main roads or sub-roads) meets the criterion of accessibility, as well as power lines where if the new power line passes near any type of existing over-head power transmission lines will meets the criterion of accessibility and there is no need for new land expropriation. To help recognize the linear features of roads and power transmission lines from satellite images and to minimize the possibility of human error, a table containing patterns has been organized to be used to recognize the linear features of roads and power lines that can be seen in any of grid connection extent area between a dam and substation (Table 8). In GIS, Calculating the accrued cost of travel (distance analysis) provides the user additional data to make decisions. ArcGIS Spatial Analyst provides many distance mapping tools to measure both linear and Euclidean distance in terms of spatial parameters such as distance from the current infrastructure of all types of linear parameters (networks) such as roads [59].

Table 8 Recognition of linear features

Linear Feature Type	Description	Pattern 1	Pattern 2	Pattern 3
Sub roads	Zigzagging, narrow, single-track lines.			
Main roads	Single, dual-track lines.			
Highways	Double, wide, triple-track and direct lines.			
Power transmission lines	Towers, shadow of towers, removal of trees or buildings along lines.			

In the extent of the area between any selected dam and its nearest substation, by using the spatial reference satellite imagery in the selected dam subgeodatabase and by comparison with the available features classes data for roads and power lines or available topography maps and Google Maps, the roads and existing power lines were digitized and have been saved as a line feature classes in the subgeodatabase of selected dam. The ability to integrate data from different resources is one of the most important functions of GIS, where GIS usually use a base map or a base layer for creating new other criteria's layers or to do serialize spatial analyzes like satellite imagery or digital elevation model [57].

In ArcMap by using one of the spatial analyst tools which is *Euclidean distance* [51], the raster layer of the distance from the new feature classes of roads and existing power lines was created which were saved before in the subgeodatabase for the selected dam, where the value of each cell in this layers represents the distance of its position from the roads or existing power lines. By reclassified distance from roads and distance from existing power lines layers in a common scale with reclassified slope by giving the low values to the low cost cells (less distances),Where the zero value will be along the roads or power lines and the values (distances) will be increased as moving away from the road or power lines. By doing this, the suitability degree of that position to create a power line according to criteria of near to roads and existing power lines has been represented.

It is possible to combine the criteria of the near to roads and current power lines in one layer while digitizing the feature classes of these two criteria as both are linear features, where when there are many attributes within the criterion, the uniform reclassified criterion becomes smoother because the lower attributes within the criterion give a more surprising measure and a more biased value for each attribute [57]. However, in this study this was not done, to allow these criteria to be controlled separately.

4.3.4. Evaluation of Land Use Criterion

Turkey has variety forms of natural land cover as well as all types of land uses, which are constantly changing as a result of growth and climate change factors, [1] (Figure 31). All specialists agree on the importance and impact of the nature of land cover and the type of land use in the process of directing power lines.

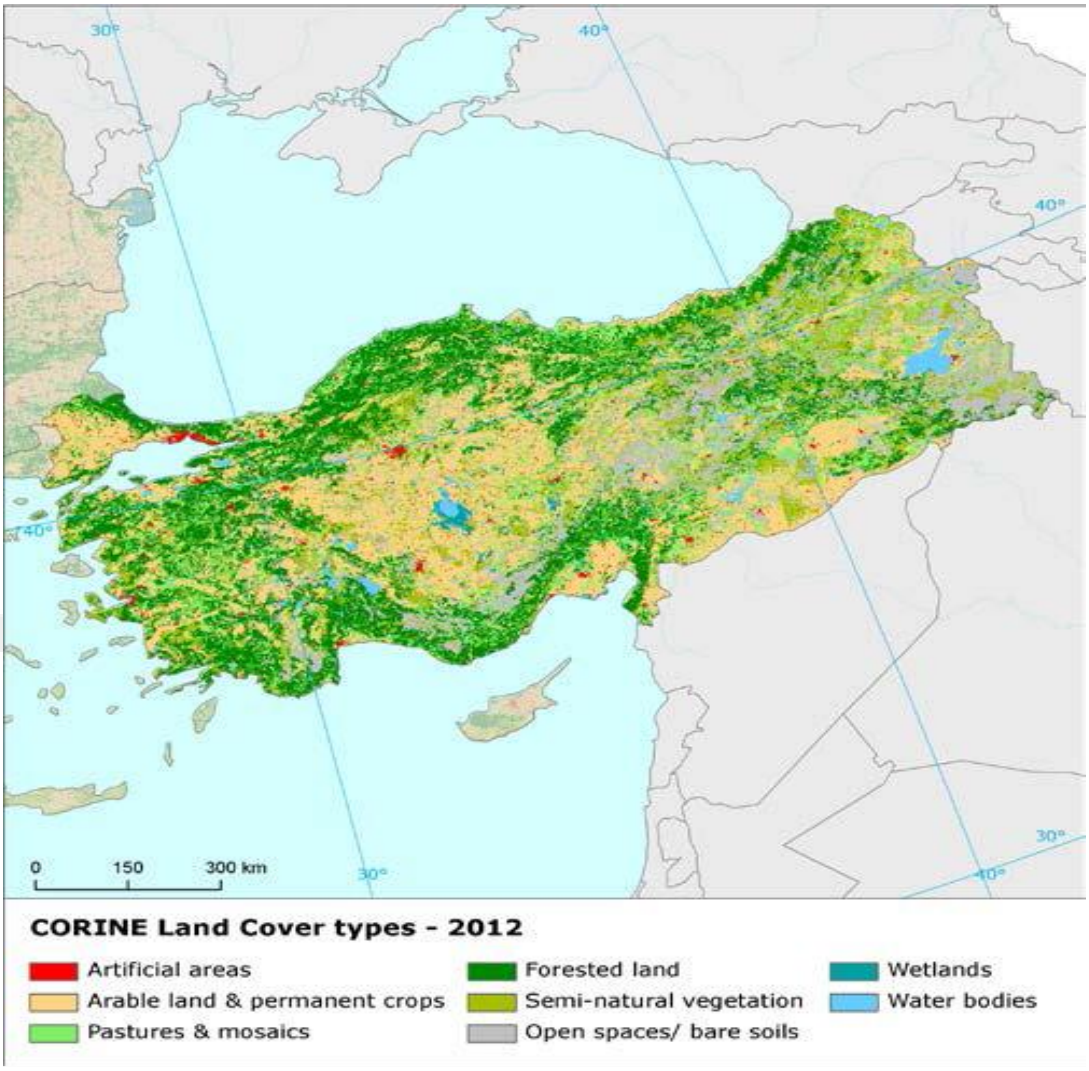


Figure 31 Map of land cover in Turkey (produced by the European Environment Agency)

In a study [8], there are different decision makers who have different professional backgrounds on the power transmission lines. One of them is an expert engineer in power lines design, where gave attention to the importance of land use. The other is an environmental engineer working on the environmental impact assessment of power transmission lines, who pays attention to minimizing the environmental impact of the new power lines during construction and operation periods, therefore land use, protected areas, water resources and urban layers have a greater important than other layers on his perspective, where the main aim of the environmental engineer is to pass the power line from the open areas, barren land, far from the habitat and settlement.

Therefore it is necessary to evaluate land cover and land use according to their suitability for directing power transmission lines before starting any new power line project, where the following considerations must take in account:

Costs of preparing the potential land: Which includes the confiscation or rent of lands to erect power towers, as well as the costs of removing trees and constructing support towers at the slopes and the crossing of linear obstacles like rivers, roads or other power lines, for example there are some restrictions on crossing rivers with wide more than 500 meter [8].

Environmental impact requirement: Where power transmission lines can have a significant impact on human body. Although the electromagnetic field effects of power lines are still not well defined in the long term, there are many studies on the negative effects on protein synthesis, Deoxyribonucleic Acid (DNA) synthesis, enzyme activity, neuronal and muscle cells, dysfunction and heart possible neurological effects [61], so directing of power lines in densely populated areas represents a real problem. The passage of power lines in forest areas requires 100% deforestation of tree around power towers and under power lines for the rights-of-way [62], which could lead to depletion of tree-based wildlife. Also in agricultural land, power lines could harm the agricultural products and can hamper the work of agricultural machinery [8].

Threats to power lines: There are many types of areas which pose a risk to the continued operation of power lines. Landslides areas can cause major problems for power lines as well as flood-prone areas that could cause problems and impede accessibility during construction or maintenance. Growing trees in the vicinity of power lines could cause an additional threat, so forest areas contain a potential hazard.

Obstacles: In addition for what has been mentioned above, there are some areas that are taboo for constructing power lines such as nature reserves, public places of entertainment, private property, military zones, airports, urban areas, archaeological sites, cemeteries, as well as natural obstacles including coastal areas, bays, lakes, wetlands and salt lakes. where the spatial nature of land cover associated with directing power lines cause to a compromise between a straight line from one point to another and a deviation of the path to avoid obstacles.

For the selected dams to find the best grid connection path, the areas of land cover were evaluated according to the above considerations. The high suitability classes have been given to land cover that has low cost, low environmental impact and low threats to power lines. Also some potential lands obstacles were excluded from the analysis and have been given "no data" value.

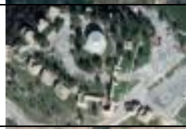
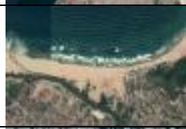
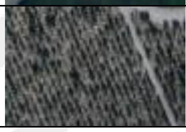
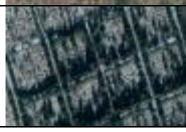
One of the most difficult and time-consuming parts of data acquisition is the digitization of the land use layer, and data availability is a vital component for any type of spatial analysis. Remote sensing can provide these data, and GIS can play a role when analyzing the obtained data. Since ArcGIS is flexible and can accept different data sets and identify different types of land use, the polygons of the land use layer were digitized by manual and digital classification, preceded by visual interpretation of satellite images which had previously been used as a base map for the extent of the study area to produce criteria maps. Additional data from Google Earth were also compared for cultural heritage sites, archaeological sites, nature reserves, and others. An online geo-information application created by the Heidelberg Institute for Technology (https://osmlanduse.org) also provided access to global land use maps [63]. The digitized land use polygons were then saved as a new polygon feature class in the subgeodatabase for each dam, for use in finding the best grid connection to its nearest substation.

In order to facilitate the process of distinguishing land use types, to reduce the risk of poor classification due to human error, and to regulate the reclassification of land use using a common scale with the other criteria, a table of typical land use patterns in Turkey was used as a comparison for the visual classification process. Each record in the table contains several images representing the types of standard land use that can be observed in any selected area, together with the value field of the suitability degree for this land use type on a scale from 1 to 9, as used for the other criteria (Table 9).

Table 9 Recognition of land use classes

Reclassified Value	Land use Type	Description	Pattern 1	Pattern 2	Pattern 3
1 (very good)	Barren	Free of features deserts or large uninhabited and uncultivated areas.			
3 (good)	Agriculture	Arable multi-green mosaics areas, pastures, semi natural vegetation.			
5 (acceptable)	Forest	Wide dark green trees areas.			
7 (poor)	Rural settlement	A few isolated buildings and settlements.			
9 (very poor)	Public Parks	Organized green areas with toys fields and small lakes.			
-1 no data (obstacles)	Airports	Flat rectangle areas with single or multi airplanes runway.			
-1 no data (obstacles)	Urban settlement	Wide dense group of different sizes squares represents building types.			
-1 no data (obstacles)	Lakes	Large irregular blue or green areas also rivers wider than 500 meters.			
-1 no data (obstacles)	Salt Lakes	Large irregular white or light blue areas.			
-1 no data (obstacles)	Wetlands	Large irregular green and light green areas.			
-1 no data (obstacles)	Military fields	Rectangle training fields, aircrafts or tanks barracks military air bases.			

Table 9 (continued)

-1 no data (obstacles)	Natural Reserves	Surrounded with green irregular polygon border in Google Earth.			
-1 no data (obstacles)	Archeological Areas	Large area of castles, walls and archeological sites.			
-1 no data (obstacles)	Gulfs	The extension of the sea into the land in the shape of large grooves.			
-1 no data (obstacles)	Beaches	The boundary between sea and land is either sandy or rocky.			
-1 no data (obstacles)	Cemetery	Large areas of regular sectors interspersed with some trees.			

In order to reclassify the land use into categories using a common scale with the rest of the criteria, and to identify obstacles with a value of "no data" that are prohibited areas for the other criteria, the polygon feature class of land use was converted from a vector data layer to a raster data layer, with the extent and sizes of the cells the same as in the elevation layer and satellite image layer. The raster data model allows the extent and the cover of analysis to be set and enables us to avoid the more common topological errors within vector layers [57]. The *Feature to Raster* tool from the spatial analysis toolbox of ArcMap was used.

Based on the considerations discussed above, the land use classes values were reclassified to be comparable with the reclassified of other criteria's layers as follow, where the higher value indicates that it is costly to create a power lines path on that particular land use:

- Obstacles which are Lakes, salt lakes, wetlands, urban settlements, natural reserves, archeological areas, cemeteries, airports and military bases are given a value of –1, indicating "no data" to exclude them from evaluation for all the criteria, any of these land uses are considered obstacles if their area diameter exceed 500 meters, which is the standard maximum distance between power towers.

- Public parks are given 9 (very poor), rural settlements are given 7 (poor), forests are given 5 (acceptable), agriculture lands are given 3 (good), and barren lands are given 1 (very good) which is the favorite lands to establish power lines. It is also possible to add a new land class to the reclassification in any time or reordered the importance of the land use classes according to different perspectives.

According to above reclassification and the European Environment Agency Report 2017 of Turkey land cover for 2012 year [1], 70% of land use in turkey are between (very good, good and acceptable) for power lines routing, and 5% considered as obstacles and excluded from power lines routing (Figure 31 and 32).

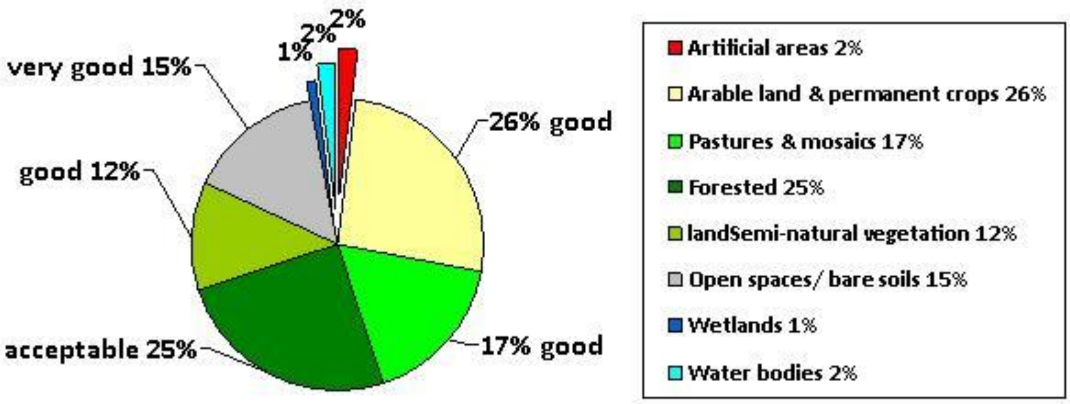


Figure 32 Statistics for land cover in Turkey and suitability for power lines routing

4.3.5. Combining the Reclassified Raster Layers of the criteria (Creating a Cost Layer)

After getting the reclassified raster layers in a common scale for all criteria layers and by using the *Map Algebra-Raster Calculator* spatial analyst tool in ArcMap tool box, all the reclassified raster layers were combined together with the possibility of giving weights for each criterion by asking the decision makers or using mathematical methods to determine weights, the cost layer was produced, where any place (one cell) on this raster layer represent's the cumulative cost value of power line routing on that place or the suitability degree of that place according to all the spatial criteria (Figure 33).

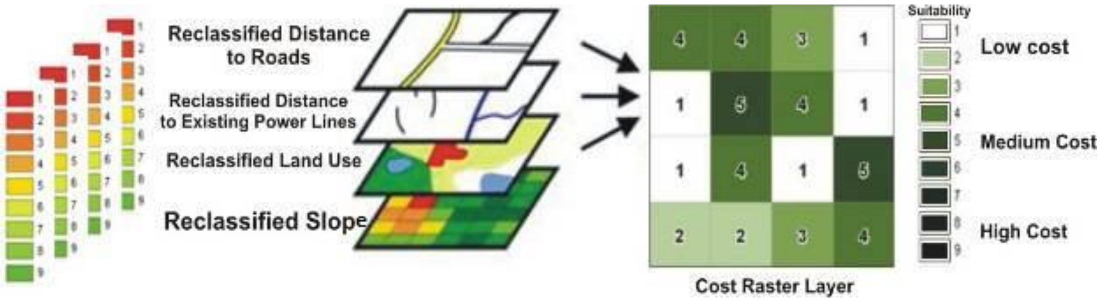


Figure 33 Creation of the cost layer

4.3.6. Creating the Layers of Least Cost Distance and Least Cost Direction

The least cost path algorithm uses the cost layer generated in the previous step with the path starting point layer (dam position), which is a temporary single-cell raster layer (created from the dam point feature class in the dam subgeodatabase) with the same extent as the cost layer, i.e. the rectangular area between the dam and the nearest substation. In this way, we produced two new visible layers: the least cost distance layer (cost distance raster) and the least cost direction layer (back link raster). These new raster layers were obtained using the *Cost Distance* and *Cost Back Link* spatial analysis tools in ArcMap (Figure 34).

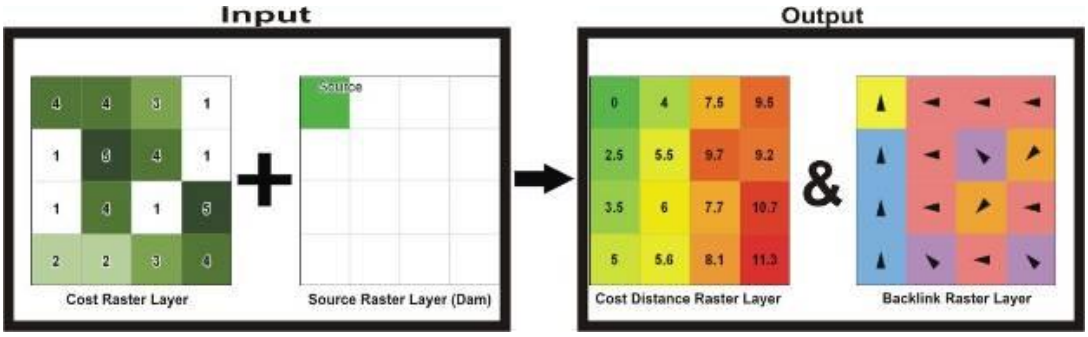


Figure 34 Generation of cost distance layer and back link layer

Each cell in the least cost distance layer in Figure 34 represents the lowest cumulative cost of traveling from that cell to the source point cell (dam position), while each cell in the back link layer represents the direction code for the lowest cost of movement to one of the eight neighbor cells back to the source point cell (dam position).

4.3.7. Creating the Least Cost Path Raster Layer (Best Path)

The destination layer was created by determining the destination point (the nearest substation). This is also a temporary one-cell raster layer (created from the substation point feature class in the dam subgeodatabase) which has the same extent as the cost layer, i.e. a rectangular area between the dam and its nearest substation. The GIS analyzer uses the least cost distance layer, the back link layer and the destination layer to calculate the least cost path raster layer (best path). This is a visible layer representing the path with the lowest possible cost from the dam to its nearest substation, based on all criteria and weights, or the most suitable path between the dam and its nearest substation i.e. with the highest suitability degree based on all the criteria. In this study, we aim to identify the best grid connection path with the shortest distance, lowest cost, most suitable land use and lowest environment impact. The least cost path raster layer (best path) was obtained using the *Cost Path* distance tool from the spatial analysis tool box in ArcMap (Figure 35).

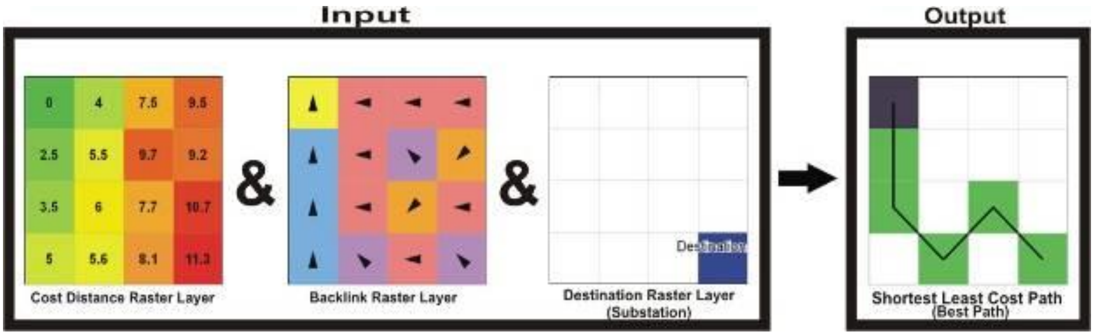


Figure 35 Derivation of the shortest least cost path

The output least cost path layer (best path) represents the shortest least costly path from the dam site to its nearest substation (Figure 36). The path avoids steep slopes and certain types of lands that are considered costlier for constructing the power line; the path also seeks to be near to roads and existing power lines and in a preferable land use.

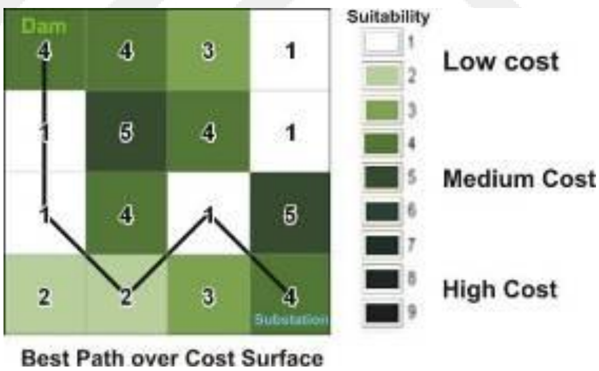


Figure 36 Shortest least cost path over the cost (suitability) layer

4.3.8. Converting Best Path Raster to Vector Feature Class

As an additional step, the raster path was converted to polyline (vector feature class) to enable control over the design of the route and placement of the pylons, also to visualize the path measurements and to create a database table for the path and apply the topology rules of power network design. This was done using the using the *Raster to Polyline* conversion tools in ArcMap [51] (Figure 37).

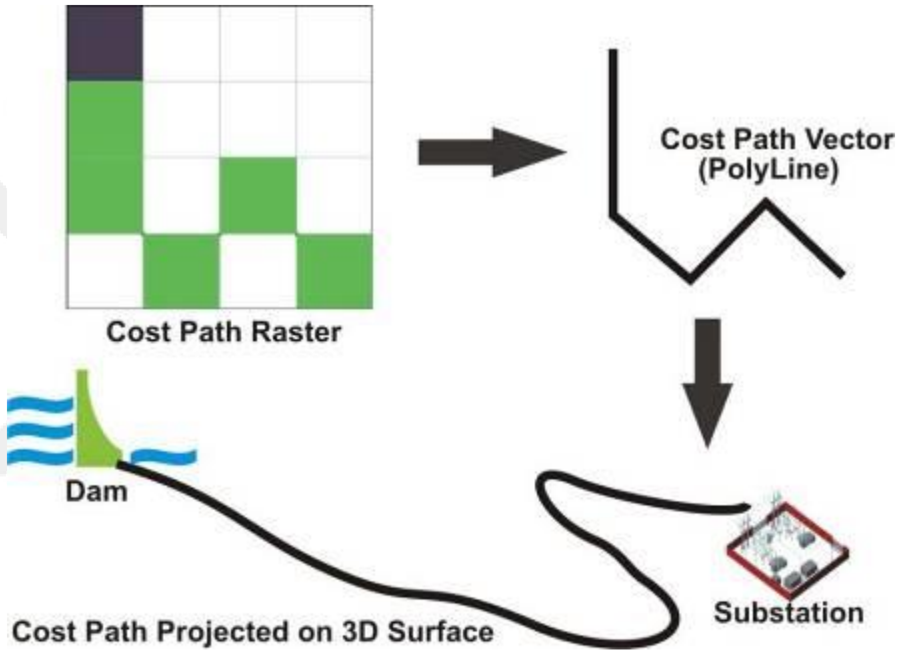


Figure 37 Converting the least cost path to a vector and visualizing it in 3D format

4.3.9. Projecting the Best Path Line Vector onto a 3D Surface

As a last step in the best path model by using ArcScene *Base Height* 3D analyst tools, the best path line vector was projected on the 3D surface of satellite imagery for the area of the path where the elevation raster layer was used as a base height to create the 3D surface for the satellite imagery in order to allow the realization of the path and the possibility of modification as well as determination of towers places by giving a realistic perception of the path on the real surface of the terrain and land cover (Figure 38).

