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Investigation of Hydropower Potential of Şemdinli River Basin

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Abstract: The most important renewable energy source in Turkey is the hydropower. Turkey's geographical location provides important advantages for extensive use of hydropower energy sources. There are many available streams in the country for energy generation, which are mostly unexploited at the moment. Besides, electricity demand has recently increased significantly due to extensive energy use in the country. However, the required energy is mostly imported from foreign countries since it cannot be met by Turkey's own resources. In this paper, the hydropower potential of Şemdinli River, which is a subbasin of Zab Basin, is investigated. During the study, Geographic Information Systems (GIS) and Remote Sensing (RS) methods were utilized. According to preliminary research, one dam was planned in the Şemdinli River Basin. The possible costs of this dam and the estimated amount of annual electric energy were also calculated. For the calculations of the total costs and the total installed power capacity of the dam, Simahpp software was used. Accordingly, the total cost, installed power capacity and total annual electricity of the dam were respectively found as 61,716x10^6 US$, 42,813 MW and 78,76 GWh.

Key words: Dam planning · Electricity generation · Hydropower plants · Water potential · Şemdinli River Basin

INTRODUCTION

Energy has a vital importance not only for Turkey, but for the whole countries in the world. Today, it is not possible to perform industrial, agricultural, educational and transportation activities and sustain a qualified life without energy. In this context, Turkey's energy need is significantly growing day by day [1]. Energy consumption is also rapidly increasing to compete against other countries and sustain country's own development. Correspondingly, Turkey's electric consumptions were respectively 230x10^9 kilowatt-hour (kWh) in 2011 and 142x10^9 kWh during the first 7 months of 2012. Hydropower plants have supplied 40x10^9 kWh of these amounts. The amount of electricity to be produced by the hydropower plants by the end of 2013 was estimated as 65x10^9 kWh [2, 3]. As Turkey does not possess adequate oil and natural gas reservoirs, it relies heavily on foreign energy resources. Most of the energy need in the country is met by oil, natural gas and coal importation. Turkey paid 33,9x10^9 USD in 2007 and 40x10^9 USD in 2010 for energy imports. In 2010, this figure was one-fifth of total imports of the country[1]. Considering these facts, it is inevitably necessary to increase hydropower plant investments in the country. According to the projections made for 2030, annual increase in the electric energy in Turkey will vary between 6-8% and the consumption per person will be 5200 kWh[2] [4].

Besides, the decrease in global reservoirs of oil, natural gas and coal, as well as increase in the amount of hazardous greenhouse gases resulting from fossil fuels have recently augmented the demand for renewable

[1]TUIK, State Institute of Statistics, www.tuik.gov.tr, 2011.
[2]DSI, State Hydraulic Works, www.dsi.gov.tr, 2010.

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energy sources worldwide [4]. Water resources are amongst the renewable, environmentally friendly, native and clean energy sources. Therefore, it is also necessary to ameliorate the water resources in Turkey and economically benefit from the current water potential [5]. Currently, a potential of $86x10^9$ kWh/yr hydropower energy generable from the rivers in Turkey are wasted, as these rivers directly discharge into the seas without any exploitation[2,3]. The monetary value of this loss is approximately $10x10^9$ USD.

Within this context, the main objective of this study is to investigate the hydropower potential of Şemdinli River and use this potential for the economical development of the region and the country. For this purpose, using Geographical Information Systems (GIS) and Remote Sensing (RS) methods, surface and geological formation analyses of the basin were performed. Existing climate and water flow data of the basin were examined in detail. This data was applied for the calculations of the planned dam. Besides, estimated total annual electricity and total costs of the dam, as well as the feasibility of the study were analysed.

MATERIALS AND METHODS

During this study, raster maps, vector maps, satellite images, meteorological and water flow data of the study area were utilized as the main materials. 293 scanned and rectified raster maps, as well as 293 coordinated vector maps (1/25 000 scale, UTM 38N zone and European Datum 1950 -ED50- coordinate system) were provided from the General Command of Mapping (HGK)[4]. 18 Aster 3A-01 satellite images were used for land use classifications with Erdas 8.6. [6]. ArcGIS 9.3.1 was utilized for performing spatial analysis within the basin [7, 8].

The meteorological data within the study area (precipitation, temperature, evaporation, relative humidity, wind, snow etc.) was provided from State Meteorological Organisation (DMI)[5] and the stream flow data in the basin were provided from Electrical Power Survey and Development Administration (EIE) and State Hydraulic Works (DSI). The flow data of missing years were generated using statistical correlations method [9].

The flow data of the planned dam axis on Şemdinli River was transported with drainage-area ratio method. The method is given in equation (1) below [10, 11]:

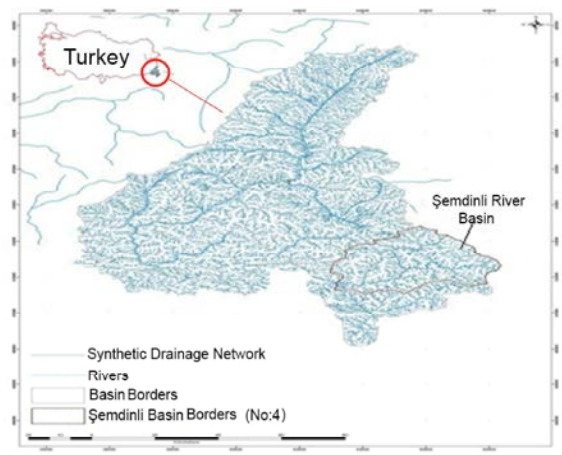


Fig. 1: The location of Zab River Basin and Şemdinli River Basin

$$Q_1 = \kappa \cdot \left(\frac{A_1}{A_2} \right)^{\phi} \cdot Q_2 \quad (1)$$

where,

Q_1: Estimated flow at point 1, m^3/s, Q_2: Known flow at point 2, m^3/s, A_1: Drainage area of point 1, km^2, A_2: Known drainage area of point 2, km^2, ϕ: Exponential factor $\kappa_{1,2}$: Correction factor between stations 1 and 2.

Installed power capacity and electric energy generation potential of the dams were calculated using Simahpp-4 (Simulation to Evaluate the Feasibility of Hydropower Projects).

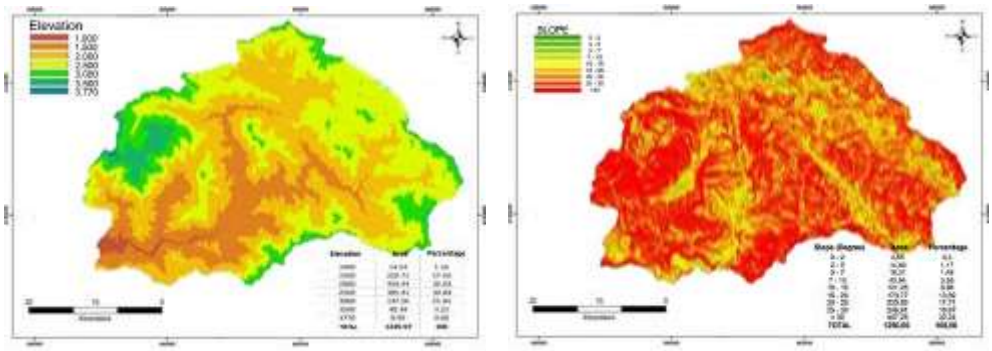
The Study Area: The study area is the Şemdinli River Basin, which is a subbasin of Zab River Basin. Zap River Basin is a subbasin of Tigris catchment (Figure 1). Şemdinli River is the main tributary of Zab River with a total area of 1407,71 km^2. The largest settlement area in the basin is Şemdinli.

A. Determination of hydrological basin borders and spatial characteristics of Zab and Semdinli Basins using geographical information systems (GIS)

In order to determine the hydrological basin borders of Şemdinli River, subbasins of Zab River were determined primarily. Zab River Basin digital elevation model (DEM) was used for the determination of subbasin boundaries

[3]EIE, Electrical Power Survey and Development Administration, www.eie.gov.tr, 2010.
[4]HKG, General Command of Mapping, http://www.hgk.mil.tr/, 2010.
[5]DMI, State Meteorological Organisation, www.dmi.gov.tr, 2010.

Fig. 2: Subbasins of Zab River [12]



a) Topographic map b) Slope map

Fig. 3: Spatial maps of Şemdinli River Basin.