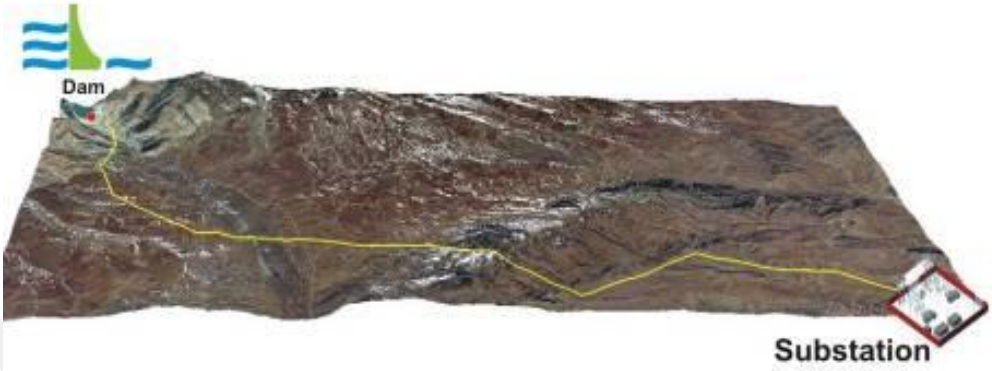


Figure 38 Virtual view of the best path, dropped onto a 3D satellite imagery scene

4.4. Multi-Criteria Spatial Analyst Modeling Using Model Builder

Using the *Model Builder* tool, ArcMap allows spatial analysis to be carried out by drawing flowcharts for the inputs and processes, exporting them in a graphical format or via a Python script. In this way, the spatial analysis processes used to find the best path can be summarized by drawing a flowchart and linking the input data to the spatial analysis tools in the chart. This capability is useful to speed up and facilitate the procedures involved in calculating the best path for any of the selected dams (Figure 39).

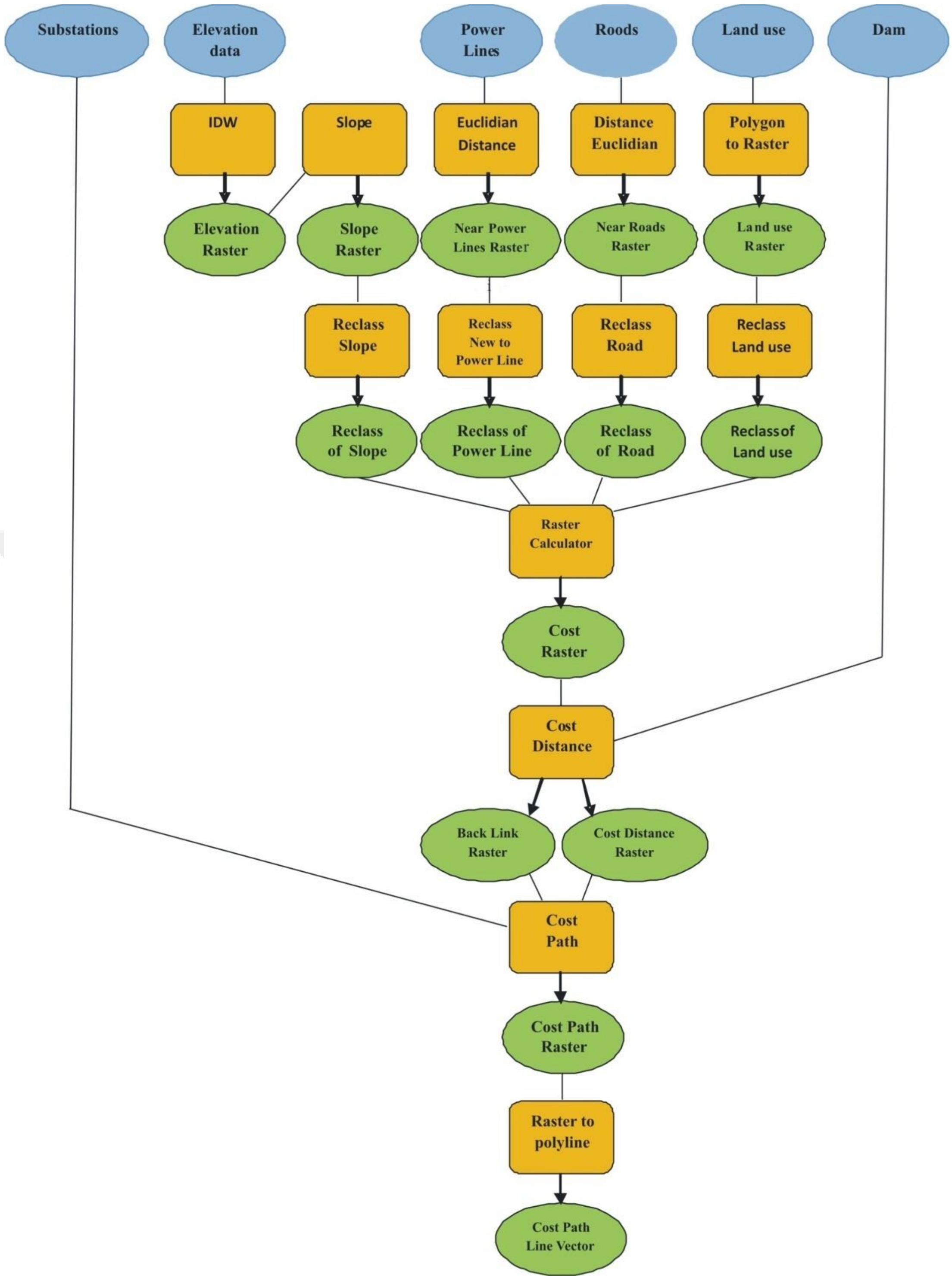


Figure 39 Flowchart for processes of finding the cost path using the *Model Builder* tool

CHAPTER 5

CASE STUDIES

In general, the potential hydropower from the development of irrigation dams may not be very large. However, if appropriate criteria are available, the irrigation dams are considered the best for the development of hydropower and preferred on municipal or flood control dams for the following reasons:

- There may not be a good flow of water throughout the year, but in the flow seasons they often have a good flow and continue of water because they are established for the purpose of irrigating large areas near rivers which provide good water supplies that encourage agriculture [18][64].

- The simple design of irrigation dams allows modifications to install various power turbines. Unlike other types of dams, the body of the irrigation dams is free from hydraulic machines and gates, where it depends on the spillway corridor to discharge the flooded water as shown in Figure 5. Irrigation is done by channels from the dam's lake or pumps located on the dam's lake and not on the dam's body [65]. For example, a siphon intake turbine can be installed, which is an elegant solution, it does not need to pierce the dam body, the design of irrigation dams crests near the water surface makes it easy to install, with generating efficiency of about 95%, there are examples with installed power up to 11 MW and heads up to 30.5 meters, it can be located either on top of the dam or on the downstream side (Figure 6). Another choice if the dam already has a bottom outlet; it will be a possible solution for install power turbine (Figure 7) [18].

- For hydropower development, the irrigation dams considered the best in light of connecting the generated power to the grid from other types of dams, as it does not contain operational installations at the body of the dam that consume the generated power, while the generated power from municipal dams is often exploited to run a water filtration plant [3], or to operate the gates and the observation station in case of flood control dams.

Based on multiple criteria related to spatial, technical, risk and environmental factors, the best irrigation dams for hydropower generation have been selected in terms of the best grid connection of the generated power. Most previous studies have separately examined factors such as the best sites for hydropower development, criteria for hydropower generation, lowest risk or environmental impact, grid connection, existing sites and power lines. However, some of these projects have not been able to be implemented, since advantages in one aspect are offset by drawbacks in others; some hydroelectric projects have suffered from inefficient power production due to the cost of grid connection [10].

From the 265 dam's suitability scoring table, 2 dams were selected from the medium and high suitability classes as a case study to evaluate the criteria of the dam and its nearest substation and the potential power also finding the best grid connection path to the nearest substation to translating the potential generated hydropower from it to the electricity grid.

5.1. Karadere Dam

Karadere is an irrigation dam located between Kastamonu and Taşköprü District (Figure 40). It was built on clay core sand land fill type, and is situated on the Karadere river. The length of the dam body is 309 m, and the height from the foundation is 90 m, with a reservoir capacity of 26.08 hm^3. The area irrigated by the dam is 6852 hm^2, and the full spillway is 1220 m^3/s. Construction of the dam began on October 20th, 1993, and it was completed on May 31st, 2007 (Figure 41). According to the DSI, the reservoir was filled at a level of 89.2% in 2018 and 100% in 2019 (Table 10).

Figure 40 Top view of Karadere Dam and its lake, in Kastamonu Province

Figure 41 Karadere Dam, body and spillway

Table 10 2018 and 2019 Reservoir status of several dams in Turkey (data from DSI)

REZERVUAR ADI	MAKSİMUM KOT (m)	MAKSİMUM (hm³)	27.05.2018 KOT (m)	27.05.2018 HACİM (hm³)	27.05.2019 KOT (m)	27.05.2019 HACİM (hm³)	AKTİF DOLULUK 2018 %	AKTİF DOLULUK 2019 %	BARAJ DOLULUK %
KARAÇOMAK	889,50	22,6	888,52	21,14	889,66	22,85	92,9	100,0	101,1
GERMEÇTEPE	843,00	7,2	843,17	7,29	843,20	7,30	100,0	100,0	101,3
KARADERE	805,00	26,1	802,92	24,09	805,06	26,14	89,2	100,0	100,2
BEZİRGAN	1011,50	16,2	1011,04	15,84	1011,72	16,39	97,5	100,0	101,1
ASAR	935,00	4,6	934,18	4,25	934,85	4,50	91,8	98,5	98,8
KULAKSIZLAR	1110,00	18,7	1108,64	17,04	1109,71	18,36	88,8	97,6	98,1
BEYLER	1115,40	26,0	1114,44	23,76	1115,11	25,28	90,7	97,0	97,2
KOZLU	178,85	25,6	175,26	21,63	175,02	21,38	83,9	82,9	83,6
KIZILCAPINAR	109,00	36,3	108,93	36,11	109,08	36,41	99,6	100,0	100,4
BÖLGE GENELİ		**183,2**		**171,2**		**178,6**	**92,4**	**97,1**	**97,5**

5.1.1. Karadere Dam's Technical Criteria

Based on the technical criteria, Karadere dam is suitable for hydropower generation and has the following specifications:

- 11 years in operation, which less than the years in operation criterion in (80–11 = 69 years), 69 more possible years in operation.

- The purpose of the dam is only irrigation.

- The height from the foundation (base height) is 90 meter, which is more than the criterion of dam height in (90–15 = 75 m).

- The reservoir capacity is 26.08 hm^3, which is more than the criterion of reservoir capacity in (26.08–3 = 23.08 hm^3).

The potential power can be calculated from equation (2) previously referred to, this equation needs dam height and a discharge flow rate to calculate the potential installed capacity. Flow rate can be estimated by reservoir size, dam height and river type [66] (Table 11).

In general, the rivers of irrigation dams have a good flow [18]. The (https://power-calculation.com/hydroelectricity-energy-calculator) site [14]; allows calculation of potential power parameters by inserting the needed equation values in equation (2) which represent the dam hydro resources values (Figure 42).

Table 11 Stream flow in m^3/s for calculation of hydropower (as given by power-calculation.com)

Water stream	Water flow in m3/s
Tap water (pressure 2-3 bar)	0.0002
Fire hose	0.008
Very small river	< 2 m3/s
Small River	> 2 m3/s
Big River	100 m3/s
Very big river	>500 m3/s

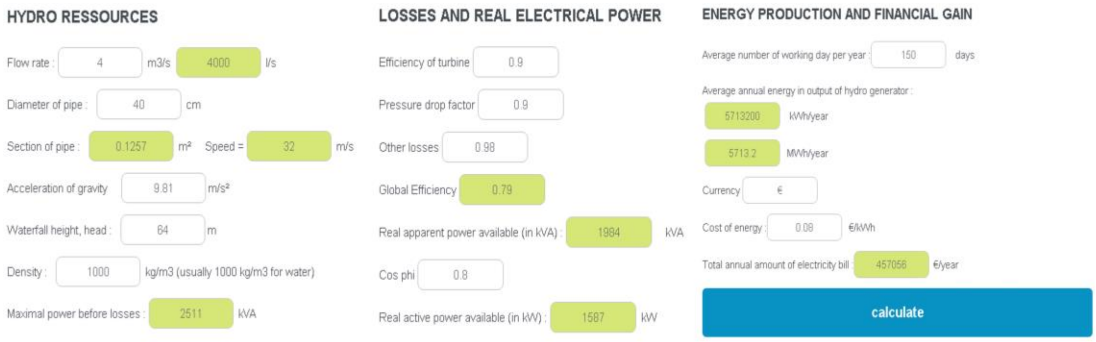


Figure 42 Hydropower calculator at power-calculation.com: data for Karadere Dam

Using Equation (1) above, we can calculate the waterfall height (normal water level, NWL) in m, which represents the head height of the water outlet at the bottom of the active storage of the dam. This value was calculated for all the dams in the geodatabase using the *Filed Calculator* in ArcCatalog. For the Karadere dam (Figure 4),

NWL = [dam Height – [crest elevation at sea level – normal water elevation at the sea level]]
NWL (head) = [70 – [811– 805]] = 64 meter

Using the Hydropower Calculator by power-calculation.com for Karadere dam values, the following parameters were got:

- Real active power available (in kW): 1587 kW.

With 150 days average number of working days per year:

- Average annual energy in the output of hydro generator: 5713.2 MWh/year.

- Annual electricity bill: €457056/year.

5.1.2. Nearest Substation to Karadere Dam

The nearest substation to this dam is Taşköprü, at a distance of 12.07 km. The substation is in operation and belongs to TEİAŞ Institute. It is a power transmission step-up substation with a capacity of 154 kV (Figure 43).

Figure 43 Top view of Taşköprü Substation

5.1.3. Suitability Score of Karadere Dam

For Karadere dam to determine the degree of meeting the criteria which are nearest substation distance, environmental impact requirement and technical criteria, also its rank of suitability score relative to the rest of all selected dams, multi-criteria fuzzy logic was used. Multi-criteria fuzzy logic depends on calculating the impact of each criterion to serve the desired objective within the available options. Fuzzy logic translates each criterion into a continuous variable that takes a value between zero and one (0<=x<=1) called suitability degree or membership degree, which reflux the actual values within the maximum and minimum values of the original criterion [39]. The criteria that have been chosen to calculate the suitability of each dam are the spatial criteria including (near substation distance, EIA requirement) and the technical criteria (reservoir capacity, natural water level, dam purpose and years in operation).

Previously by using equation (4), the suitability score for all the criteria of selected dams were calculated. The dams were arranged according to their suitability score in Excel table, then the suitability score field was exported from this table to the selected dams table in the geodatabase. However, the calculation of suitability score for Karadere dam was as following:

$S(D_i) = \sum W_j * C_{ij}$ i=1,2,...,n j=1,2,…,r

Where i is the dam number, j is the criterion number, n=265 is the total selected dams, r=6 is the total number of the criteria, W_j is the weight of the criterion j, C_{ij} is the suitability degree of the criterion j for the dam i and $S(D_i)$ is the suitability score of the dam i.

C_{ij} for Karadere dam are:

Suitability degree for reservoir capacity:

Selected 265 dams reservoir capacity median = 18.5 hm^3
Minimum Selected 265 dams reservoir capacity = 3 hm^3
Maximum Selected 265 dams reservoir capacity = 717.7 hm^3
Karadere dam reservoir capacity = 23.08 hm^3
Since reservoir capacity = 23.08 hm^3 is greater than the median = 18.5 hm^3 then..
Karadere reservoir capacity suitability degree = [(23.08–18.5)/(717.7–18.5)]*(1– 0.5) + 0.5
Karadere reservoir capacity suitability degree = 0.505453506 (Figure 44).

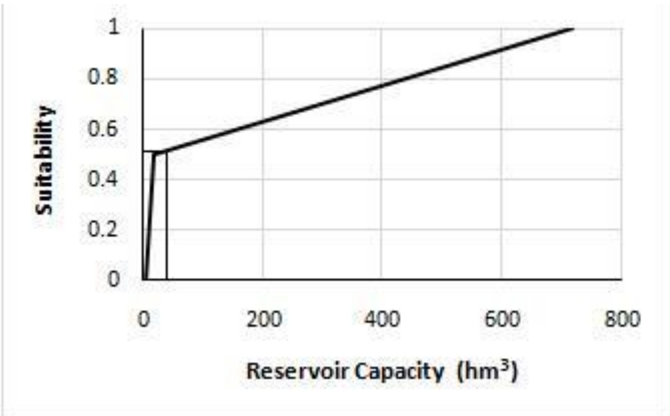


Figure 44 Suitability function for reservoir capacity, Karadere Dam

Suitability degree for normal water level (head):

Selected 265 dams normal water level median = 33.5 m

Minimum Selected 265 dams normal water level = 9 m

Maximum Selected 265 dams normal water level = 98 m

Karadere dam normal water level = 64 m

Since normal water level = 64 is greater than the median = 33.5 then..

Karadere normal water level suitability degree = [(64–33.5)/(98–33.5)]*(1–0.5) + 0.5

Karadere normal water level suitability degree = 0.736434109 (Figure 45).

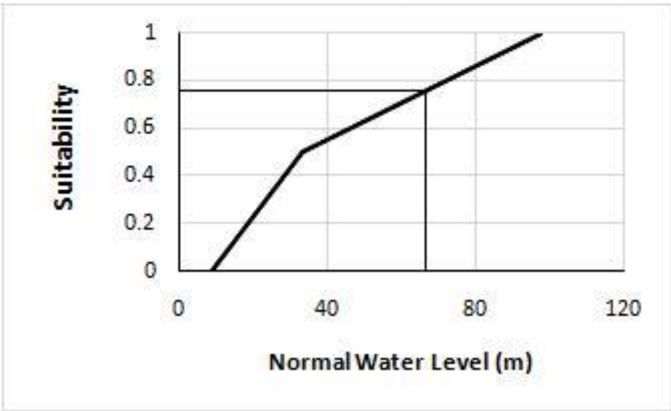


Figure 45 Suitability function for normal water level, Karadere Dam

Suitability degree for purpose:

Purpose = Irrigation = 1

Since Karadere is a single purpose dam then..

Karadere purpose suitability degree = 1 (Figure 46).

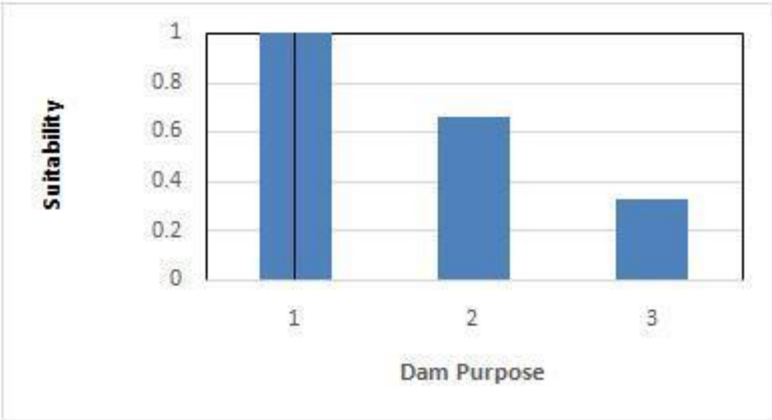


Figure 46 Suitability function for dam purpose, Karadere Dam

Suitability degree for dam years in operation:

Minimum Selected 265 years in operation = 1 year

Maximum Selected 265 dams years in operation = 60 years

Karadere dam years in operation = 11 years

Karadere years in operation suitability degree = 1– (11/60)

Karadere years in operation suitability degree = 0.819672131 (Figure 47).

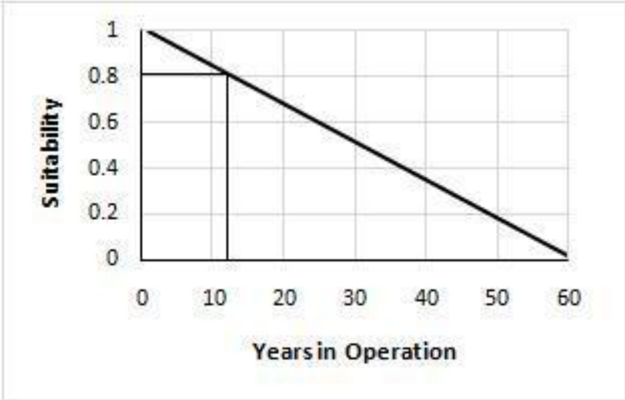


Figure 47 Suitability function for years in operation, Karedere Dam

Suitability degree for distance to nearest substation:

Minimum Selected 265 dams nearest substation distance = 0.7 km

Maximum Selected 265 dams nearest substation distance = 38.2 km

Karadere dam nearest substation distance = 12.07 km

Karadere nearest substation distance suitability degree = 1– (12.07/38.2)

Karadere nearest substation distance suitability degree = 0.6904013 (Figure 48).

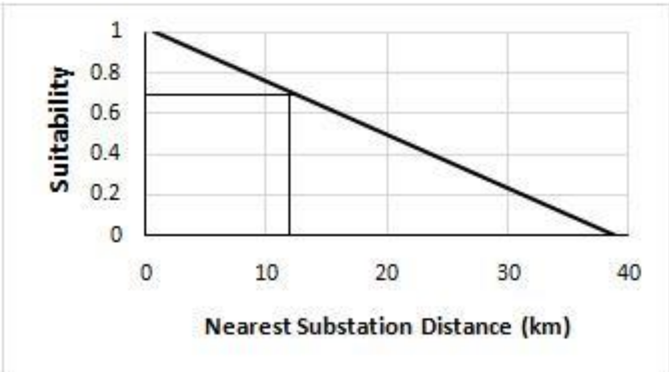


Figure 48 Suitability function for nearest substation distance, Karadere Dam

Suitability degree for EIA requirement:

Since Karadere nearest substation distance = 12.07 km lees than 15 km then..
Karadere EIA requirement suitability degree = 1 (Figure 49)

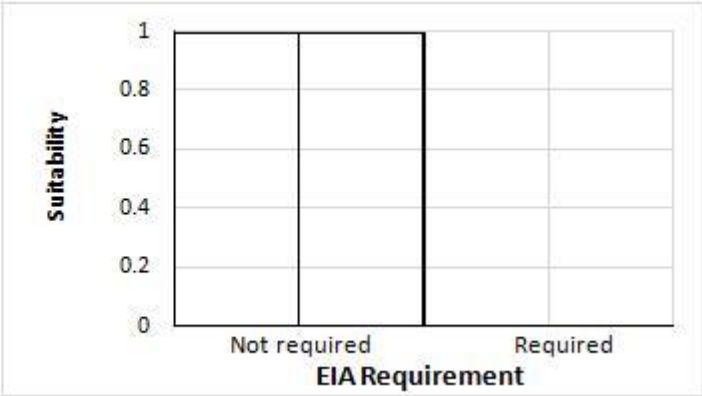


Figure 49 Suitability function for EIA requirement, Karedere Dam

Then the suitability score for Karadere dam S (D_i) is:

S (D_i) = 0.505453506 (0.16) + 0.736434109 (0.16) + 1 (0.16) + 0.819672131 (0.16) + 0.690401261 (0.16) + 1 (0.16)

S (D_i) = 0.788825527 = 78%

78% is the suitability score of Karadere dam according to all the criteria, which put Karadere dam in the high suitability class, which are 21 dams had a suitability score of between 75% and 87%, where Karadere Dam was ranked the ninth in its the suitability score from the selected 265 dams.

5.1.4. Best Grid Connection Path (Least Cost Path) from Karadere Dam to its Nearest Substation

Both Karadere Dam and its nearest substation (Taşköprü) are located in Kastamonu province. At first in ArcMap, the feature classes of Karadere Dam and Taşköprü substation were selected from geodatabase tables, then they have been added them over the layer of Turkey provinces map (Figure 50).

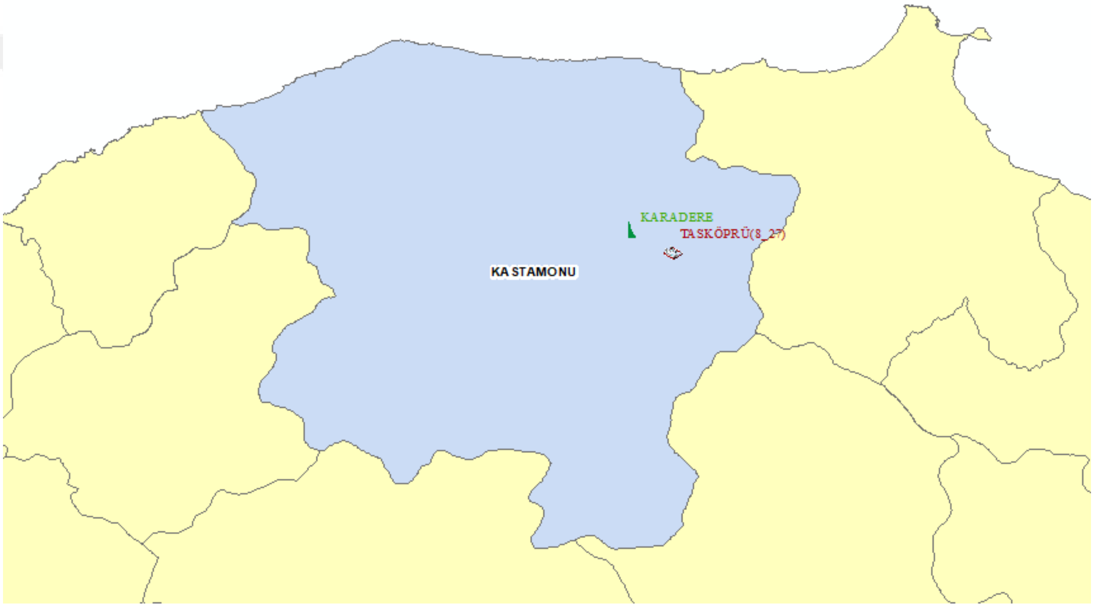


Figure 50 Karadere Dam and its nearest substation (Taşköprü) on a map of Turkey

We found the straight distance between them while generating the *Near Table* of nearest substation for each dam in the geodatabase, where the straight distance between Karadere dam and Taşköprü substation is 12.07 km (Figure 51).

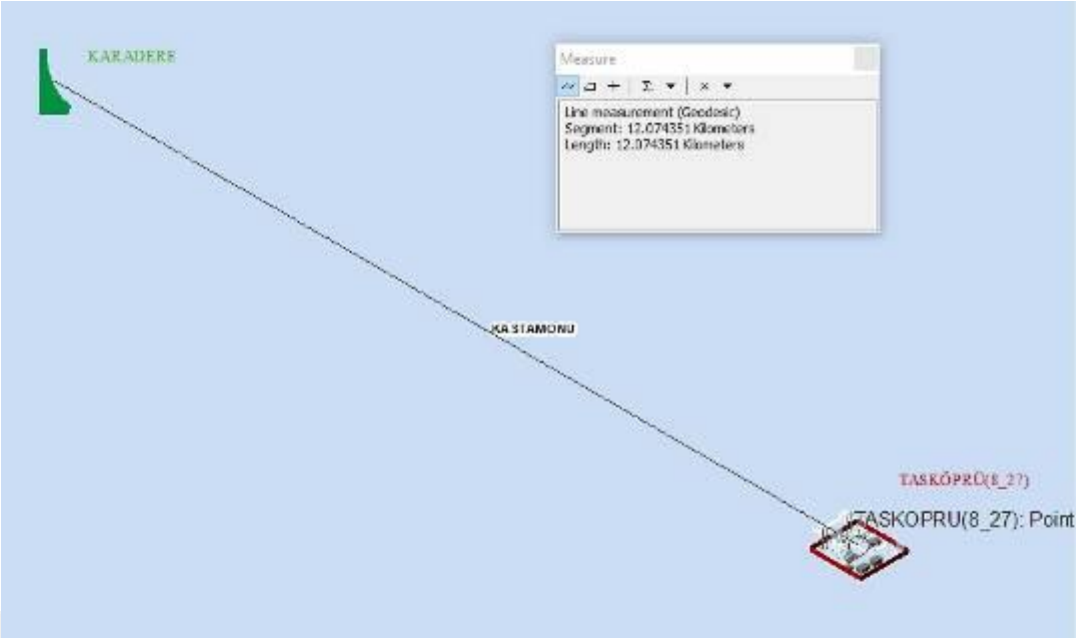


Figure 51 Straight-line distance (12.07 km) between Karadere Dam and Taşköprü Substation

The multi-criteria GIS spatial analyst depends on calculating the impact of each spatial criterion to serve the desired objective within the available spatial options. The criteria that have been chosen to find the best grid connection path are the measurable continues phenomenon spatial criteria's including (shortest distance, suitable elevation, least slope, near to roads, near to existing power lines) which related to the cost of establish and maintenance of new power lines, and the attributed spatial criteria's which are land cover criteria including (avoids or exclude some public and private property, avoid natural reserves, avoid large water surfaces, land use preferences) which related to the lands costs, EIA requirement, and natural and artificial obstacles.

Multi-criteria GIS spatial analyst starts by translating each spatial criterion from the extent of the study area (a rectangular area between the dam and the nearest substation) into a visible raster layer, where each cell in this layer represents a variable that has a value compatible with the spatial value of its criterion.

A reference satellite image was used to calculate the extent of the area between the Karadere Dam and Taşköprü substation in order to generate the criteria layers. The satellite imagery and spatial references were downloaded via the SASPlanet application and Google Earth Pro.

In the ArcCatalog, a new subgeodatabase was created and gave Karadere name. In this subgeodatabase the satellite imagery of the area extent was imported, also the feature classes of Karadere dam and Taşköprü substation were imported from the original geodatabase of all the selected dams and substations, in ArcMap all those subgeodatabase components were projected on the satellite imagery using the coordinate system of Turkey provinces feature class polygons WGS 1984 Lambert Conformal Conic (Figure 52).

Figure 52 Extent of spatial reference satellite imagery for Karadere Dam and Taşköprü Substation feature classes

To create the layers for the criteria of suitable elevation and least slope, using the cells coordinates of the satellite imagery base map and the TCX Convertor application the elevation points data were downloaded for the coordinates of the area extent of Karadere dam and Taşköprü substation in an excel format table. In ArcMap and from the new subgeodatabase of Karadere dam, the elevation data excel table was imported to create the elevation raster layer using the inverse distance weighted *IDW* interpolation tool in spatial analyst tools box (Figure 53).

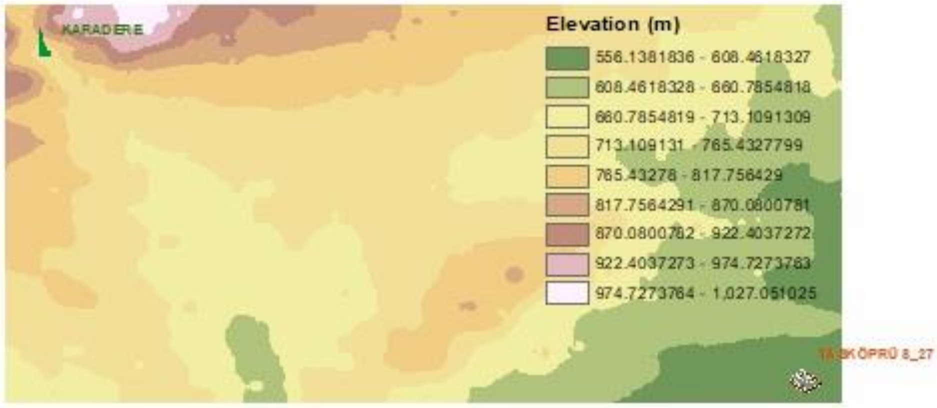


Figure 53 Elevation raster layer for the extent between Karadere Dam and Taşköprü Substation

Then by using the ArcMap *Slope* tool in the surface spatial analyst tools box the slope raster layer was created, where each cell in this raster layer represents the slope of its position (Figure 54). According to TEİAŞ, the degree of slope, which is more than 30%, is unsuitable for design. Also areas with a slope greater than 40% are prone to landslides.

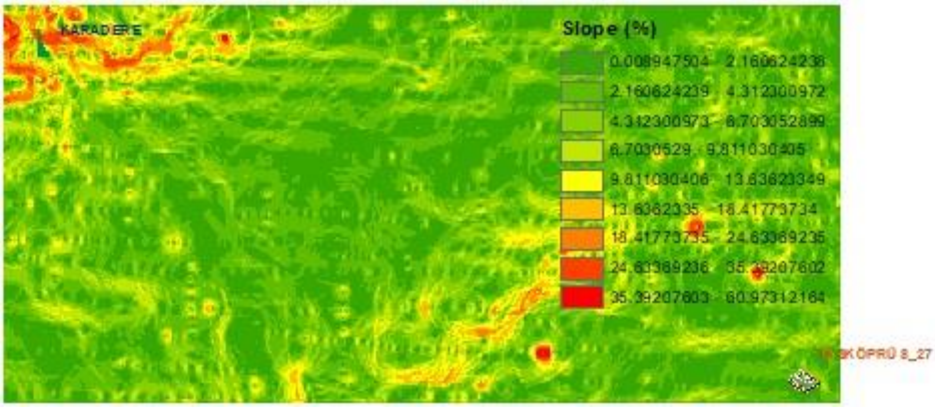


Figure 54 Slope raster layer for the extent between Karadere Dam and Taşköprü Substation

Then by reclassified the slope layer in a common scale range from 1 to 9 with the other reclassified criteria's, by giving the low values to the low slope cells (low cost) the slope suitability degree of that position to create a power line will represented. The high values represent the areas not good for power lines routing (Figure 55).

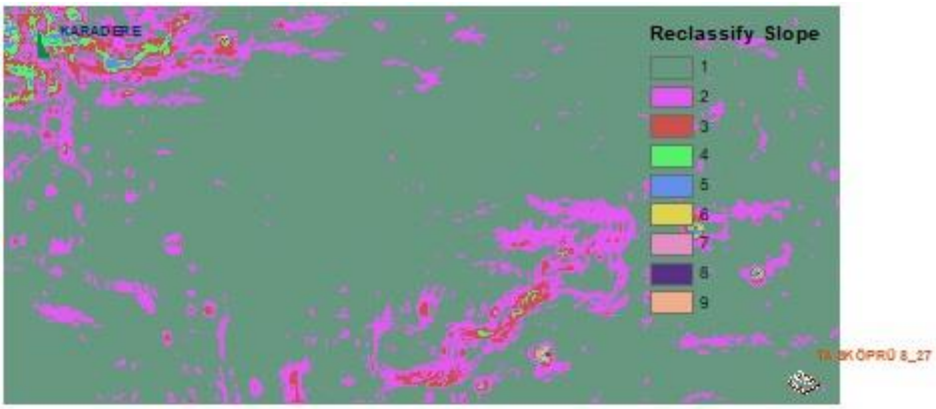


Figure 55 Reclassified slope raster layer for the extent between Karadere Dam and Taşköprü Substation

For the criteria of near to roads and near to existing power lines, where near to current power lines and roads makes the installation and maintenance of the new power lines easier.

To calculate the distance from roads and the distance from existing power lines. In the extent of the area between Karadere dam and Taşköprü substation, the roads and existing power lines were digitized and saved them as line feature classes in the selected dam subgeodatabase (Figure 56).

Figure 56 Feature classes for roads and power lines, for the extent between Karadere Dam and Taşköprü Substation

In ArcMap by using one of the spatial analyst tools which is *Euclidean Distance*, the raster layer of the distance from feature classes of roads and existing power lines was created which was saved before in the subgeodatabase of Karadere dam, each cell's value in this layers represents the distance in meters from its position to the roads or existing power lines (Figure 57 and 58).

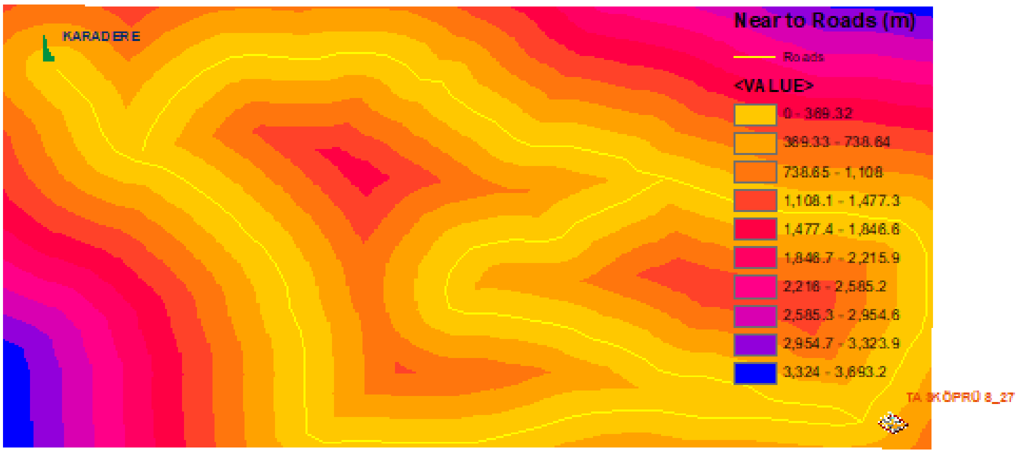


Figure 57 Raster layer representing near to roads for the extent between Karadere Dam and Taşköprü Substation

Figure 58 Raster layer representing near to existing power lines for the extent between Karadere Dam and Taşköprü Substation

By reclassified distance from roads and distance from existing power lines layers in a common scale with reclassified slope from 1 to 9 by giving the low values to the low cost cells (short distances), where the zero value will be along the roads or power lines and values (distances) will be increased by moving away from the roads or existing power lines. By doing this, the suitability degree of any position to create a new power line according to criteria of near to roads and existing power lines was represented (Figure 59 and 60).

Figure 59 Reclassified raster layer for near to roads for the extent between Karadere Dam and Taşköprü Substation

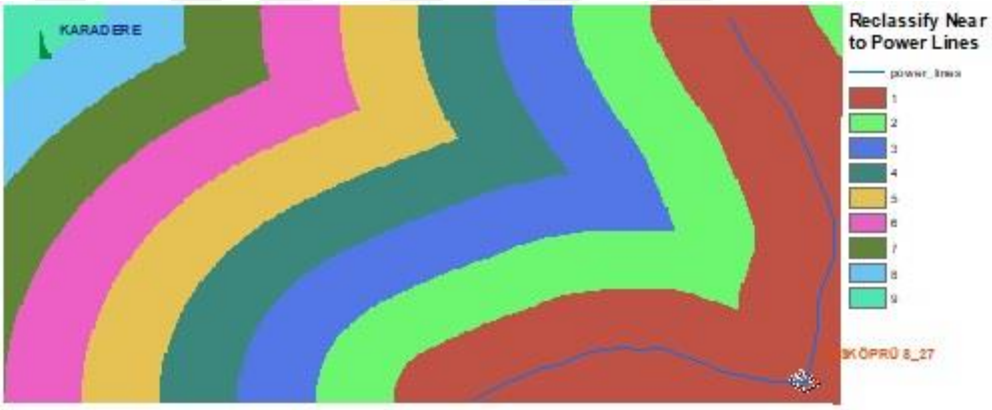


Figure 60 Reclassified raster layer for near to power lines for the extent between Karadere Dam and Taşköprü Substation

For the criterion of land use, all specialists agree on the importance and impact of the nature of land cover and the type of land use in the process of directing power lines, where the main purpose is to passing the power line through open areas, barren lands, far from the habitat and settlements. The high suitability classes were given to land uses that have low cost, low environmental impact and low threats to power lines. Also some potential lands obstacles were excluded from the analysis and have been given "no data" value.

The polygons of land use layer feature class were digitized by manual recognition and digital classification preceded by visual interpretation of satellite images that used before as a base map over the extent area to produce criteria's maps. Also the additional data that Google Earth provides were compared, such as cultural heritage sites, archaeological sites, nature reserves, and others. As well as (https://osmlanduse.org) where provides access to global land use maps [63]. Then the digitized polygons of land use were saved as a new polygon feature class in the Karadere dam subgeodatabase (Figure 61).

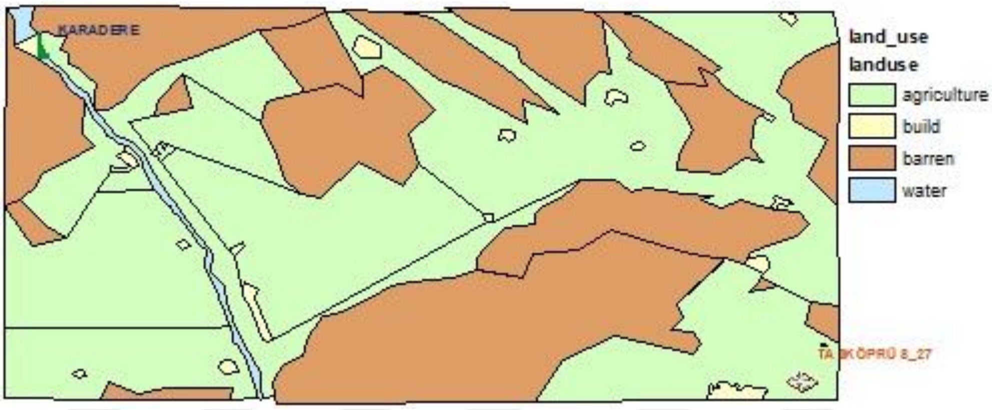


Figure 61 Land use feature class map for the extent between Karadere Dam and Taşköprü Substation

For the purpose of the possibility of reclassification by categories of land use within a common scale with the rest of other criteria and for the purpose of giving the obstacles value "no data", which will be considered as prohibited areas for all other criteria, the polygon feature class of the land use was converted from vector data layer to raster data layer (Figure 62). The *Feature to Raster* tool was used from the conversion tools in the spatial analysis toolbox of ArcMap.

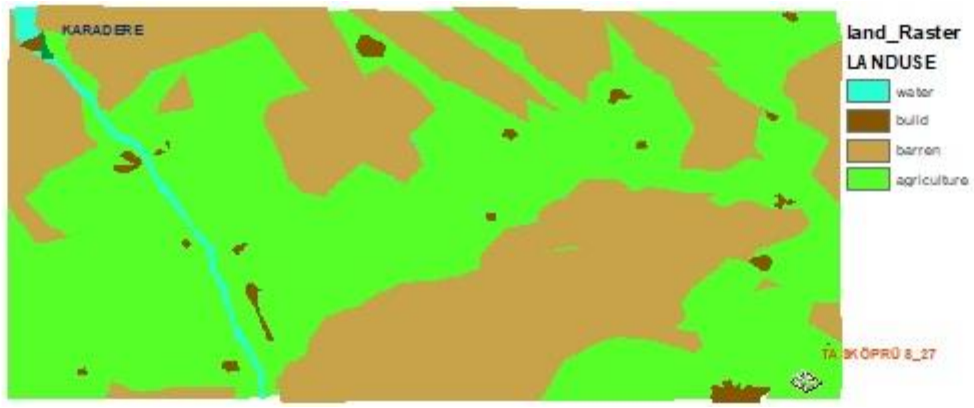


Figure 62 Land use raster layer for the Extent between Karadere Dam and Taşköprü Substation

The land use class values were reclassified to be comparable with the reclassified of other criteria's layers, where the higher value indicates that it is costly to create a power lines path on that particular land use (Figure 63).

Figure 63 Reclassified land use raster layer for the extent between Karadere Dam and Taşköprü Substation

After getting the reclassified raster layers in a common scale for all the criteria layers and by using the *Map Algebra-Raster Calculator* spatial analyst tool in ArcMap tool box, all the reclassified raster layers together were combined, the cost layer was produced where any place (one cell) on this raster layer represent's the cumulative cost value or the suitability degree of that place for power lines routing according to all spatial criteria (Figure 64).

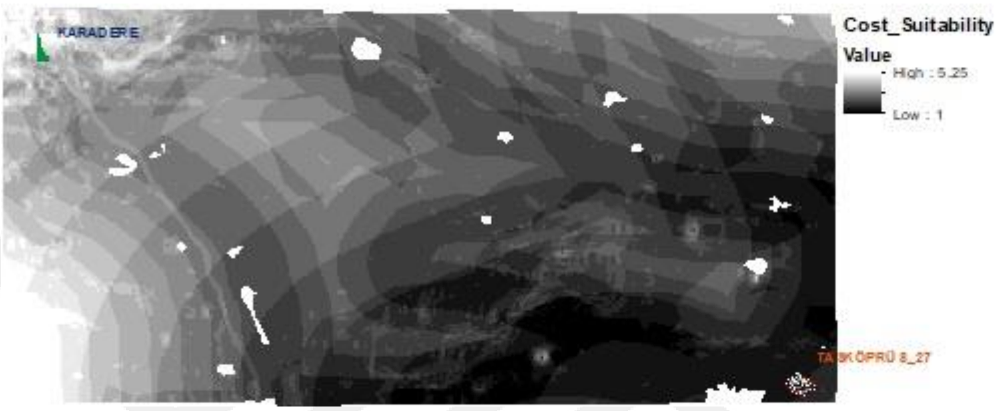


Figure 64 Cost raster (suitability layer) for the extent between Karadere Dam and Taşköprü Substation

The least cost path algorithm use the cost layer that was got in the previous step and the path starting point layer (Karadere dam position) to produce two new visible layers, which are the least cost distance layer (cost distance raster) (Figure 65), and the least cost direction layer (back link raster) (Figure 66), where those new raster layers were got using the spatial analyst *Cost Distance* and *Cost Back Link* distance tools in ArcMap spatial analyst tools box.

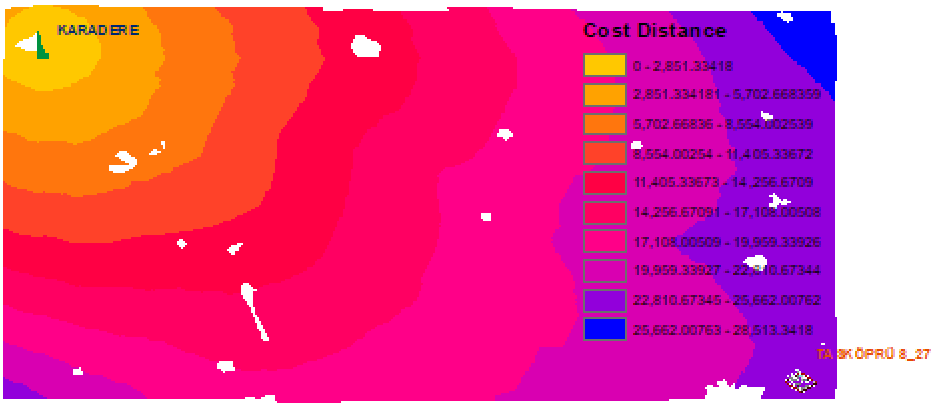


Figure 65 Cost distance raster layer for the extent between Karadere Dam and Taşköprü Substation

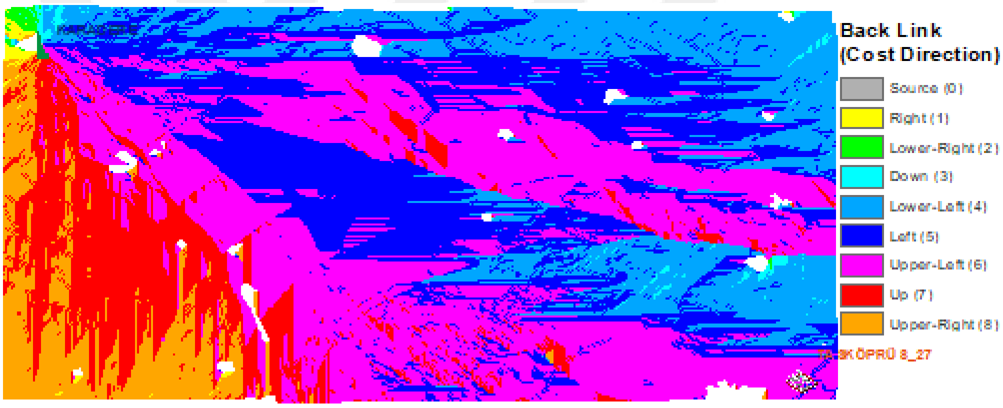


Figure 66 Back link raster layer for the extent between Karadere Dam and Taşköprü Substation

Each cell in the cost distance layer in Figure 65 represents the least cumulative cost of traveling from that cell to the source point cell (Karadere dam). While each cell in the back link layer in Figure 66 represents the direction code of the least cost movement to one of the eight neighbor cells back to the source point cell (Karadere dam).