Table 1: Areas of Zab Basin and subbasins in Turkey and Iraq

Basin No	Total area in Turkey (km^2)	Total area in Iraq (km^2)	Total Area of Zab Basin (km^2)
1 (Zab Main River)	6815,54	402,77	7218,31
2	220	216,65	436,65
3	754,35	147,75	902,10
4 (Şemdinli River Basin)	1250,87	156,84	1407,71
5	448,56	300,63	749,19
Total	9449,32	1224,64	10713,96

(Figure 2) and the drainage area, as well as to perform spatial analyses for the production of various maps of the study area such as topography, slope and aspect.

Digitised maps and satellite images were used for the determination of basin characteristics. ArcHydro Tools 9 was utilized to detect the flow direction, the synthetic drainage network that is formed as a result of the precipitations in the subbasins, the main stream of each subbasin and number of streams in each subbasin. Table 1 gives the total areas of the subbasins.

The spatial characteristics of Şemdinli were classified using geostatistical methods (Figure 3). According to the maps, the elevation of the basin varies between 1000-3770 m. and 70% of the study area (874,98 km^2) has a slope over 20%. The basin is considerably mountainous.

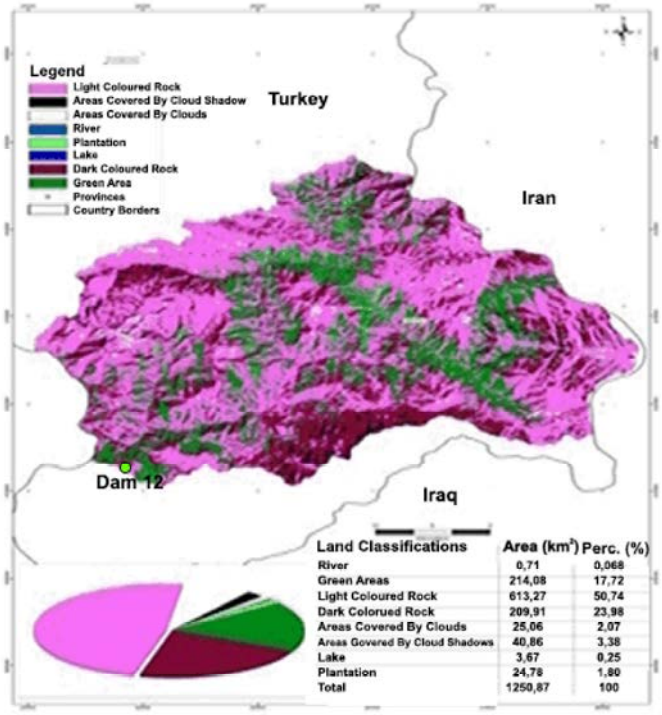


Fig. 4: Land classification of Şemdinli River Basin.

B. Determination of Land Use and Geological Formation of Zab River Basin Using Satellite Images

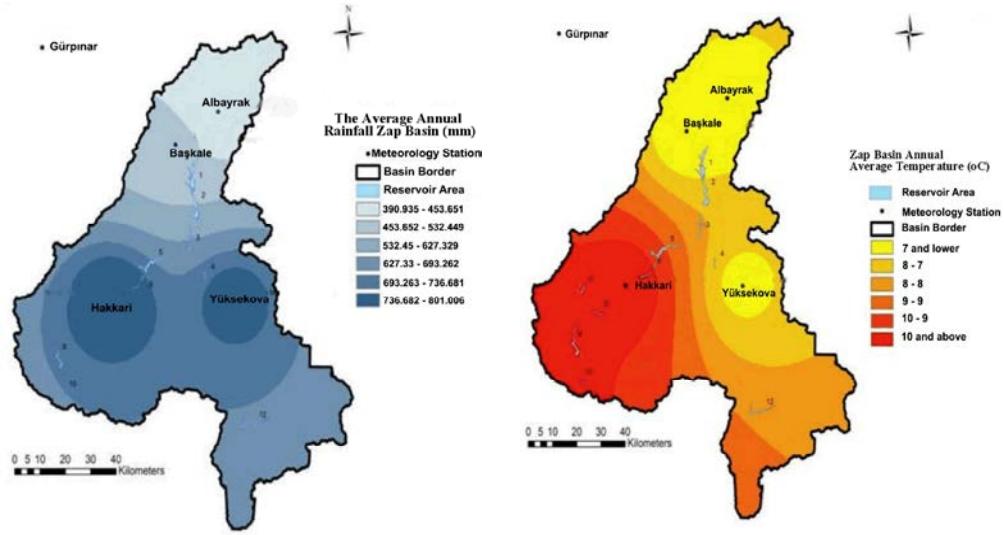
Aster 3A-01 images and Erdas 8.6 image processing software were used for land classifications and geological structure determination process. The geological structure and the characteristics of Zab River Basin is of great significance for this study. However, it was not possible to exactly determine the geological characteristics of the area from the satellite images. For this reason, 1/500 000 scale digitised map of Turkey, provided from The General Directorate of Mineral Research and Exploration (MTA)[6], was also examined to obtain the most accurate results. Thus, it was possible to determine the most appropriate dam locations in the study area. In Figure 4, land classification of Şemdinli River Basin is given. According to the geological characteristics and land classifications, designated dam is located in a narrow valley and lies on Neritic limestone (dark green area). It was considered that the dam area had a very low permeability.