By determination of the destination point which is Taşköprü substation, the destination layer is created. The analyzer of the GIS use the cost distance layer, the back link layer and the destination layer to calculate the least cost path raster layer (best path). The output cost path layer (best path) represents the shortest least costly path from Karadere dam to Taşköprü substation. The path avoids steep slopes and certain types of lands that are considered costlier for constructing of power line; the path also seeks to be near to roads and existing power lines and in a favorite land use. The least cost path raster layer (best path) was got using the spatial analyst *Cost Path* distance tools in ArcMap spatial analyst tools box. As an additional step, the raster path was converted to polyline (vector feature class) to give the possibility for controlling the design of the power line path and placing the towers (Figure 67). This was done using the from raster *Raster to Polyline* conversions tools in the ArcMap tools box.

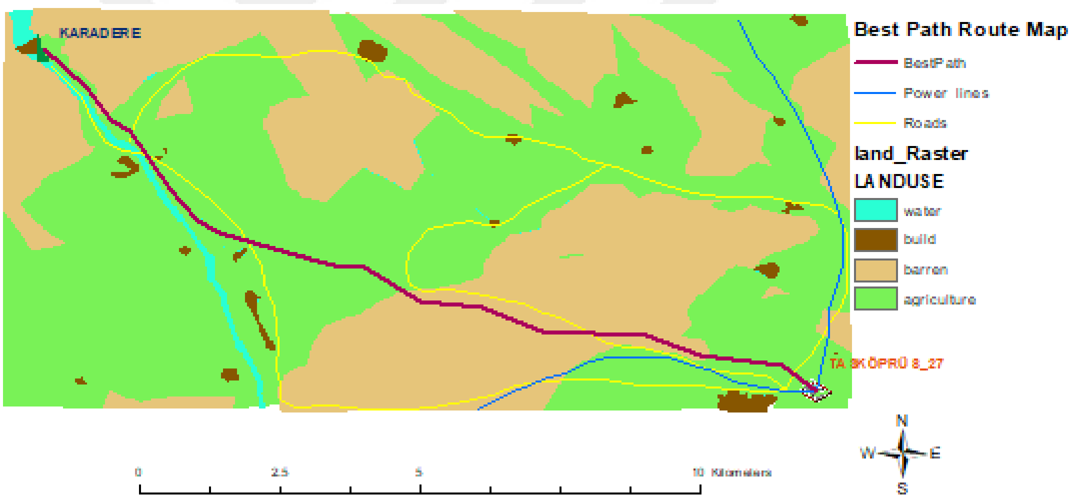


Figure 67 Least cost path (best Path) for grid connection between Karadere and Taşköprü Substation (12.789 km)

The difference between the cost path for power line grid connection and straight line between Karadere dam and Taşköprü substation is:

12789–12074 = 715 meter.

As a last step in the best path's model using ArcScene *Base Height* 3D analyst tools, the best path line vector was projected on the 3D surface of satellite imagery for the area of the path using the elevation raster layer as a base height to create the 3D surface for the satellite imagery and the path in order to allow the realization of the path and the possibility of modification as well as determination of towers places by giving a realistic perception of the path on the real surface of the terrain and land cover (Figure 68).

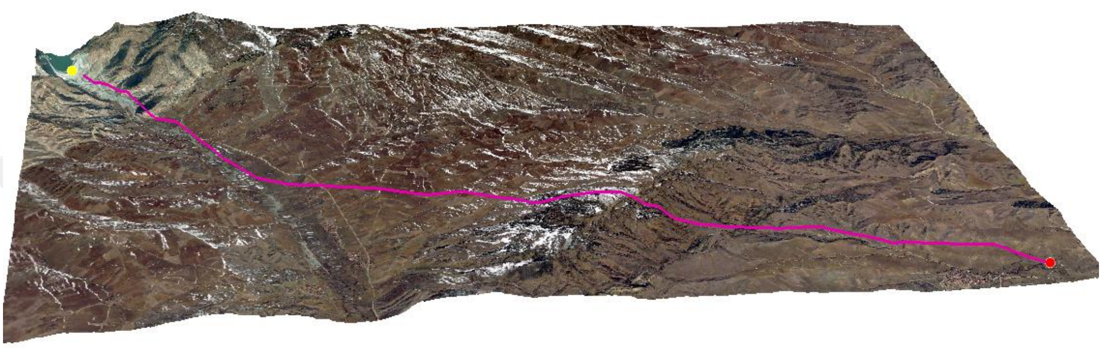


Figure 68 3D view of the best path between Karadere Dam and Taşköprü Substation

5.2. Karaçomak Dam

Karaçomak Dam is a multi-purpose dam that is used for irrigation, flood control and municipal supply, and is located in Kastamonu province (Figure 69). It was built on clay core sand fill type, and is located on the Karaçomak stream. The volume of the dam body is 1100 m^3, and the height from the foundation is 70 m, with a reservoir capacity of 23 hm^3. The area irrigated by the dam is 2596 hm^2 and the full spillway is 900m^3/s. It began operation in 1976 (Figure 70). According to the DSI, the reservoir was filled at 92.9% capacity in 2018 and 100% in 2019 (Table 10).

Figure 69 Top view of Karaçomak Dam and its lake in Kastamonu province

Figure 70 Karaçomak Dam and its lake

5.2.1. Karaçomak Dam's Technical Criteria

Karaçomak Dam is suitable for hydropower development since it has the following technical specifications:

- 42 years in operation, which less than the years in operation criterion in (80–42 = 38 years), 38 more possible years in operation.

- The Dam is a multipurpose of irrigation, flood control and municipal.

- The height from the foundation (base height) is 70 meter, which is more than the criterion of dam height in (70–15 = 55 m).

- The reservoir capacity is 23 hm^3, which is more than the criterion of reservoir capacity in (23–3 = 20 hm^3).

The waterfall height (NWL) (head) was previously calculated in m for all the dams in the geodatabase using the *ArcCatalog-Filed Calculator* tool based in Equation (1) (Figure 4). The NWL represents the head height of the water if the outlet at the bottom of the active storage of the dam. For Karaçomak Dam:

NWL = [dam height – [crest elevation at sea level – normal water elevation at sea level]]

NWL (head) = [49 – [895–889]] = 43 meter

The potential power can be calculated from equation (2) previously referred to, this equation needs dam height and discharge flow rate to calculate the potential installed capacity. Flow rate can be estimated by reservoir capacity, dam height and river type [66] (Table 11). It is known that multipurpose dams have a good flow of water discharge because they always have many water recourses. The (https://power-calculation.com/hydroelectricity-energy-calculator) site [14]; allows calculation of potential power parameters by inserting the values of equation (2) which represent the dam hydro resources values (Figure 42).

Using the Hydropower Calculator by (power-calculation.com) for Karaçomak dam values, the following parameters were got:

- Real active power available: 799 kW.

With 150 days average number of working days per year:

- Average annual energy in output of hydro generator: 2876.4 MWh/year.

- Annual electricity bill: €230112/year.

5.2.2. Nearest Substation to Karaçomak Dam

The nearest substation to this dam is Kastamonu, at a distance of 8.56 km. The substation is in operation and belongs to the TEİAŞ Institute. This is a power transmission step-up class substation with a capacity of 154 kV (Figure 71).

Figure 71 Top view of Kastamonu Substation

5.2.3. Suitability Score of Karaçomak Dam

Multi-criteria fuzzy logic was used to determine the suitability degree to which the Karaçomak dam meets all the criteria of distance, environmental impact and technical criteria, and to calculate its overall suitability score relative to the rest of the selected dams. This approach depends on calculating the impact of each criterion on reaching the desired objective. Fuzzy logic translates each criterion into a continuous variable that takes a value between zero and one (0<=x<=1); this is called the suitability degree or membership degree, and reflects the actual values as a proportion of the maximum and minimum original values of the criteria [39]. The criteria chosen to calculate the suitability of each dam are spatial criteria (such as nearest substation distance, EIA requirements) and technical criteria (such as reservoir capacity, natural water level, dam purpose and years in operation).

Using equation (4), the suitability score of all the criteria for selected dams were calculated. The dams were arranged according to the suitability score in Excel table then the suitability score field was exported from this table to our selected dams table in the geodatabase. However, the calculation of suitability score for Karaçomak dam was as following:

$$S(D_i) = \sum W_j * C_{ij} \qquad i=1,2,...,n \qquad j=1,2,\dots,r$$

Where i is the dam number, j is the criterion number, n=265 is the total selected dams, r=6 is the total number of the criteria, W_j is the weight of the criterion j, C_{ij} is the suitability degree of the criterion j for the dam i and $S(D_i)$ is the suitability score of the dam i.

C_{ij} for Karaçomak dam are:

Suitability degree for reservoir capacity:

Selected 265 dams reservoir capacity median = 18.5 hm^3
Minimum Selected 265 dams reservoir capacity = 3 hm^3
Maximum Selected 265 dams reservoir capacity = 717.7 hm^3
Karaçomak dam reservoir capacity = 23 hm^3
Since reservoir capacity = 23 hm^3 is greater than the median = 18.5 hm^3 then..
Karaçomak reservoir capacity suitability degree = [(23–18.5)/(717.7–18.5)*(1–0.5)] + 0.5
Karaçomak reservoir capacity suitability degree = 0.503252091 (Figure 72).

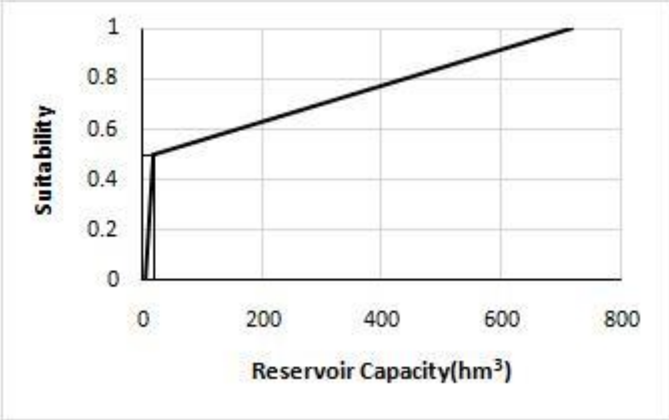


Figure 72 Suitability function for reservoir capacity, Karaçomak Dam

Suitability degree for normal water level (head):

Selected 265 dams normal water level median = 33.5 m

Minimum Selected 265 dams normal water level = 9 m

Maximum Selected 265 dams normal water level = 98 m

Since Karaçomak dam normal water level = 43 is greater than the median = 33.5 then..

Karaçomak normal water level suitability degree = [(43–33.5)/(98–33.5)*(1–0.5)] + 0.5

Karaçomak normal water level suitability degree = 0.573643411 (Figure 73).

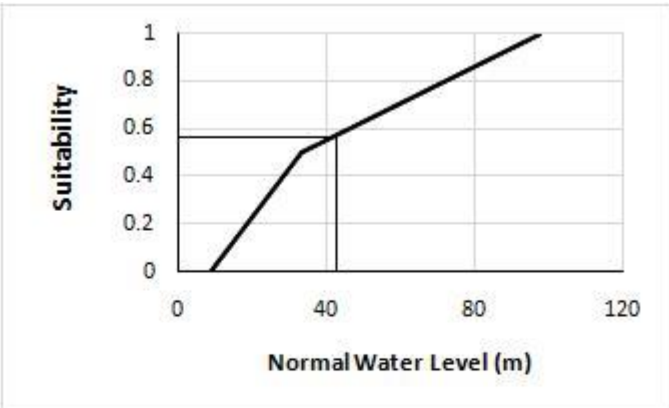


Figure 73 Suitability function for normal water level, Karaçomak Dam

Suitability degree for dam purpose:

Purpose = Irrigation + Flood control + Municipal = 3 (triple-purpose)
Since Karaçomak is a multipurpose dam then..
Karaçomak purpose suitability degree = 0.33 (Figure 74).

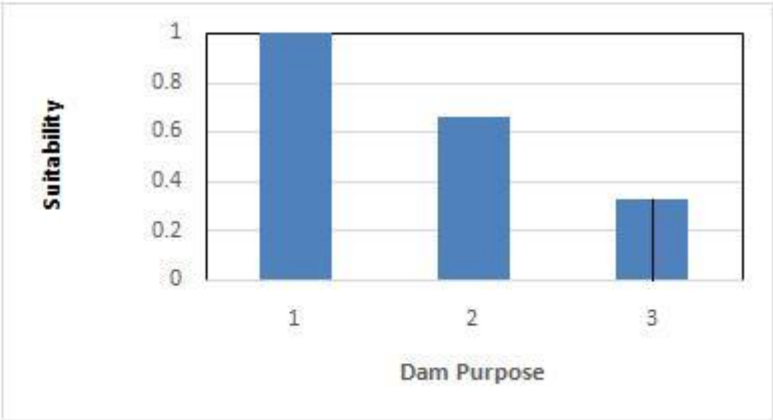


Figure 74 Suitability function for dam purpose, Karaçomak Dam

Suitability degree for dam years in operation:

Minimum Selected 265 years in operation = 1 year
Maximum Selected 265 dams years in operation = 60 years
Karaçomak dam years in operation = 42 years
Karaçomak years in operation suitability degree = 1– (42/60)
Karaçomak years in operation suitability degree = 0.31147541 (Figure 75).

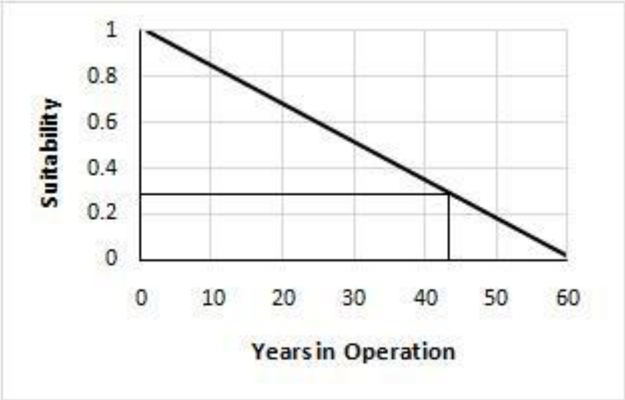


Figure 75 Suitability function for years in operation, Karaçomak Dam

Suitability degree for nearest substation distance:

Minimum nearest substation distance for the Selected 265 dams = 0.7 km

Maximum nearest substation distance for the Selected 265 dams = 38.2 km

Karaçomak dam nearest substation distance = 8.56 km

Karaçomak nearest substation distance suitability degree = 1– (8.56/38.2)

Karaçomak nearest substation distance suitability degree = 0.780445748 (Figure 76).

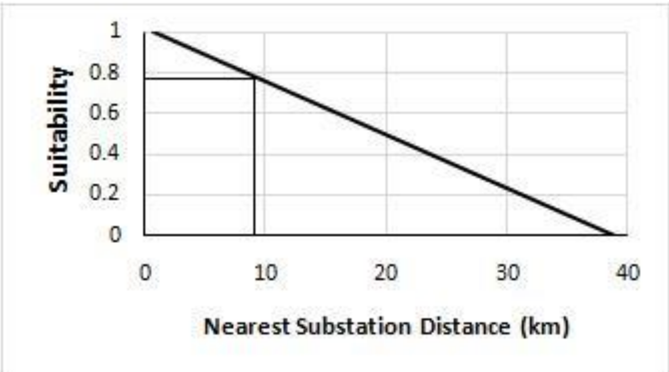


Figure 76 Suitability function for nearest substation distance, Karaçomak Dam

Suitability degree for EIA requirement:

Since Karaçomak nearest substation distance = 8.56 km lees than 15 km then..
Karaçomak EIA requirement suitability degree = 1 (Figure 77).

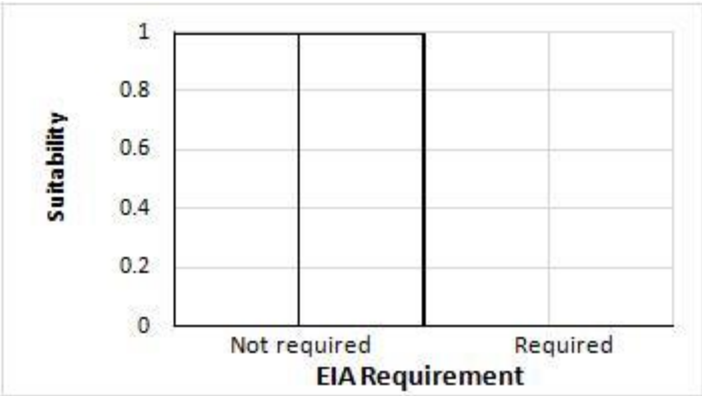


Figure 77 Suitability function for EIA requirement, Karaçomak Dam

Then the suitability score for Karaçomak dam S (D_i) is:

S (D_i) = 0.503252091 (0.16) + 0.573643411 (0.16) + 0.33 (0.16) + 0.31147541 (0.16) + 0.780445748 (0.16) + 1 (0.16)

S (D_i) = 0.580803565 = 58%

58% is the suitability score of Karaçomak dam according to all the criteria, which put Karaçomak dam in the medium suitability class, which are 149 dams had a suitability score of between 50% and 75%, where Karaçomak dam was ranked 112th in its suitability score from the selected 265 dams.

5.2.4. Best Grid Connection Path (Least Cost Path) from Karaçomak Dam to its Nearest Substation

Both the Karaçomak dam and its nearest substation Kastamonu are located in Kastamonu province. Using ArcMap, the feature classes for the Karaçomak dam and Kastamonu substation were selected from their geodatabase. Then they were added over the layer of Turkey provinces map (Figure 78). The straight distance between them was found while generating the *Near Table* of nearest substation for each dam in the geodatabase, where the straight distance between Karaçomak dam and Kastamonu substation is 8.56 km (Figure 79).

The multi-criteria GIS spatial analyst depends on calculating the impact of each spatial criterion to serve the desired objective within the available spatial options. The criteria that have been chosen to find the best grid connection path are the measurable continues phenomenon spatial criteria's including (shortest distance, suitable elevation, least slope and near to roads) which related to the cost of establish and maintenance of new power lines, and the attributed spatial criteria's which are land cover criteria including (avoids or exclude some public and private property, avoid natural reserves, avoid large water surfaces and land use preferences) which related to the lands costs, EIA requirement, and natural and artificial obstacles.

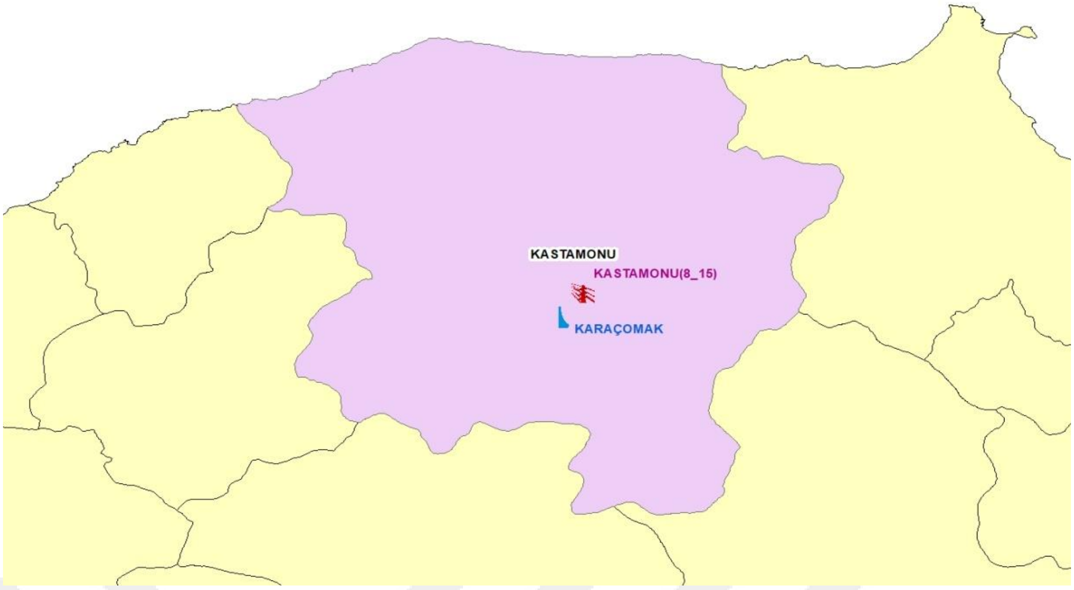


Figure 78 Karaçomak Dam and its nearest substation (Kastamonu) on a map of Turkey

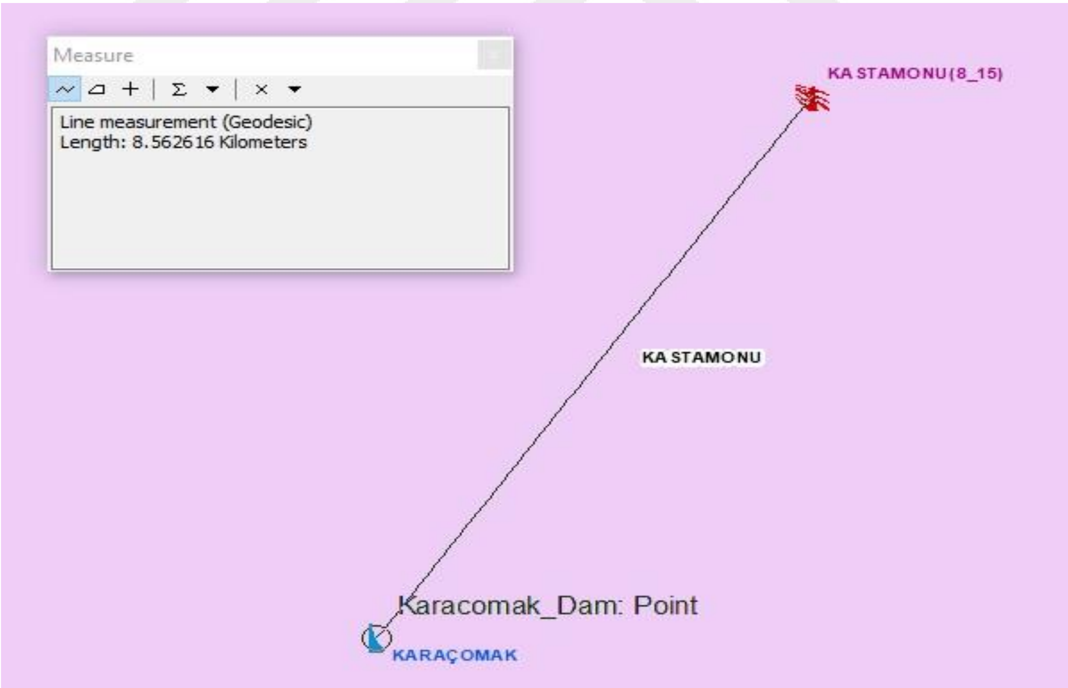


Figure 79 Straight line distance (8.56 km) between Karaçomak Dam and Kastamonu Substation

As the first step in the multi-criteria analyst, each spatial criterion from the extent of the study area (a rectangular area between the dam and the nearest substation) into a visible raster layer, where each cell in this layer represents a variable that has a value compatible with the spatial value of its criterion.

The spatial reference satellite image was used as a basis for the extent of the area between the Karaçomak dam and Kastamonu substation to generate the criteria layers. The satellite imagery was downloaded with spatial reference by using SASPlanet application and Google Earth Pro.

In the ArcCatalog, a new subgeodatabase was created and gave it Karaçomak name. In this subgeodatabase the satellite imagery of the area extent was imported, also the feature classes of Karaçomak dam and Kastamonu substation were imported from original geodatabase of all the selected dams and substations, in ArcMap all those subgeodatabase components were projected on the satellite imagery using the coordinate system of Turkey provinces feature class polygons WGS 1984 Lambert Conformal Conic (Figure 80).

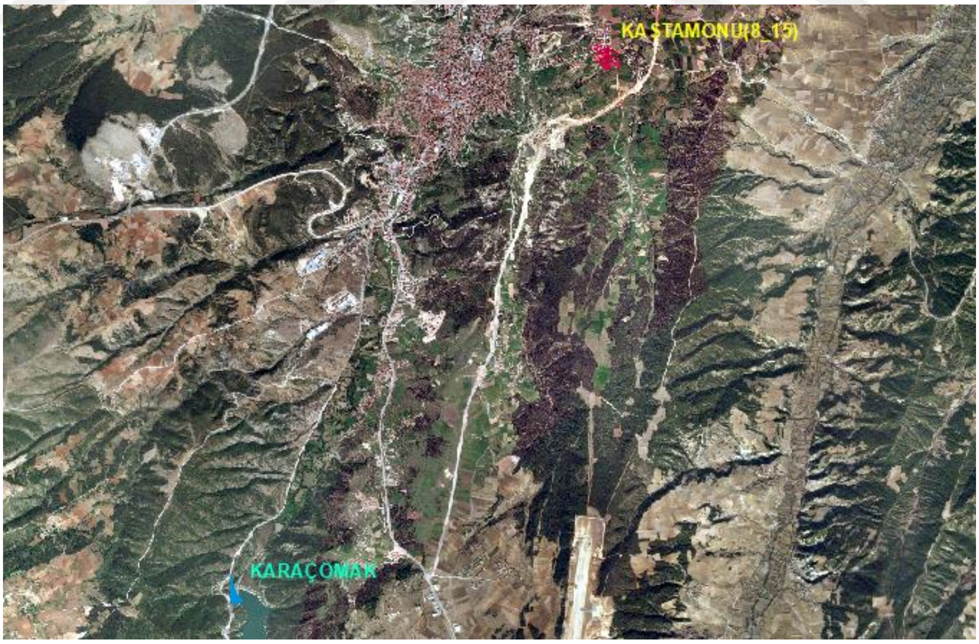


Figure 80 Extent of spatial reference satellite imagery for Karaçomak Dam and Kastamonu Substation feature classes

To create the layers for the criteria of suitable elevation and the least slope, using the cells coordinates of the satellite imagery base map and the TCX Convertor application the elevation points data were downloaded for the coordinates of area extent of Karaçomak dam and Kastamonu substation in an excel format table. In ArcMap and from the new subgeodatabase of Karaçomak dam, the elevation data excel table was imported to create the elevation raster layer using the inverse distance weighted *IDW* interpolation tool in spatial analyst tools box (Figure 81).

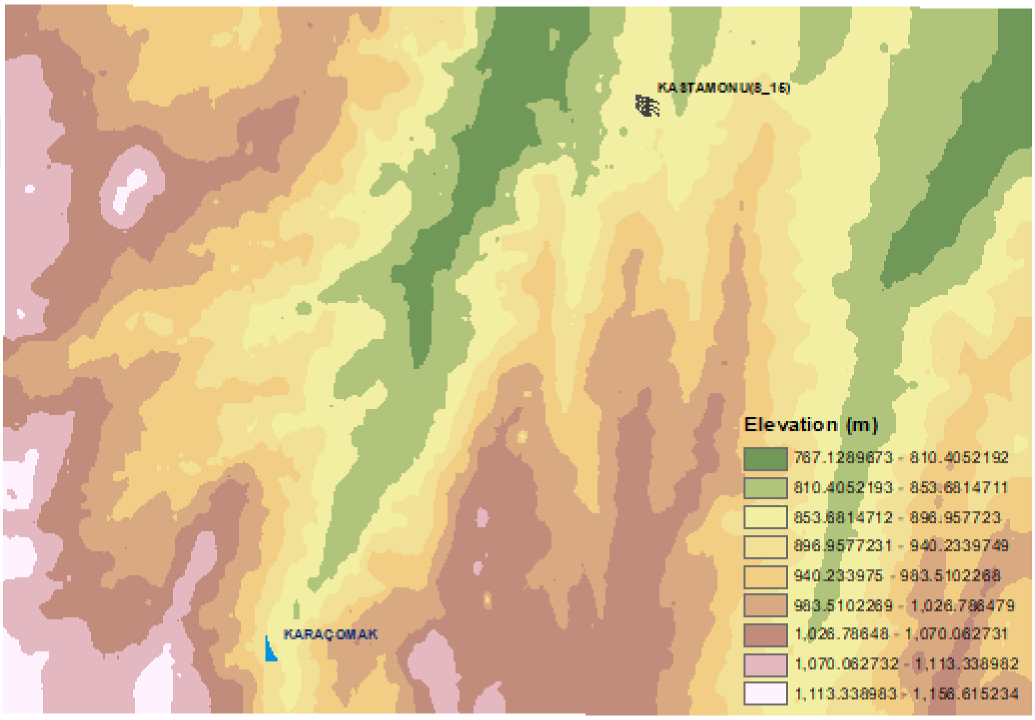


Figure 81 Elevation raster layer for the extent between Karaçomak Dam and Kastamonu Substation

Then by using the ArcMap *Slope* tool in the surface spatial analyst tool box the slope raster layer was created, where each cell in this layer represents the slope of its position (Figure 82). According to TEİAŞ, the degree of slope, which is more than 30%, is unsuitable for design. Also areas with a slope greater than 40% are prone to landslides.

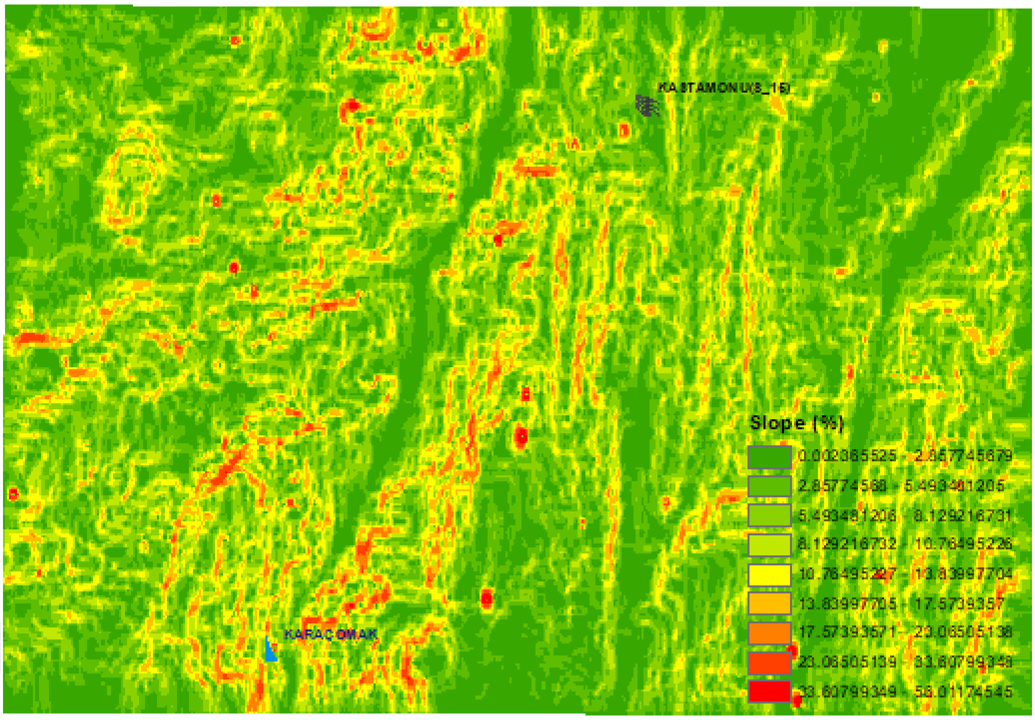


Figure 82 Slope raster layer for the extent between Karaçomak Dam and Kastamonu Substation

Then by reclassified the slope layer in a common scale from 1 to 9 with the other reclassified criteria's by giving the low values to the low slope cells (low cost), the slope suitability degree of that position to create a power line was represented. The high values represent the areas not good for power lines routing (Figure 83).

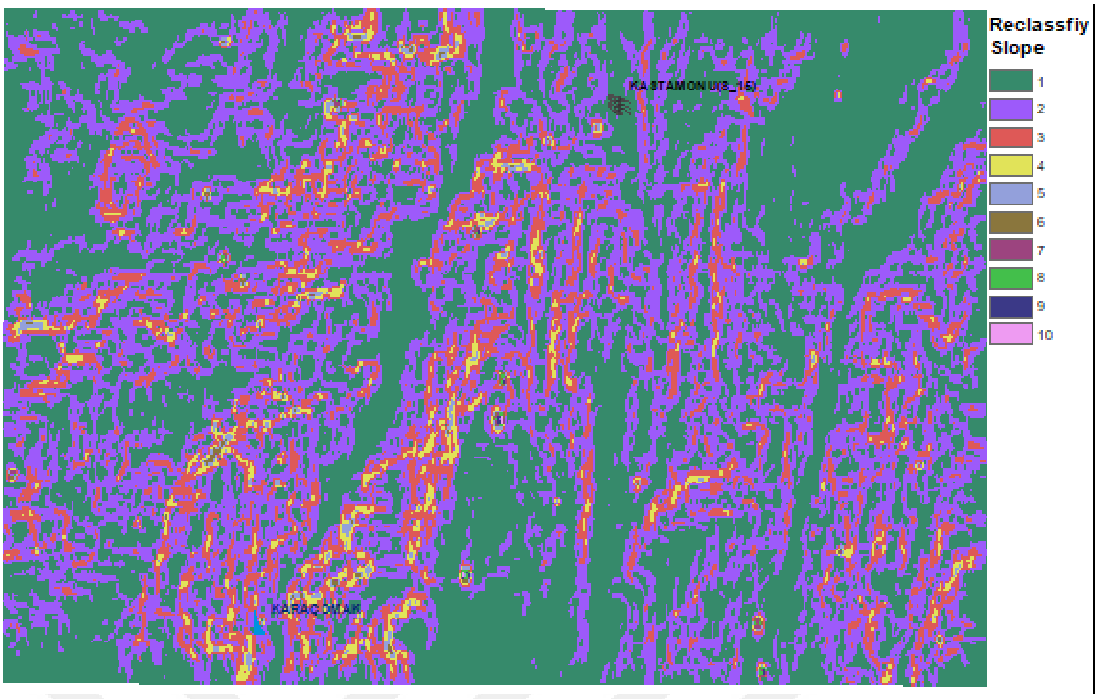


Figure 83 Reclassified slope raster layer for the extent between Karaçomak Dam and Kastamonu Substation

To calculate the distance from roads, in the extent of the area between Karaçomak dam and Kastamonu substation, the roads were digitized and saved as a line feature class in the selected dam subgeodatabase (Figure 84).

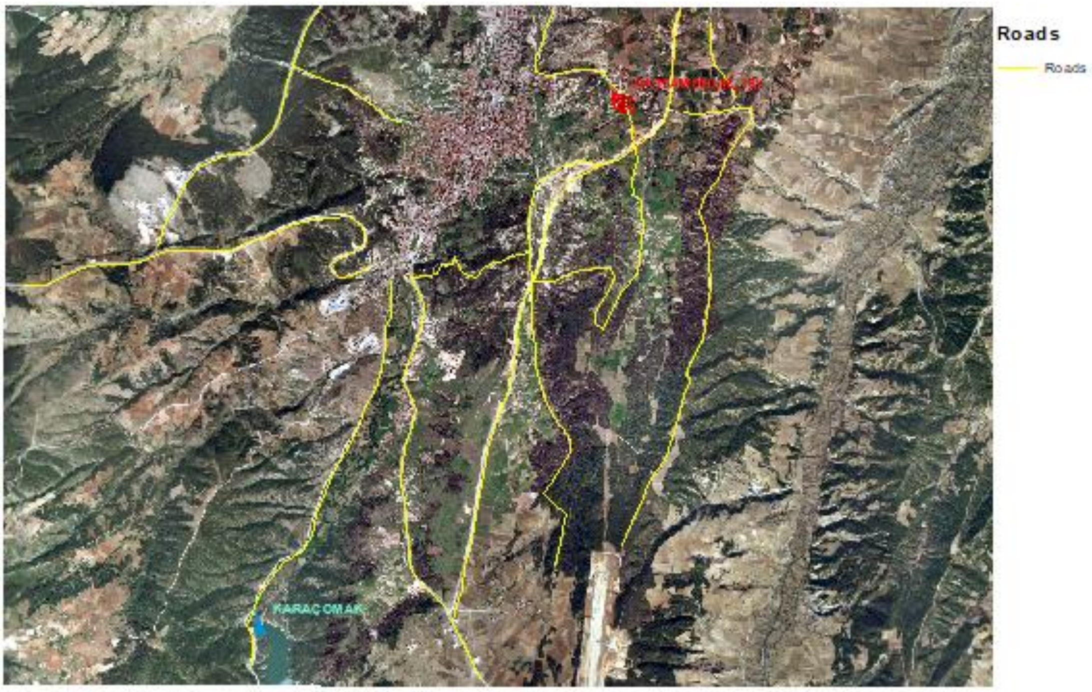


Figure 84 Roads feature class for the extent between Karaçomak Dam and Kastamonu Substation

In ArcMap using one of the spatial analyst tools which is *Euclidean Distance*, the raster layer of the distance from the feature class of roads which is saved before in the subgeodatabase of Karaçomak dam was created, each cell's value in this layer represents the distance in meters from its position to the roads (Figure 85).

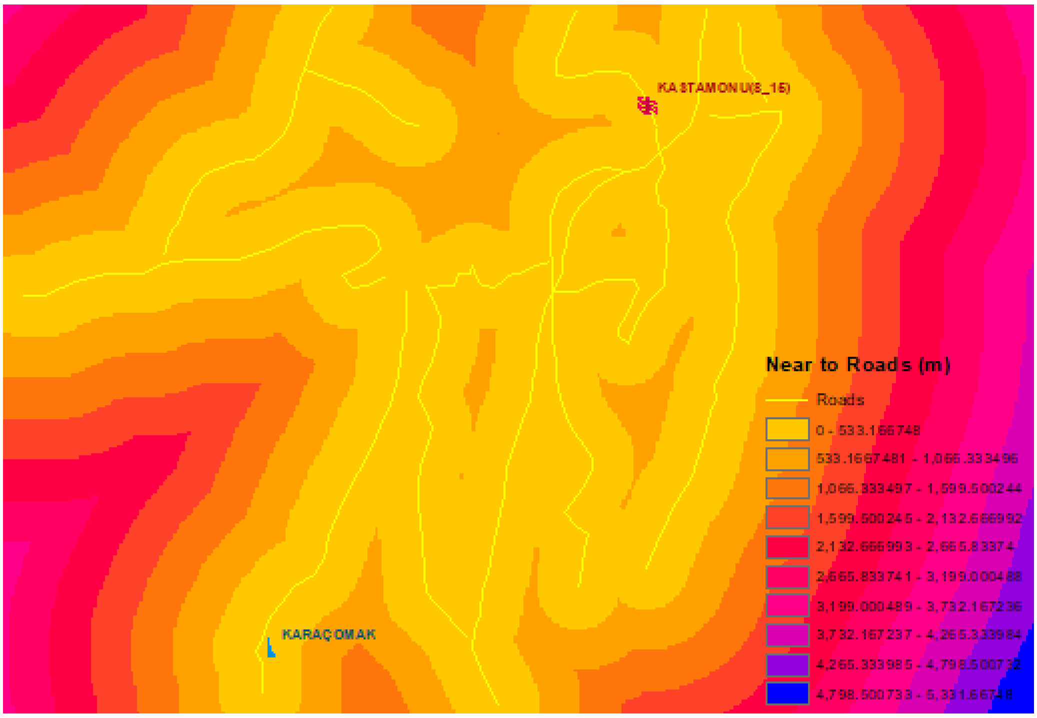


Figure 85 Raster layer representing near to roads for the extent between Karaçomak Dam and Kastamonu Substation

By reclassified distance from roads layer in a common scale with reclassified slope from 1 to 9 by giving the low values to the low cost cells (short distances), where the zero value will be along the roads and the values (distances) will be increased by moving away from the road. By doing this, the suitability degree of that position to create a power line according to criterion of near to roads was represented in Figure 86.

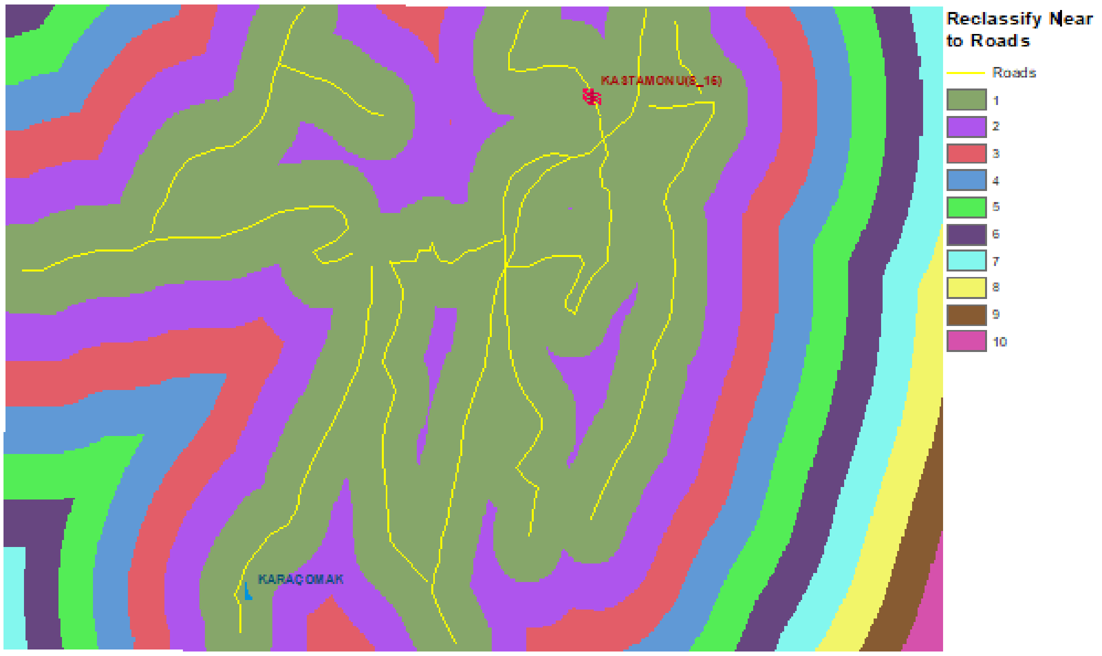


Figure 86 Reclassified raster layer for near to roads for the Extent between Karaçomak Dam and Kastamonu Substation

For the criterion of land use, all specialists agree on the importance and impact of the nature of land cover and the type of land use in the process of directing power lines, where the main purpose is to passing the power line from the open areas, barren land, far from the habitat and settlement. The high suitability classes were given to land uses that have low cost, low environmental impact and low threats to power lines. Also some potential lands obstacles were excluded from the analysis and have been given "no data" value.

The polygons of land use layer feature class were digitized by manual recognition and digital classification preceded by visual interpretation of satellite images which was used before as a base map for the extent area to produce several criteria's maps. Also the additional data that Google Earth provides were compared, such as cultural heritage sites, archaeological sites, nature reserves, and others. As well as (https://osmlanduse.org) which provides an access to global land use maps [63]. Then the digitized polygons of land use were saved as a new polygon feature class in the Karaçomak dam's subgeodatabase.

For the purpose of reclassification by categories of land use within a common scale with the rest of other criteria and for the purpose of giving the obstacles "no data" value, which will be considered as prohibited areas for all other criteria, the polygons feature class of land use were converted from vector data layer to raster data layer. The *Feature to Raster* tool was used from the conversion tools in the spatial analysis toolbox of ArcMap (Figure 87).

Figure 87 Land use raster for the extent between Karaçomak Dam and Kastamonu Substation

The land use feature class values were reclassified to be comparable with the reclassified of other criteria's layers, where the higher value indicates that it is costly to create a power lines path on that particular land use (Figure 88).

Figure 88 Reclassified land use raster for the extent between Karaçomak Dam and Kastamonu Substation

After getting the reclassified raster layers in a common scale for all criteria layers and by using *Map Algebra-Raster Calculator* spatial analyst tool in ArcMap tool box, all the reclassified raster layers were combined together, the cost layer was produced. Any place (one cell) on this raster layer represent's the cumulative cost value or the suitability degree of that place according to all spatial criteria (Figure 89).

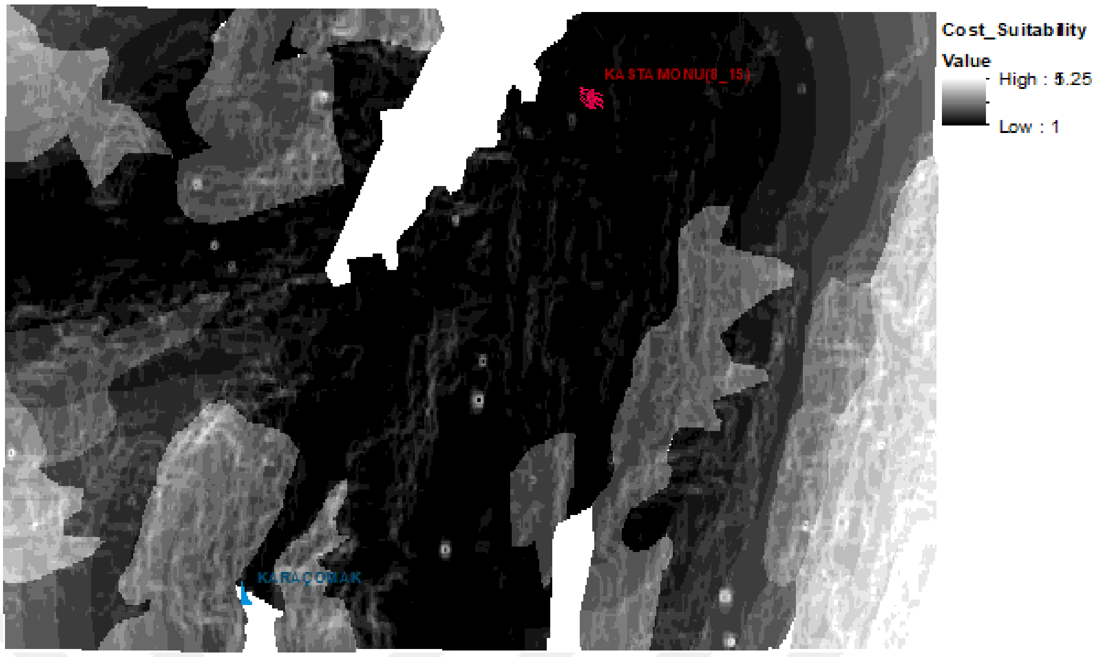


Figure 89 Cost raster (suitability layer) for the extent between Karaçomak Dam and Kastamonu Substation

The least cost path algorithm use the cost layer that was got in the previous step and the path starting point layer (Karaçomak dam position) to produce two new visible layers, which is the least cost distance layer (cost distance raster) (Figure 90), and the least cost direction layer (back link raster) (Figure 91). Those new raster layers were got using the spatial analyst *Cost Distance* and *Cost Back Link* distance tools in ArcMap spatial analyst tools box.

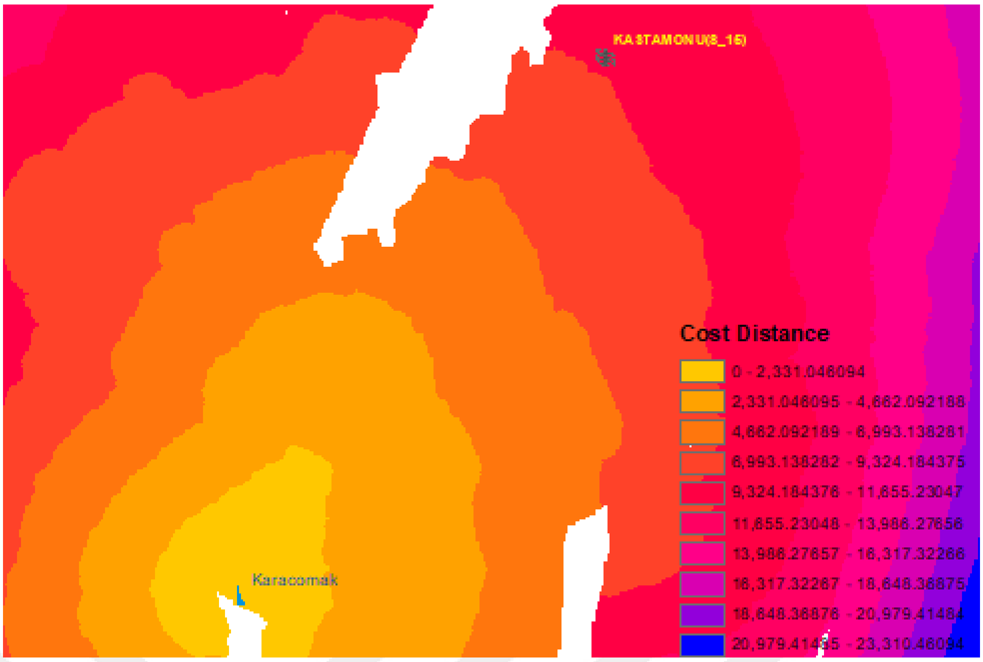


Figure 90 Cost distance raster layer for the extent between Karaçomak Dam and Kastamonu Substation

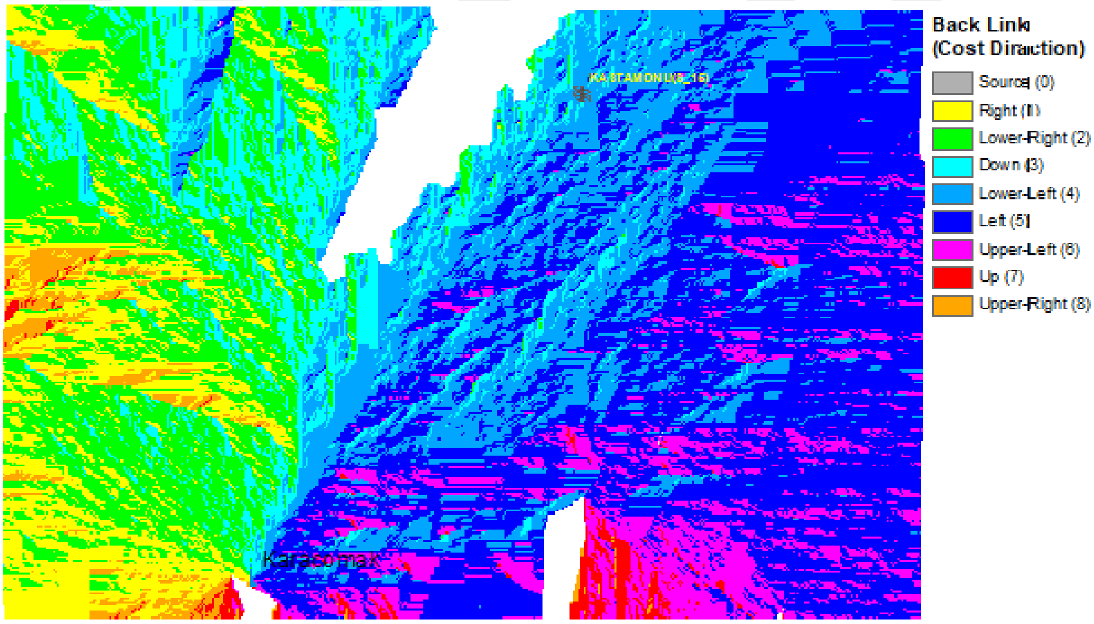


Figure 91 Back link raster layer for the extent between Karaçomak Dam and Kastamonu Substation

Each cell in the cost distance layer in Figure 90 represents the least cumulative cost of traveling from that cell to the source point cell (Karaçomak dam). While each cell in the back link layer in Figure 91 represents the direction code of the least cost movement to one of the eight neighbor cells back to the source point cell (Karaçomak dam).

By determination of the destination point which is Kastamonu substation, the destination layer is created. The analyzer of the GIS use the cost distance layer, the back link layer and the destination layer to calculate the least cost path raster layer (best path). The output cost path layer (best path) represents the shortest least costly path from Karaçomak dam to Kastamonu substation. The path avoids steep slopes and certain of types of lands that are considered costlier for constructing power line; the path also seeks to be near to roads and existing power lines and in a favorite land use. The least cost path raster layer (best path) was got using the spatial analyst *Cost Path* distance tools in ArcMap spatial analyst tools box. As an additional step, the path raster was converted to polyline (vector feature class) to give the possibility of controlling the design of the path and placing the towers (Figure 92). This was done using the from raster *Raster to Polyline* conversions tools in the ArcMap tools box.

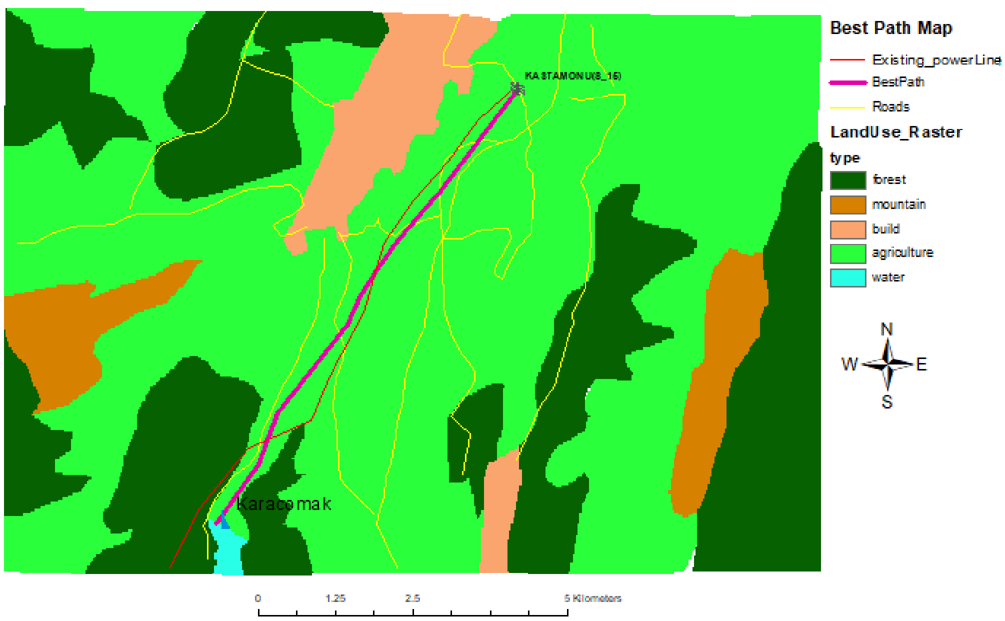


Figure 92 Least cost path (best path) for grid connection between Karaçomak Dam and Kastamonu Substation (8.607 km)

The difference between the cost path for power line grid connection and straight line between Karaçomak dam and Kastamonu substation is:

8607–8560 = 47 meter.

As a last step in best path model by using ArcScenen *Base Height* 3D analyst tools, the best path line vector was projected on the 3D surface of satellite imagery for the area of the path were used the elevation raster layer as a base height to create the 3D surface for the satellite imagery and the path in order to allow the realization of the path and the possibility of modification as well as determination of pylons locations by giving a realistic perception of the path on the real surface of the terrain and land cover (Figure 93).

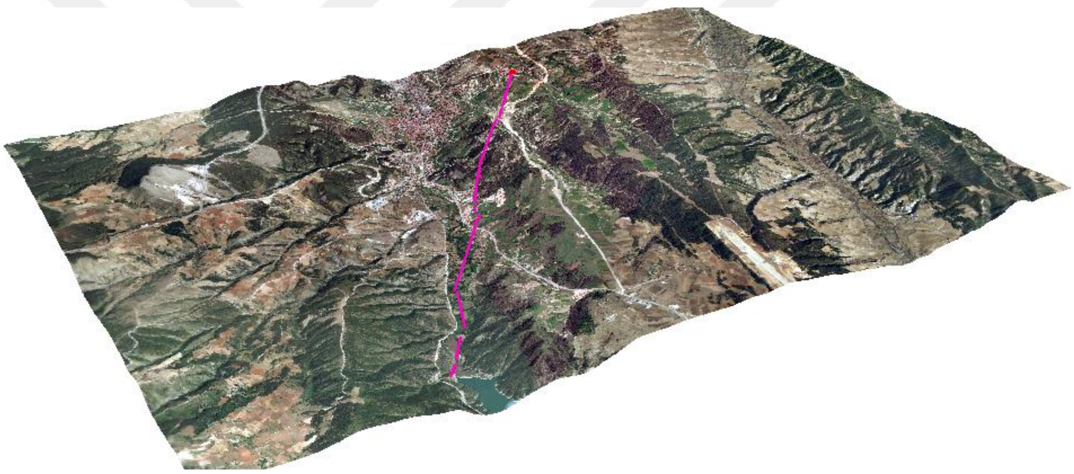


Figure 93 3D view of the best path between Karaçomak Dam and Kastamonu Substation

CHAPTER 6

CONCLUSION

6.1. Conclusion

This study investigated on 751 operated dams in Turkey in terms of their potential for hydropower development. A total of 265 of 711 irrigation dams were found to be most suitable for hydropower development, and 183 substations were found within a maximum distance of 40 km from these 265 dams for the purpose of grid connection. These were found by assessing a set of spatial and technical criteria for both the dams and the substations, and applying a geodatabase query to filter the dams and substations and to choose the most suitable options based on the specified criteria.

Using Equation (3), an average distance of 35 km was calculated between substations in Turkey, meaning that each dam should have a substation within approximately 40 km. Some of the selected 183 substations based on the technical and spatial criteria were close to more than one dam, and eight of the selected 273 dams based on the technical criteria were found not to have a substation within 40 km, therefore they excluded and the number of the selected dams becomes 265.

A variation was observed in the preferences of the criteria for any selected dam through the results of statistical indicators of the criteria. For example, the dam with the highest preference for the criterion of shortest distance to the nearest substation, which is 720 meters, had low preferences in relation to its other criteria where the reservoir capacity was 3.7 hm^3. Therefore, the selected dams were arranged according to their suitability using multi-criteria fuzzy logic, which was assessed in terms of meeting the specified technical and spatial criteria. Three categories were identified: 21 dams with high suitability i.e. a suitability score greater than 75%; 149 dams with medium suitability, i.e. a suitability score of between 50% and 74.9%; and 95 dams with low suitability, i.e. a suitability score of less than 50%.

The first case study was Karadere Dam, with an overall suitability score of 78%. This dam was therefore from the high suitability class. The potential power was calculated at 1587 kW, and the annual benefit was estimated at €457,056/year. By applying the methodology for finding the best path for grid connection to the nearest substation, which was within a distance of 12.07 km, the best grid connection path was found with a length of 12.789 km, i.e. a difference from the straight-line distance of 719 m. In addition, although the criterion of near to rivers was not one of the criteria examined in this study, the proposed path was close to the Karadere river (Figure 67). This can be attributed to the criterion of land use, which takes into account the important factors that affect the cost of grid connection such as land confiscation and slope, which always have low values near rivers. This result can be considered a good indicator of the accuracy of the method.

The second case study was Karaçomak Dam, with an overall suitability score of 58%, which places it in the medium suitability class. The potential power was calculated at 799 kW, and the annual benefit was estimated at €230,112/year. By applying the methodology for finding the best path for grid connection to the nearest substation, which was within a distance of 8.56 km, the best grid connection path was found with a length of 8.607 km, which differed from the straight-line distance by 47 m. In the case of Karaçomak Dam, the criterion of near to existing power lines was deliberately not taken into account, due to the presence of an existing power line between the dam and the nearby Kastamonu substation (Figure 92). This was in order that the proposed line could be evaluated and compared with the existing line. The proposed best path almost matched the existing line, thus demonstrating the accuracy of the methodology and criteria used to find the best route.

By comparing the two case studies, it can be observed how the differences in potential power affect the suitability score for each dam. It can also be noted that the length of the proposed grid connection route is related to the distance of the dam from the nearest substation; this length is close to the straight-line distance when the nearest substation is close to the dam, as in the Karaçomak dam case study, and is more different from the straight-line distance when the substation is further from the dam, due to the effect of taking the various spatial criteria into account and avoiding obstacles in wide areas, as in the Karadere case study.

The methodology used in the study and its results, main findings and conclusions are summarized in Figure 94.

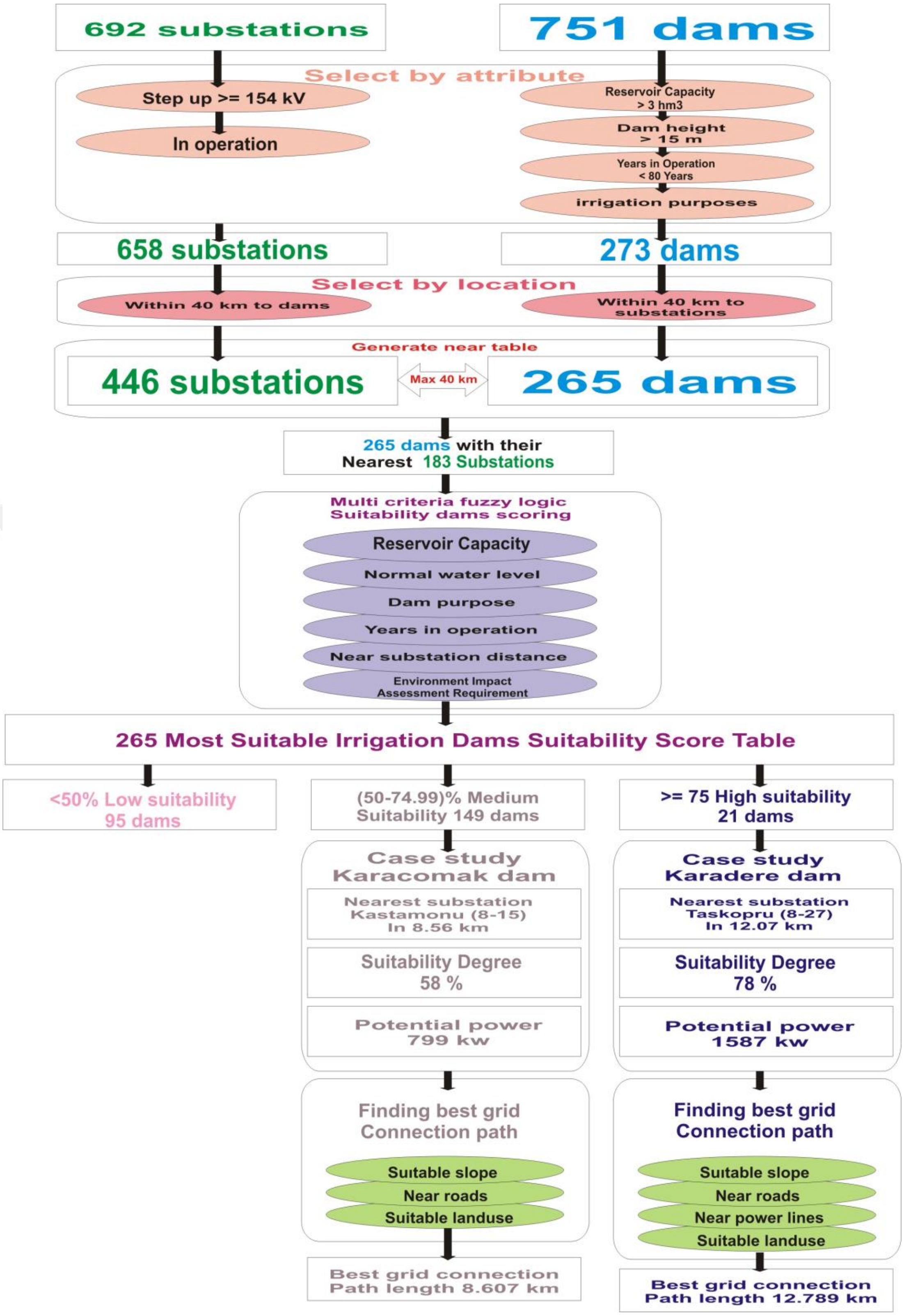


Figure 94 Conclusions and structure of the thesis

6.2. Discussion

The study has succeeded in proving the availability and capability of irrigation dams in Turkey; these are distinguished from other types of dams due to their characteristics, which allow them to generate hydropower with high quality, low cost, low environment impact and ease of implementation, this done by verifying the (technical, spatial, grid connection, risk and environmental impact) criteria's. By applying these criteria the best dams have been selected for the possibility of hydropower development.

One of the most important criteria that often overlooked in hydropower projects is the grid connection distance. In this study, the criterion of distance to the nearest substation was considered in order to ensure that the potential power quantity is consistent with the cost and distance of the grid connection. Considering an average of 35 km between substations in turkey found using equation (3), the maximum grid connection distance (break-even distance) between the selected dams and their nearest substations was therefore set to 40 km, in order to avoid exceeding power losses of 4.5% and to ensure consistency between the potential benefits and the grid connection cost.

Although all the selected dams are suitable for hydropower development, knowing the best or start on the best was certainly wanted. Implementing agencies and beneficiaries aim to choose dams that meet the highest criteria (i.e. highest power production, lowest cost and environmental impact, and shortest grid connection), especially after the variation which observed in the preference of the criteria for any selected dam through results of statistical indicators of the criteria. Using multi-criteria fuzzy logic, the overall suitability score of each dam was calculated based on all the required criteria and the dams were then sorted according to their suitability score and classified into suitability ranges to allow the best to be selected for grid connection spatial analysis and other tests. The selected dams were arranged based on their overall suitability scores into three classes: high, medium and low suitability.

A methodology for finding the best grid connection route was presented using multi-criteria GIS spatial analysis to find the option with lowest risk, least loss, least cost and lowest environmental impact of the power line. The criteria were short distance to nearst substation, least slope, near from roads and existing power lines, which were related to the risks and costs of establishing and maintaining new power lines. Other criteria included avoiding or excluding certain types of public and private property, avoiding natural reserves and large water surfaces, and crossing some types of land, which were related to land costs, lands confiscation, EIA requirements, and natural and artificial obstacles.

Two dams were selected as case studies: Karadere, a dam from the high suitability class, and Karaçomak, from the medium suitability class. For each of these dams, the technical and spatial criteria were discussed and the potential power and economic benefits were estimated. In addition, multi-criteria GIS spatial analysis was applied to find the best routes for grid connection for each of the two dams to their nearest substations.

6.3. Recommendations

The study propose investment in hydropower development for the best 265 irrigation dams, which were identified in this study according to their overall suitability scores, based on several technical, spatial and environmental criteria. The study also proposes the use of siphon turbines for hydropower development, since it does not need to tamper the irrigation dam's body.

In terms of grid connection, it is possible to control the weights of the criteria according to different perspectives, removing or adding criteria to give new results. Where this study provides a methodology for identifying the nearest substation for each dam and finding the best grid connection path to it, based on the common criteria for the routing of power lines and the amount of power that can be potentially generated.

For the dams with good values of their technical criteria for hydropower development but not have substations within 40 km for grid connection, the proposed methodology can be used to find the best grid connection route within isolated grids to the nearest potential energy investment site, which may be the nearest small village, factory or other.

The proposed methodology can also be applied to other types of dams or renewable energy resources, or to irrigation dams in other countries.

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APPENDIX A

MULTI-CRITERIA HIGH SUITABILITY SCORE DAMS

Table 12 High Suitability Class: 21 Dams had a Suitability Score of between 75% and 87%

Rank	Dam Name	Start Operation	River	Province	Purpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
1	Aktaş	2017	Aktaş	Izmir	I	CCS	43.79	105.5	100	98		1580	9.921	Ödemiş	0.871
2	Burgaz Zeytinova	2013	Falaka Çayi	Izmir	I	CCS	33	115	84.5	81.5		3009	11.906	Tire	0.829
3	Çayirdere	2017	Kocadere	Kirklareli	I	CFR	28.25	63	58.5	57.5	232.73	2583	10.597	Pinarhisar	0.814
4	Taşoluk	2009	Çinarcikdere	Çanakkale	I	CCR	79.4	75	65	63	1352	9606	8.948	Biga	0.813
5	Yenidere	2010	Yenidere Çayi	Denizli	I	CCS	65.37	46	43	40	1432	3304	5.087	Tavaş	0.801
6	Havran	2010	Havran	Balikesir	I	CCR	66.5	79.5	63.5	60.5	1406	3330	12.836	Edremit	0.794
7	Vezirköprü	2005	Istavloz Çayi	Samsun	I	CCR	51.47	75	73.5	67.5	887.75	10994	11.444	Vezirköprü	0.794
8	Madra	1998	Madra	Balikesir	I	CCR	79.4	97	87	84		7872	13.822	Ayvalik	0.789
9	Karadere	2007	Karadere Çayi	Kastamonu	I	CCS	26.08	90	70	64	1220	6852	12.074	Tasköprü	0.789
10	Derinöz	2002	Derinöz	Amasya	I	CCR	18.9	77	74	70	158	4990	10.970	Ladik	0.787

Table 12 (continued)

Rank	Dam Name	Start Operation	River	Province	Purpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
11	Beşkariş	2012	Muratçay	Kütahya	I	CCS	75.6	62.85	52.35	48.35	314	9093	12.971	Altintaş Tm	0.784
12	Yazici	2008	Altinçayir	Ağri	IM	CCS	220.55	90	83.5	78.5	257	31918	11.440	Ağri Tm	0.780
13	Saraydüzü	2011	Asarcik	Sinop	I	CCS	36.28	73.5	58.5	50.5	558.98	4109	14.294	Boyabat	0.774
14	Kestel	1989	Kestel Çayi	Izmir	I	CCS	37.4	65	58	53		4077	2.103	Bergama	0.769
15	Çamgazi	1998	Deyran	Adiyaman	I	CCS	53.12	45	39	36	77.86	8000	3.462	Adicim	0.768
16	Kalecik	1985	Kalecik Deresi	Osamniye	I	CCR	31.25	80	77	75	1690	4395	7.659	Bahce	0.763
17	Kalecik	2016	Uludere	Ankara	IM	CCS	16.25	55	53	50		2455	4.018	Kalecik	0.762
18	Ibrala	2012	Ibrala	Karaman	IM	CCR	134	58	49	45	728.3	8700	6.407	Karaman_Osb	0.758
19	Naras	2016	Manavgat	Antalya	IF	RCC	36.18	78	68	56	915	7142	9.903	(Yavrudogan)Gundogdu	0.757
20	Erzincan	1997	Göğne	Erzincan	I	CCS	11.54	81	74.5	73.5		5406	8.564	Erzincan_Osb	0.757
21	Ardil	2017	Ardil	Gaziantep	I	RCC	10.97	54	49	44	507	2126	12.736	Ps5 Tm	0.753

*CCS: Clay Core Sand-Gravel, CCR: Clay Core Rock, RCC: Roller Compacted Concrete, CFR: Concrete Faced Rock Fill, HE: Homogeneous Earth, CFS: Concrete Faced Sand-Gravel, CG: Concrete Gravity

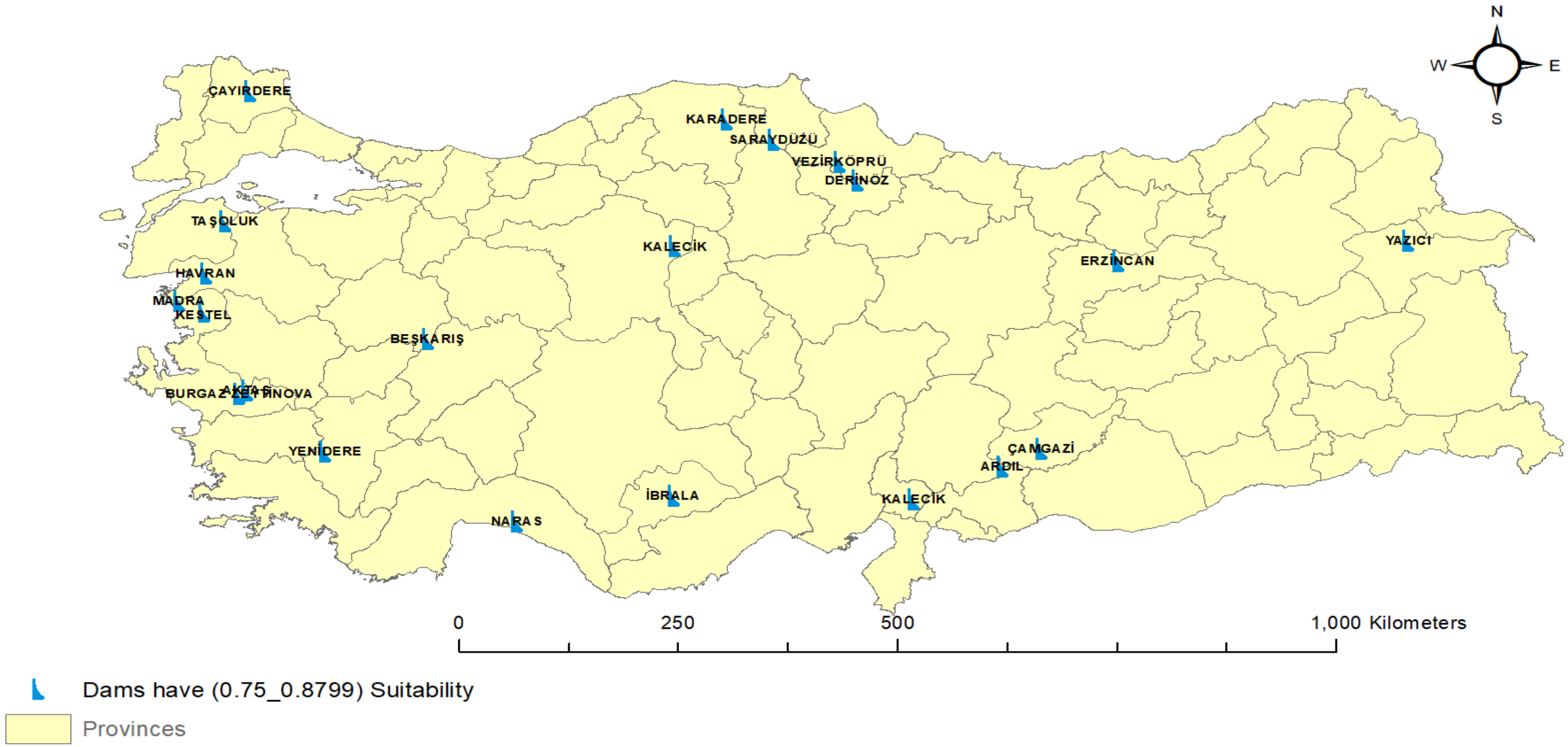

Figure 95 High Suitability 21 Dams

APPENDIX B

MULTI-CRITERIA MEDIUM SUITABILITY SCORE DAMS

Table 13 Medium suitability class: 149 dams had a suitability score of between 50% and 74.99%

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
1	Babasultan	2009	Karadere	Bursa	I	CCR	12.098	53	46	44	305.39	4006	9.551	Inegöl	0.7498
2	Sultansuyu	1994	Sultansuyu Çayi	Malatya	I	CCS	53.3	60	53	50	1050	8596	9.797	Malorsa	0.7484
3	Akgedik	2008	Sariçay	Muğla	IM	CCS	29.032	55	48	45	403	1642	4.786	Milas	0.7420
4	Kizildamlar	2003	Söğüt	Bilecik	I	CCR	10.7	46.7	40	35	296	1974	4.003	Söğüt Tm	0.7392
5	Hancağiz	1990	Nizip Çayi	Gaziantep	I	CCS	100	48	45	42	2430	6945	8.517	Belkis Tm	0.7382
6	Musabeyli	2012	Bişeközü	Yozgat	IM	CCS	48.6	67	61	57	238	1850	13.922	Yozgat	0.7318
7	Güzelhisar	1982	Güzelhisar Çayi	Izmir	IM	CCR	158	89	86	84		9230	6.776	Alosb I	0.7283
8	Hasanlar	2012	Kabaklar	Kütahya	I	CFR	7.9	57.85	48	47		863	13.511	Emet Tm	0.7261
9	Seferihisar	1994	Yassiçay	Izmir	I	CCS	29.1	59	54	49	113.63	1277	14.602	Urla	0.7237
10	Sevişler	1982	Yağcili Çayi	Manisa	I	CCS	122.4	65	59.5	51.5		7063	10.288	Soma Santr. A	0.7237

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
11	Seve	2005	Sinnep	Kilis	IM	CCR	20.9	41	34	31	513	196	2.309	Kilis Tm	0.7225
12	Kovali	1987	Dündar	Kayseri	I	CCS	25.1	48.5	42	40	416	2850	7.981	Yeşilhisar	0.7208
13	Korkuteli	1976	Korkuteli	Antalya	I	CCS	42.74	70.2	50.2	46.2	815	5985	3.316	Korkuteli	0.7208
14	Deliçay	2010	Kurt Deresi	Karaman	IF	HE	25.6	45	35	30	339	3690	5.647	Karaman	0.7199
15	Yeşilburç	2013	Kaynardere	Niğde	I	CCR	3.24	40.5	35.5	32.5	37.4	450	6.133	Nigde2	0.7194
16	Kiliçli	2007	Kapali Deresi	Adana	I	HE	9.5	38	27	23	156.1	677	4.267	Clhadlye	0.7156
17	Bayir	2007	Sirainler	Muğla	I	CCR	7.21	52.5	47	43	311.87	373	11.230	Muğla	0.7139
18	Koçhisar	2011	Büyükköz	Çorum	IM	HE	161.7	57.4	37.4	32.4	442	12427	13.181	Alaca	0.7127
19	Çiçeközü	2013	Boğazdere	Bursa	I	CCS	4.9	53	48.5	45.5		1730	13.895	Yenişehir1	0.7117
20	Demirtaş	1983	Ballikaya Dere	Bursa	I	CCS	14.457	54	46	41	362	1710	3.507	Bdgkçs	0.7115
21	Gökpinar	2001	Gökpinar	Denizli	IM	CCS	27.72	50	43	41	819	6522	6.613	Denizli2	0.7099
22	Onaç 2	1998	Onaç	Burdur	I	HE	16.58	32.5	23.5	18.5	564	1953	4.803	Bucak	0.7096
23	Türkmenli	2001	Kumdere	Tekirdağ	I	HE	15.29	29.8	26.8	22.8	355.88	515	7.884	Botaş	0.7095
24	Karamanli	1987	Değirmendere	Burdur	I	CCS	24.813	53.75	47.25	42.25	631	3747	11.563	Tefenni	0.7084
25	Şarkişla Kanak	2013	Kanak	Sivas	IM	CCS	23.67	49	37.5	33.5	275	2313	13.026	Sarkisla	0.7051
26	Gödet	1988	Gödet Akarsuyu	Karaman	IF	CCR	158	93	64.7	62.7	972	16000	10.598	Karaman	0.7009
27	Ikizcetpeler	1991	Kille	Balikesir	IM	CCR	164.58	52	47	45	2776	4688	7.936	Balikesir_Seka	0.6984
28	Topçam	1984	Madran	Aydin	IF	CCS	106.2	61.65	56.15	54.15		4983	5.608	Çine	0.6942
29	Peçenek	2010	Peçenek	Ankara	IM	HE	75.5	33	32	29	412	1410	13.323	Sereflikochisar	0.6907
30	Günyurde	2005	Bakraş	Bilecik	I	CCR	8.79	46	37	32	122	805	13.570	Karaköy(Tcdd) Tm	0.6897

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
31	Şehitler	2003	Çukur	Isparta	I	CCR	5	46	42.9	40.9	1.8	884	11.422	Sarkikaraağaç	0.6896
32	Alaca	1984	Suludere Akarsuyu	Çorum	I	CCR	12.6	57	44.3	40.3	344	1546	7.327	Alaca	0.6887
33	Kunduzlar	1984	Yönek A.	Eskişehir	I	CCS	22	42.5	28	26	804	5014	8.000	Kirka Tm	0.6853
34	Ariklar	2003	Karaağaç	Kocaeli	I	HE	11.75	27	21	18		1832	9.100	Kaynarca	0.6819
35	Kayapa	1998	Değirmendere	Bursa	I	HE	3.85	48.85	36.85	34.15	185.2	1418	7.193	Görükle	0.6801
36	Hacihidir	1989	Şehir Çayi	Şanliurfa	I	CCR	62.6	42	36.4	27.4		2080	14.448	Siverek Tm	0.6797
37	Keskin 75Yil	1998	Karaöz	Eskişehir	I	HE	8.4	28.6	24.6	22.6	80	1112	5.763	Eskişehir Iii Tm	0.6788
38	Karaidemir	1980	Poğaça Deresi	Tekirdağ	I	HE	111.6	34	29.8	24.8	1154	7720	9.057	Malkara	0.6775
39	Kirklareli	1999	Şeytandere	Kirklareli	IFM	CCR	113.31	70.5	67.5	61.5	1835	13679	8.821	Kirklareli	0.6768
40	Asar	2008	Değirmendere	Kastamonu	I	CCS	5.68	36.7	32.15	28.15	145.08	1010	13.885	Tasköprü	0.6730
41	Hacidede	2000	Allahu	Amasya	I	CCR	4.267	44	40	36	135	520	11.654	Merzifon	0.6708
42	Çatören	1987	Harami	Eskişehir	IF	CCS	47.1	45	35	33	1150	10500	5.785	Kirka Tm	0.6667
43	Sarsap	2012	Üçpinar	Kahramanmaraş	I	CCR	4.23	26	20	18	27.38	557	10.663	Doğanköy Tm	0.6659
44	Hatap	2008	Hatap Çayi	Çorum	IM	CCR	11.6	63	42	38	249	780	13.229	Corum2	0.6650
45	Değirmendere	2012	Değirmendere	Amasya	IM	CCS	5.52	52.7	49.6	45.6	260	277	12.726	Amasya	0.6605
46	Devegeçidi	1972	Furatakşa	Diyarbakir	I	CCR	202	34.8	32.8	30.8	2580	5800	14.157	Diyarbakir_Iii	0.6597
47	Hidirbeyli	1998	Çamurluca	Aydin	I	CCS	3.24	29.5	26.5	22.5	125	292	5.038	Germencik	0.6585
48	Uluağaç	1998	Kargasekmez	Niğde	I	CCS	3.82	48	37.5	33.5	219.4	552	12.146	Nigde2	0.6581
49	Kizilcakişla	2009	Sofular	Sivas	I	CCS	3	31.75	22.25	20.25	81.1	504	10.611	Sarkisla	0.6580
50	Taşbasan Depolamasi	2013	Firat	Şanliurfa	I	HE	5.355	22.5	17.5	14.5		73690	12.959	Suruç Tm	0.6552

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
51	Kazan	1995	Kazan Deresi	Muğla	I	CCS	3	41.5	38.5	34.5		518	10.752	Yatağan	0.6534
52	Yapialtin	1977	Çayilak Deresi	Sivas	I	HE	14.6	36.5	30	27	205	2600	7.989	Sarkisla	0.6510
53	Germeçtepe	1986	Şadibey Deresi	Kastamonu	I	CCR	7.3	50.5	41.7	37.7	436	2495	11.967	Kastamonu Osb	0.6472
54	Artova	1990	Karasu Çayi	Tokat	I	HE	3.5	26	25.5	22.5	42.5	917	2.966	Adocim	0.6467
55	Ivriz	1984	Ivriz Çayi	Konya	IF	HE	83	65	44	41	1760	37000	12.147	Eregli	0.6466
56	Dedeyolu	2008	Kumardi	Elaziğ	I	HE	3.758	35.5	25.7	22.7	44.5	408	14.930	Hazar1	0.6464
57	Cihanbeyli	1989	Insuyu	Konya	I	HE	8.5	18	15	13	60	1137	2.554	Cihanbeyli	0.6447
58	Gölcük	1995	Kayran	Bursa	I	HE	4.3	28	23	20	88.56	820	6.881	Turanköy	0.6410
59	Kartalkaya	1970	Aksu Çayi	Kahramanmaraş	IFM	CCS	717.7	57	56	49	1760	20000	12.520	Narli Tcdd Tm	0.6378
60	Gölköy	1970	Büyüksu Mudurnu	Bolu	I	HE	24.073	24.5	21.5	18.5	60	8545	6.569	Bolu1	0.6349
61	Kapikaya	2012	Mamikan	Malatya	I	CCR	71.14	89.5	81	78	302.3	3662	18.328	Malatya2	0.6332
62	Onaç	1967	Onaç	Burdur	I	CCR	13.2	30	28	25		1854	3.270	Bucak	0.6326
63	Kayaliköy	1986	Teke Deresi	Kirklareli	IFM	CCR	149.9	72	68.7	60.7	2165	15957	12.319	Kirklareli	0.6299
64	Kiziliniş	1995	Imali Çayi	Kahramanmaraş	I	CCS	3.95	31.9	24.9	21.9	107.49	304	11.158	Kilili Tm	0.6259
65	Afşar	1979	Alaşehir Deresi	Manisa	IF	CCS	69	45.5	43.5	34.5		13270	11.637	Alaşehir	0.6252
66	Kesiksuyu	1971	Kesiksuyu Deresi	Adana	IF	CCS	59.1	66.4	57.4	53.4	915	8764	12.310	Kalealti Hes	0.6237
67	Hasanağa	1985	Hasanağa Deresi	Bursa	I	CCS	3.71	37	30	26	174	742	7.486	Görükle	0.6234
68	Hakkibeyli	1994	Handeresi	Adana	I	CCS	5	24.2	22.2	19.2	115	1091	10.808	Adana	0.6227
69	Yayladağ	2000	Kureyşi	Hatay	IM	CCR	7.55	47.4	44.4	40.4	346	719	14.751	Sebenovares Tm	0.6216
70	Bozkir	1981	Höşür	Aksaray	I	CCR	6.1	52.1	47	42	378	971	14.872	Ağaçören	0.6214

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
71	Gülbahar	2014	Koçan	Bingöl	I	CCS	21.162	66.25	60.25	58.25	362.2	1572	15.894	Bingöl	0.6176
72	Çorum	1977	Çomar Akarsuyu	Çorum	IM	HE	6.5	48.5	47.5	44.5	125	1589	1.214	Corum1	0.6172
73	Karahöyük	1998	Halya Derivasyonu	Adiyaman	I	HE	3	25.5	22.5	20.5	31.6	304	13.876	Adiyaman	0.6148
74	Sarimsakli	1968	Sarimsakli	Kayseri	IF	CCS	31.9	48	38	35	500	5000	6.441	Kayseri_Kap	0.6136
75	Kocadere	1981	Kocadere	Edirne	I	HE	3.71	23.75	16.75	13.75	125	381	0.725	Kesan	0.6110
76	Çaltikoru	2011	Ilyas Çayi	Izmir	I	RCC	41.6	66	61	56		4251	17.330	Bergama	0.6029
77	Kelkit Köse	2011	Köse	Gümüşhane	I	CCR	15.73	93	82	78	105	5079	20.503	Gümüşhane	0.6027
78	Biyikali	1987	Değirmenler Deresi	Tekirdağ	I	HE	3.59	23.2	21.7	19.7	27	302	10.437	Tekirdağ	0.6002
79	Atikhisar	1973	Sariçay	Çanakkale	IM	CCS	52.52	43.7	33.7	26.7	2220	3069	9.014	Çanakkale1	0.5999
80	Değirmenci	1979	Doprali Deresi	Edirne	I	HE	7.48	20.7	15.8	13.8	54	476	6.356	Uzunköprü	0.5987
81	Yortanli	2011	Yortanli	Izmir	I	CCS	67.25	52.5	45.5	41.5		6990	15.598	Bergama	0.5946
82	Akkaya	1974	Tabakhane Deresi	Niğde	I	CCS	5.8	19	18	15	600	2277	3.248	Nişde_Osb	0.5937
83	Derince	2014	Derince	Muğla	I	CFS	20.6	64	54	51		1470	20.043	Milas	0.5906
84	Harmancik	1994	Kanliirmak	Sivas	I	HE	3.4	22	16	13	165	520	13.249	Deceko	0.5898
85	Ürkmez	1991	Ürkmez Deresi	Izmir	IM	CCS	7.92	44.5	32	29		370	12.251	Tahtali	0.5894
86	Umurbey	2008	Umurbey	Çanakkale	I	CCR	52.694	80.6	61.1	59.1	1582	3661	20.354	Gelibolu	0.5872
87	Bydağ	2009	Küçük Menderesi	Izmir	I	RCC	248.27	95	51	47		19650	23.015	Nazilli	0.5862
88	Gümüşler	1967	Gümüşler Çayi	Niğde	I	CCS	4	30.6	25.6	23.6	56	400	4.386	Nigde2	0.5830
89	Gördes	2010	Gördes Çayi	Manisa	IM	CFR	448.46	94.9	82.9	80.9		14890	27.004	Demirköprü	0.5829
90	Koyunbaba	2014	Terme	Çankiri	I	CFS	210	51.85	49	47		9600	26.085	Kalecik	0.5822

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
91	Karaçomak	1976	Karaçomak Deresi	Kastamonu	IFM	CCS	23	70	49	43	900	2596	8.563	Kastamonu	0.5808
92	Yaylakavak	1996	Kocaçay	Aydin	I	CCS	31.4	89	71	68	880	3123	16.554	Çine	0.5796
93	Bezirgan	2013	Koldan	Kastamonu	I	CCR	17.5	60	50	45	286.5	2312	20.785	Araç Tm	0.5724
94	Maksutlu	1977	Maksutlu Deresi	Sivas	I	HE	3	25.5	19	15	235	450	7.246	Sarkisla	0.5722
95	Cip	1965	Cip Çayi	Elaziğ	I	CCS	8.269	24	23	19	690	1100	7.746	Hankendi	0.5711
96	Hamzadere	2011	Hamzadere	Edirne	I	CCR	207	47.7	26.5	24.5	15	33564	17.578	Enez Tm	0.5702
97	Beylikova Dep	2010	Porsuk Çayi	Eskişehir	I	CCS	71.37	37.14	34.14	33.14		11760	18.536	Alpu(Tcddy) Tm	0.5687
98	Kaynarca	2013	Kaynarca	Çanakkale	I	HE	18.51	44	31.5	26.5	392.4	2045	15.422	Biga	0.5674
99	Güzelce	2012	Finize	Tokat	I	CCS	37.59	57.5	48.5	45.5	278.44	4737	23.080	Adocim	0.5671
100	Çat	2005	Abdülharap	Malatya	I	CCS	288.3	78	65	60	333	14481	31.377	Malatya2	0.5612
101	Pusat Özen	2009	Pusat	Sivas	I	CCR	95.4	85.5	72	68	662	10599	31.733	Zara	0.5580
102	Bakacak	1998	Kocaçay	Çanakkale	I	CCR	139	65	50	47	501	9000	19.944	Çan	0.5564
103	Belkaya	2008	Guluman	Burdur	I	CCS	8.076	69	61	58	464.25	2682	16.245	Tefenni	0.5525
104	Ulaş Karacalar	2007	Karacalar Irmaği	Sivas	I	CCS	43.6	51	33	30	770	4100	18.134	Deceko	0.5512
105	Ayhanalr	2003	Kizilöz	Nevşehir	I	HE	21.87	42.5	35.36	31.36	447.93	1773	16.005	Avanos	0.5502
106	Kayacik	2006	Aynifar	Gaziantep	I	CCS	116.76	49.5	45	42	612	20000	24.814	Gaziantep4 Tm	0.5483
107	Akhasan	2010	Elma Deresi	Çankiri	I	CCS	16.49	48	35.8	31.8	166	2253	19.499	Ismetpaşa	0.5462
108	Siddikli	2002	Körpeli Boğaz	Kirşehir	I	CCR	28.5	53	50.2	45.2	675	4945	21.452	Kirşehir	0.5454
109	Beyramdere	2011	Karanlikdere	Çanakkale	IM	CCR	18.45	60	56	51	376.6	1050	15.582	Gelibolu	0.5447
110	May	1960	May Nehri	Konya	IF	HE	42.7	19.6	19	16	535	1200	7.369	Alibeyhüyüğü	0.5439

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
111	Karaçal	2009	Bozçayi	Burdur	I	CCS	63.5	70	59.5	57.5	1176.6	5006	31.189	Burdur	0.5430
112	Nevruz	2017	Pöhrekli	Sivas	I	CCR	22.12	54	41.3	38.3	70.7	4829	29.654	Sivas	0.5417
113	Uluborlu	2010	Pupa Çayi	Isparta	IF	HE	19.9	75	56.46	49.46	286	1808	15.253	Keciborlu	0.5416
114	Kavakdere	2006	Kavakdere Çayi	Izmir	I	CCS	13.8	42	36.5	32.5		560	15.708	Tahtali	0.5411
115	Sihke	1958	Akköprü Dersi	Van	I	HE	9.2	18.2	11.2	10.2		1200	6.395	Van Tm	0.5402
116	Sulakyurt	2015	Taretözü	Kirikkale	I	CFS	43.8	51	46	41	307	2569	30.278	Kalecik	0.5396
117	Çayboğazi	2002	Sancikisik	Antalya	I	CCS	54.95	78.7	67.7	64.7	96	13593	29.702	Elmali	0.5385
118	Durağan	2010	Çarşak Çayi	Sinop	I	CCR	8.44	76	51	46	431.52	624	17.701	Boyabat	0.5379
119	Çokal	2012	Kabakçayi	Çanakkale	IM	CFR	204	80.5	57	51	1500	12757	23.007	Malkara	0.5378
120	Damsa	1971	Damsa	Nevşehir	IF	CCS	7.12	33.5	31.5	27.5	350	1390	10.031	Urgup	0.5371
121	Akköy	1967	Asarcik	Kayseri	IF	CCR	7.5	43.5	41.5	36.5	744	946	12.296	Yeşilhisar	0.5370
122	Damlapinar	2013	Damla Çayi	Konya	I	CFR	10.13	57.5	54.5	51.5	339	1070	23.591	Beyşehir	0.5357
123	Pamukçay	2012	Pamukçay	Diyarbakir	I	CCS	44.82	37.5	31.5	28.5	310.64	5100	24.190	Bismil	0.5355
124	Kulaksizlar	2007	Bük	Kastamonu	I	CCR	18.72	46	33	28	543	5128	20.143	Kastamonu Osb	0.5347
125	Naipköy	2016	Kocadere	Tekirdağ	IM	HE	21.59	58.5	36.5	33.5	393	100	16.930	Tekirdağ	0.5304
126	A.Kuzfindik	2007	Kocadere	Eskişehir	I	CCS	20.95	46.5	30	25	341	2496	19.652	Seyitömer Tm	0.5297
127	Erfelek	2001	Karasu Çayi	Sinop	IM	CCS	25.23	87.2	67	63	602.5	2873	17.004	Ayancik	0.5277
128	Çavdir	2005	Bayir	Burdur	I	CCR	32.216	60	44	39	317	1157	25.765	Tefenni	0.5277
129	Kurtbey	1975	Karacacrman Deresi	Edirne	I	HE	3.26	17.65	14.15	11.15	28.1	234	14.546	Uzunköprü	0.5274
130	Selim Bayburt	2012	Bozkuş	Kars	IM	CCS	52.43	57	52	48		5237	20.514	Kars2	0.5266

Table 13 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Volume (hm3)	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
131	Bedirkale	1995	Kala Deresi	Tokat	I	CCS	17.87	45.56	34.66	30.66	292.13	2813	15.359	Adocim	0.5264
132	Bademli	2013	Pirinç Çayi	Izmir	I	CCS	4.96	56.5	51	47		1048	19.069	Ödemiş	0.5259
133	Gelingüllü	1993	Kanak	Yozgat	I	HE	270	54	44.4	38.4	1890	24806	25.269	Sorgun	0.5246
134	Doğanözü	2011	Kirmir Çayi	Ankara	I	CCS	35.64	52	33.5	30.5		2777	27.288	Kazan	0.5234
135	Yarseli	1991	Beyazçay	Hatay	I	CCS	55.4	43.5	36.5	34.5	888	7300	17.127	Antakya I	0.5233
136	Köprüköy	2010	Köprüköy D.	Isparta	I	CCR	5.48	50.78	40.78	38.78	137.18	1508	16.109	Sarkikaraağaç	0.5221
137	Akçin	2012	Kocadere	Çanakkale	I	CCS	10.3	40	34	30	226.3	820	19.153	Ezine	0.5208
138	Beyler	1994	Incesu	Kastamonu	I	CCR	26	40	31	27	313	6121	15.139	Kure	0.5190
139	Göksu	1995	Göksu	Diyarbakir	I	CCR	56.5	53	46	44	2215	3582	24.035	Mazidaği(Etifosfat)	0.5171
140	Dereköy	2003	Dereycan	Samsun	I	CCR	9.603	51.2	48.2	44.2	261	1183	18.891	Vezirköprü	0.5167
141	Armağan	1998	Kocadere	Kirklareli	I	CCR	51.5	60.5	57.5	52.5	665	590	28.967	Pinarhisar	0.5146
142	Kurusaray	2009	Dereköy	Sinop	I	CCR	4.5	50	45	41	154	765	17.332	Boyabat	0.5126
143	Demirözü	2013	Lori	Bayburt	I	CCR	61.8	44.5	32.5	27.5	409.75	11260	30.097	Bayburt	0.5126
144	Boztepe	2002	Kuruçay	Malatya	I	CCS	116.1	82	71	65	1270	11560	37.706	Malorsa	0.5121
145	Sille	1960	Sille Çayi	Konya	IF	CCR	3.1	40	39	36	235	220	9.429	Konya1	0.5098
146	Beylerli	2005	Değirmendere	Denizli	I	CCS	3.25	52	48	45	256	828	15.933	Bozkurt	0.5072
147	Ayvacik	2008	Tuzlaçayi	Çanakkale	IM	CCR	39	53	49	47	1190	3368	21.889	Ezine	0.5070
148	Ayvali	2007	Erkenez Çayi	Kahramanmaraş	IFM	CCS	85.11	103	75.5	71.5	500	1680	17.245	Kahramanmaraş 2	0.5063
149	Gayt	1997	Gayt Çayi	Bingöl	I	CCS	40.762	36	31.5	25.5	2610	4420	19.997	Bingöl	0.5046

*CCS: Clay Core Sand-Gravel, CCR: Clay Core Rock, RCC: Roller Compacted Concrete, CFR: Concrete Faced Rock Fill, HE: Homogeneous Earth, CFS: Concrete Faced Sand-Gravel, CG: Concrete Gravity

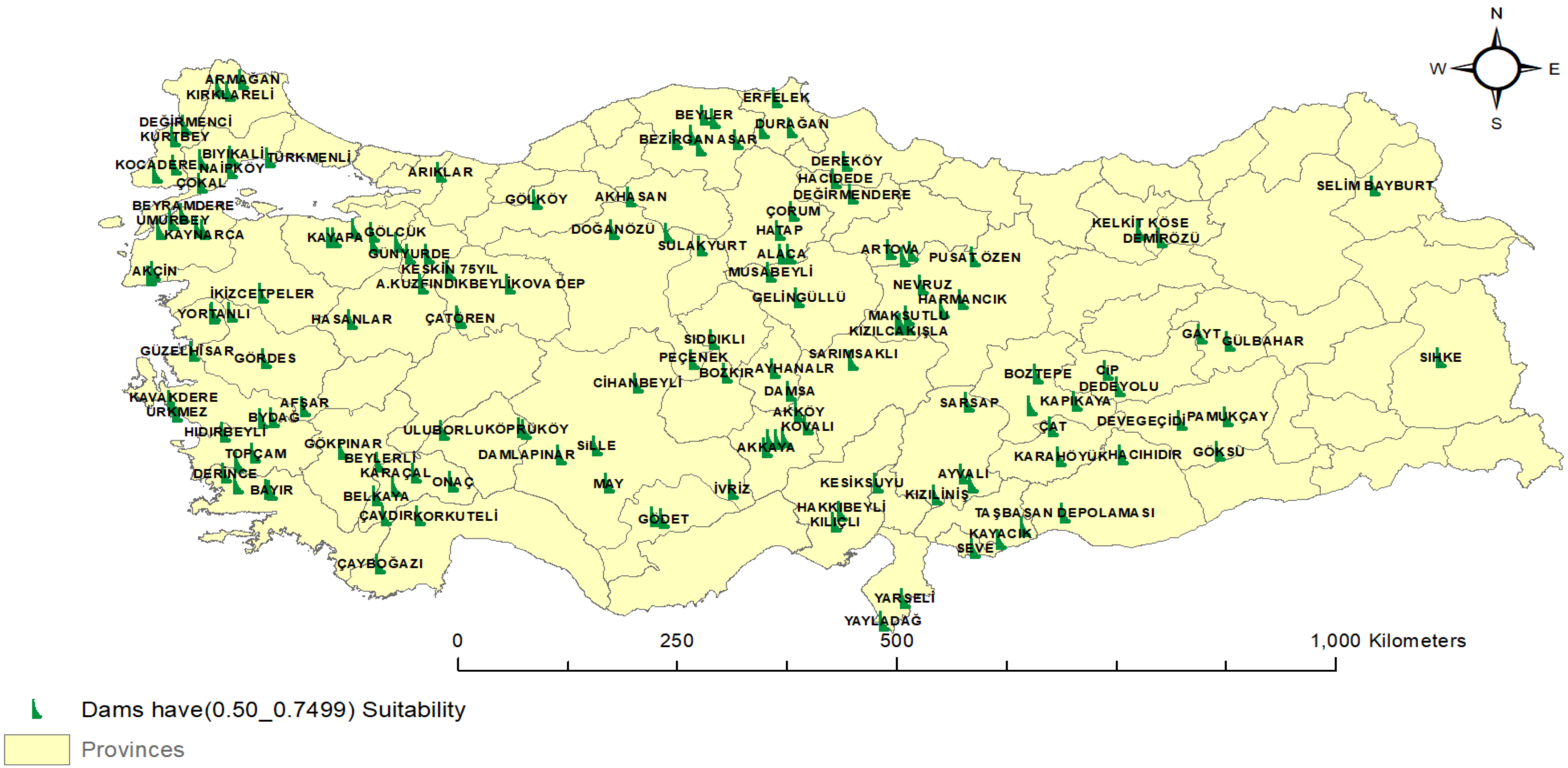

Figure 96 Medium Suitability 149 Dams

APPENDIX C

MULTI-CRITERIA LOW SUITABILITY SCORE DAMS

Table 14 Low suitability class: 95 dams had a suitability score of between 27% and 49.9%

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
1	Yahyasaray	1991	Konak	Yozgat	I	CCS	25	54	47	41	12111	3436	23.832	Akdağmadeni	0.4995
2	Karacasu	2012	Dandalaz	Aydin	IM	CFS	17.2	60	53.5	46.5	1389	1125	24.170	Kemerbaraj	0.4995
3	Belpinar	1984	Silisözü	Tokat	I	CCR	29.63	61.16	58.16	55.16	453	2472	24.032	Turhal	0.4984
4	Yaprakli	1991	Dalaman	Burdur	I	CCS	144.461	69.5	52.5	47.5	275.1	7663	29.630	Esen	0.4974
5	Kültepe	1983	Köşközü	Kirşehir	I	HE	28.46	46.7	37.2	34.2	725	2778	17.563	Ağaçören	0.4961
6	Örenler	1993	Karadirek	Afyonkarahisar	I	CCS	26	30.9	24.9	21.9	628.22	3874	17.374	Sandikli Tm	0.4942
7	Sadak	2013	Kelkit	Gümüşhane	I	CCS	23.23	47.5	35	31		7497	35.459	Erzincan	0.4938
8	Güneşli	2014	Inderesi	Manisa	I	CCR	8.13	42.7	36.2	33.2		1422	26.607	Demirçi	0.4927
9	Asar	2011	Kocadere	Çanakkale	I	CCR	3.56	45	42	38	147	870	21.859	Çan	0.4907
10	Hotamiş	2016	Ahi Kanali	Konya	I	HE	55.2	15	12	10		77	26.879	Çumra	0.4903

Table 14 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
11	Yedikir	1985	Tersakan	Amasya	I	CCS	60.3	28	25.7	23.7	107	7966	15.615	Merzifon	0.4884
12	Altinapa	1967	Meram Çayi	Konya	IFM	CCR	32.3	31.5	30.5	20.5	1180	1400	14.536	Konya1	0.4876
13	Duruçay	2003	Kuyma	Samsun	I	CCS	4.732	38	34.3	29.3	216	1229	15.192	Vezirköprü	0.4864
14	Sariveliler	2011	Çevik	Karaman	I	HE	9.25	33.5	29.5	26.5	87.5	1412	23.570	Daran Havza Tm	0.4859
15	Yeniköy	2003	Aciöz	Kirşehir	I	HE	13.9	24.5	21	18	155.925	1425	18.633	Petlas	0.4850
16	Kestel	2012	Kestel	Afyonkarahisar	IM	CCS	9.9	59	48.5	45.5		2061	19.604	Sandikli Tm	0.4848
17	Ceritmüminli	2012	Yaycili	Kirikkale	I	HE	5.1	52	32.2	29.2	56.56	951	21.682	Hacilar	0.4847
18	Sultanköy	1995	Manastirdere	Edirne	I	HE	27	28.9	26.9	23.9	45.58	7773	22.155	Kesan	0.4843
19	Kacarlar	2006	Kacarlar	Tunceli	I	CCS	3.631	36.5	35.5	32.5	47.9	613	18.359	Tunceli	0.4841
20	Sarayözü	1989	Balikli Deresi	Amasya	I	CCS	13.1	47.5	44.5	41.5	250	3600	21.774	Merzifon	0.4786
21	Koruluk	2005	Ceviz	Gümüşhane	I	CCS	11.5	51	43.6	40.6	8045	4074	30.400	Çamoluk	0.4771
22	Kizderbent	2006	Ömeroğlu	Kocaeli	I	HE	3.56	38	36	33		720	20.331	Yalova	0.4766
23	Derebucak	2006	Kocaçay	Konya	I	CCR	11.7	51.8	40.8	36.8	732	3750	30.235	Seydişehir	0.4765
24	Murataza	1993	Melendiz	Niğde	I	CCR	7.4	41	38	36	55	1191	17.382	Misliova	0.4755
25	Bademli	1997	Babemli	Burdur	I	HE	6.174	44	40	35	247	523	18.602	Tefenni	0.4744
26	Sarioğlan	2006	Kestuvan Çayi	Kayseri	I	HE	25.6	38	31.2	30.2	490.7	6123	35.188	Sizir	0.4742
27	Uzunlu	1991	Kozanözü	Yozgat	IF	HE	48.23	61	50	43	62.85	7800	17.827	Boğazliyan	0.4740
28	Demirdöven	1997	Timar	Erzurum	I	CCS	37.1	67.35	58	54	198	9844	37.965	Horasan	0.4739
29	Kalecik	1985	Kalecik Akarsuyu	Elaziğ	I	CCR	12.5	36.6	34	30	743	900	16.126	Seyrantepe	0.4701
30	Küçüklü	1998	Aşağidere	Çanakkale	I	HE	5.92	31.75	29.3	27.3		796	15.967	Çan	0.4699

Table 14 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
31	Palandöken	2005	Lezgi	Erzurum	IM	CCS	157	49	44.45	39.45	392.67	12038	30.901	Erzurum3	0.4648
32	Ayitdere	2012	Çinardere	Çanakkale	I	HE	6.78	20	15	13	500	1157	18.751	Biga	0.4646
33	Pazaryolu	2014	Değirmendere	Erzurum	I	CCR	3.02	69.5	57.5	53.5	98.5	605	34.652	Kuzgun	0.4619
34	Asartepe	1980	Ilhan Çayi	Ankara	I	HE	20	50	36.5	31.5		2850	22.224	Kazan	0.4612
35	Işiktepe	1999	Zugur	Elaziğ	I	CCS	4.47	52.6	25.6	23.6	51	313	15.314	Maden	0.4597
36	Üçöz	2007	Üçöz	Sivas	I	HE	13.74	28.4	23.4	19.4	85.6	989	27.863	Kangal	0.4593
37	Mamasin	1962	Uluirmax	Aksaray	I	CCR	165.8	48.4	44.9	35.9	570	23640	17.262	Aksaray	0.4587
38	Dumluca	1992	Buğur	Mardin	I	HE	22.5	29.5	24	20	356	1860	23.882	Ps_4_A Tm	0.4586
39	Medik	1975	Tohma Çayi	Malatya	I	CCR	22	43	42	34	3850	15842	21.079	Malorsa	0.4583
40	Ağcaşar	1987	Yahyali	Kayseri	I	CCS	61.7	27	24	22	16	15035	23.871	Yeşilhisar	0.4547
41	Osmankalfalar	2003	Sevindirik	Antalya	I	CCS	8.19	30.7	25.7	22.7	266.11	842	22.874	Tefenni	0.4529
42	Tahtaköprü	1975	Karasu Deresi	Hatay	I	CCS	200	46.5	35.5	33.5	2480	11900	27.462	Fevzipasa Tm	0.4516
43	Kizik	2003	Miçöz	Tokat	I	CCR	7.108	45.7	26.25	22.25	248	1800	22.387	Adocim	0.4490
44	Bayrmiç	1997	Karamenderesi	Çanakkale	IM	CCS	86.5	55.5	45.5	39.5	880	16694	27.741	Ezine	0.4481
45	Akşahan	2013	Kavakdere	Konya	I	CFR	4.6	42	38	35	170	716	33.539	Konya1	0.4473
46	Kayapinar	2013	Özdere	Kayseri	I	HE	3.795	41	32	28	100.95	637	29.451	Kayseri_Kap	0.4455
47	Gazibey	1992	Osugülüç	Sivas	IF	CCR	16	58.3	45.5	40.5	358	2537	22.520	Sarkisla	0.4389
48	Çavdarhisar	1990	Bedir	Kütahya	IF	CCS	38.8	50.5	45.5	41.5	555	5242	25.175	Gediz Tm	0.4369
49	Selevir	1964	Gali	Afyonkarahisar	I	CCS	65	32	31.4	27.4	560	8310	16.769	Seka Tm	0.4361
50	Mumcular	1989	Kocadere	Muğla	IM	CCS	19.4	34	32	30	598	1266	19.809	Yeniköy	0.4358

Table 14 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
51	Küçükler	2005	Gavural	Uşak	IM	CCS	10.92	41	36.3	32.3		1608	23.608	Gediz Tm	0.4348
52	Doyduk	2013	Kalaycik	Nevşehir	I	HE	13.7	24	22	19	163	1452	37.272	Kalaba	0.4345
53	Ceffan	1995	Ceffan	Batman	I	HE	6.845	30	26.56	23.56	192	400	21.184	Kurtalan	0.4344
54	Büyükorhan	1992	Cuma Dere	Bursa	I	HE	6.93	36	23	21	535	707	18.032	Orhaneli	0.4337
55	Postalli	2004	Postalli	Niğde	I	CCS	3.26	31.2	29.2	26.2	97.4	620	25.297	Bor	0.4318
56	Saribeyler	1985	Savaştepe	Balikesir	I	CCS	15.6	37.5	35	30	304	2065	28.973	Balikesir1	0.4294
57	Apa	1962	Çarşamba Akarsuyu	Konya	I	CCS	171.6	30.8	29.8	26.8	500	97015	19.761	Alibeyhüyüğü	0.4291
58	Kozçeşme	1998	Kocadere	Çanakkale	I	HE	4.24	27.6	23.6	21.6		504	20.550	Biga	0.4287
59	Fehimli	1988	Fehimli	Yozgat	I	HE	11	23	17.4	13.4	350	1000	17.058	Kalaba	0.4264
60	Serban	1994	Serban	Afyonkarahisar	I	HE	3.35	28	26.5	23.5	199	922	20.101	Afyon I Tm	0.4204
61	Çağlayan	2013	Yayla	Konya	I	CCS	3.85	33	31	27	75.5	713	35.774	Akseki	0.4163
62	Çayhan	1994	Çayhan	Konya	I	HE	3.71	36	23.5	20.5	138.53	721	20.191	Eregli	0.4142
63	Seyitler	1964	Seydiler	Afyonkarahisar	I	CCS	40.47	27	26	22	450	3222	18.291	Afyon Ii Tm (Salt)	0.4133
64	Bozarmut	2004	Devrent	Sivas	I	HE	4.3	29	21	18	203	1010	25.984	Kangal	0.4132
65	Porsuk	1972	Porsuk Çayi	Eskişehir	IFM	CG	454	64.7	49.7	45.7	792	24850	19.400	Karagözler (Tcddy) Tm	0.4124
66	Sürgü	1969	Sürgü Nehri	Malatya	I	CCS	70.06	57	55	49	535	11968	34.302	Golbaşi	0.4107
67	Boztepe	1983	Boztepe Akarsuyu	Tokat	I	HE	14.2	35.5	27.3	25.3	240	4872	27.926	Turhal	0.4105
68	Üçpinar	2007	Deliçay	Kilis	I	HE	4.57	28	23	19	148	370	29.535	Kilis Tm	0.4100
69	Çiftliközü	2001	Karakaya	Konya	I	HE	3.36	43	36.5	33.5	64	475	33.198	Ilgin	0.4085
70	Çataldağ	2008	Biçkidere	Balikesir	IM	CCR	4.96	34.5	26	22	234	53	19.641	M.Kemal_Paşa	0.4076

Table 14 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
71	Dutluca	1992	Sapoğlu	Tokat	I	HE	5	37	27.5	23.5	32.55	662	23.969	Adocim	0.4059
72	Uluköy	1983	Derebey Deresi	Amasya	I	HE	3.65	28	23	20	52.5	1190	16.007	Erbaa	0.4006
73	Mercan	1987	Sazliüvet Deresi	Edirne	I	HE	3.52	23.3	19.8	15.8	77.61	61	16.039	Kesan	0.4004
74	Daridere	1977	Sarisu	Bilecik	IF	CCS	19.21	33.4	27	21	220	3105	15.879	Bozüyük Tm	0.3975
75	Çatmapinar	1994	A.Dereboyu	Eskişehir	I	HE	4.154	26.9	15.9	12.9	196.9	838	20.303	Çifteler Tm	0.3969
76	Kirkat	1985	Nehir Deresi	Batman	I	HE	3.156	23.8	21	18		345	17.346	Midyat	0.3932
77	Yalvaç	1973	Sücüllü D.	Isparta	I	HE	8.567	35.5	41.57	36.57	360	2062	25.786	Akşehir	0.3913
78	Çoğun	1975	Kizilözü	Kirşehir	IF	CCR	21.77	46	29.5	23.5	790	3762	18.116	Kirşehir	0.3891
79	Balikli	1999	Deliçay	Kilis	I	HE	3.94	30.2	25.7	22.7	113	348	31.013	Kilis Tm	0.3883
80	Süloğlu	1981	Süloğlu Deresi	Edirne	IFM	CCR	50	53.41	50	43	960	4009	18.898	Ediçim	0.3876
81	Üçpinar	1992	Kurbağali Dere	Uşak	I	CCS	5.3	26.5	25.5	22.5	447.4	205	28.040	Akenerji Osb. Dgçs	0.3875
82	Aydoğmuş	1988	Boğaz	Konya	I	HE	4.7	27	21	19	88	450	23.591	Alibeyhüyüğü	0.3842
83	Çitli	1992	Gömük	Amasya	I	HE	3.25	26	19.2	16.2	105	382	23.008	Merzifon	0.3841
84	Dokuzdere	1976	Dokuzdere	Edirne	I	HE	4.02	30.2	24.2	21.2	208	510	16.525	Kesan	0.3840
85	Yalintaş	1994	Alaçoraközü	Nevşehir	I	HE	10	23.5	14.5	11.5	148.9	1212	30.735	Nevşehir2	0.3753
86	Yildiz	1997	Kayaligöl	Sivas	I	CCS	8.24	33	23.5	20.5	138	1723	36.372	Sivas_Osb	0.3739
87	Halilan	1981	Çoruk	Diyarbakir	I	HE	7.452	26.8	21	18	409.22	670	24.441	Ergani	0.3714
88	Kuzayca	1997	Kuzayca	Yozgat	I	HE	7.68	19.8	16.6	14.6	134	1008	35.230	Boğazliyan	0.3616
89	Gökçeada	1983	Büyükdere	Çanakkale	IM	CCS	16.6	51	33	29	163	700	32.353	Kumlimani	0.3551
90	Deliilyas	1993	Ulusuluk	Sivas	I	HE	3.6	26	25	22	155	398	34.222	Sarkisla	0.3550

Table 14 (continued)

Rank	Dam Name	Start Operation	River	Province	Perpose	Body Type*	Reservoir Capacity	Height from Base (m)	Height from Thalweg (m)	Normal Water Level or Head	Full Spill Way (m3/s)	Irrigated Area (hm2)	Near Substation (km)	Substation Name	Suitability Score
91	Kayaboğazi	1988	Kocasu	Kütahya	IFM	CCS	37.84	45	38	31	1780	6103	26.493	Tunçbilek Ts(Tutes)	0.3545
92	Kadiköy	1973	Doğanca Dervent D.	Edirne	IFM	HE	56.5	37.8	34	30	46.3	4451	17.021	Kesan	0.3537
93	Altinyazi	1967	Basamaklar Deresi	Edirne	IF	HE	36.764	27.1	23.5	20.5	170	7524	22.869	Kesan	0.3414
94	Takmak	1984	Değirmendere	Uşak	I	HE	3.06	24.5	19.5	16.5		237	35.044	Akenerji Osb. Dgçs	0.3110
95	Ayranci	1958	Kocadere Çayi	Karaman	IF	HE	30.9	36	34	31	500	5438	38.204	Karaman_Osb	0.2770

*CCS: Clay Core Sand-Gravel, CCR: Clay Core Rock, RCC: Roller Compacted Concrete, CFR: Concrete Faced Rock Fill, HE: Homogeneous Earth, CFS: Concrete Faced Sand-Gravel, CG: Concrete Grav

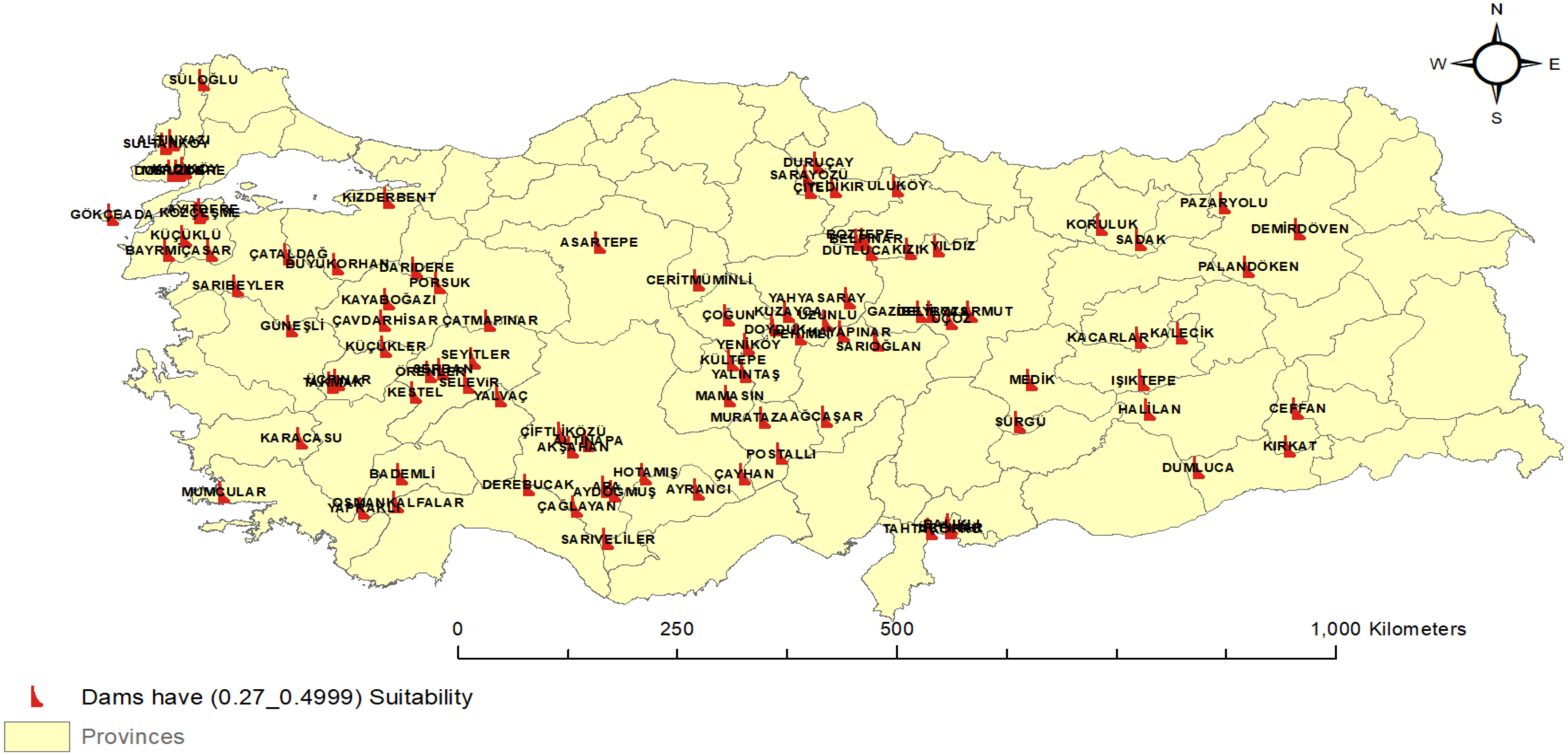

Figure 97 Low Suitability 95 Dams

CURRICULUM VITAE

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Quality Management System ISO9001:2008 (2015)	Training Course	University of Information Technology and Communication
Computing Fundamentals, Key Applications, Living Online (2010)	IC3 Certification (Internet Core Competency)	Certiport IC3
ArcGis Level 2 (2008)	Training Course	University of Baghdad/ Computer Center
Geographic Information System (2007)	Training Course	AL Quds School for Computers

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