C. Meteorological characteristics of the study area

The meteorological data recorded at Meteorology Observation Stations (MOS) within the study area, varying between 1929 and 2008, were provided from DMI and used to calculate the monthly averages of the meteorological characteristics such as precipitation (mm), temperature (°C), evaporation (mm), relative humidity (%), snow depth (cm) and wind speed (m/s). Inverse Distance Weighted-IDW interpolation method was utilized to produce precipitation, temperature and evaporation distributions in the Zab Basin[7] (Figure 5).

To achieve the most precise results possible, not only meteorological data of Şemdinli River Subbasin but the data of the MOS in and around Zab River Basin (except the ones in Gaziantep and Diyarbakır), were investigated as well. The long-term annual average precipitation in the basin was calculated as 647,8 mm. The average precipitation within Turkish borders of the basin varies between 390-801 mm (minimum 390, average 647, maximum 801 mm). The annual average temperature in the basin is 8°C. The reservoir area and the influence factors of precipitation, temperature and evaporation in the basin were calculated according to these maps. The annual average evaporation in Zab Basin is 646,3 mm (minimum 0,019 and maximum 1439,85 mm). In order to

[6]MTA, Digital Geology Maps. General Directorate of Mineral Research and Exploration, http://www.mta.gov.tr, 2011.
[7]ESRI, Implementing Inverse Distance Weighted (IDW), http://webhelp.esri.com/, 19.06.2011.



a) Precipitation distribution (mm) b) Temperature distribution (°C)

Fig. 5: Annual average precipitation (mm) and temperature (°C) distributions in Zab Basin according to long-term data [12]

Table 2: Estimated maximum flood discharges at different return periods

Return Period	EIE-2620	EIE-2621	EIE-2622[a]	EIE-2627	EIE-2630	EIE-2636	EIE-2639	DSI-2630	DSI-2631	DSI-2634	DSI-2636	DSI-2637	DSI-2643[c]	DSI-2656[b]
2	262,4	52,2	104,71	483,34	181,00	47,59	35,14	19,12	2,27	365,56	406,64	440,19	144,27	20,13
5	402,6	75,4	177,63	731,86	297,49	75,84	50,42	26,75	3,97	657,30	715,52	674,43	262,74	42,55
10	517,2	92,7	237,36	932,47	393,93	101,02	62,43	33,27	5,23	936,97	972,65	847,17	357,60	62,51
25	687,5	116,4	324,91	1227,05	537,47	141,58	79,69	43,48	6,93	1414,46	1353,32	1079,61	491,93	93,06
50	834,3	135,4	399,28	1478,53	661,28	179,18	94,17	52,69	8,25	1880,46	1679,14	1263,04	602,05	119,72
100	999,4	155,6	481,65	1759,08	800,32	224,09	110,09	63,44	9,62	2460,12	2041,83	1454,79	720,14	149,69
200	1191,8	178,0	575,72	2083,72	961,93	279,40	128,27	76,31	11,02	3203,85	2457,09	1661,01	848,23	183,59
1000	1462,0	218,3	716,03	2555,16	1188,56	342,25	156,46	91,84	13,98	3867,20	3062,14	2063,74	1070,70	244,69

check the accuracy of estimations, one meteorological gauging station (17285-Hakkari Meteorological Station) with proper spatial distribution was selected as the control station and removed and then rainfall, temperature and evaporation distributions were recalculated using IDW interpolation method. Surface values, which were calculated by using the previously converted data for normal distribution, instead of real values of control stations, were compared with calculated values and accuracy of estimations was analysed by calculating root mean square errors (RMSE) in this scope [12].

The precipitation generally takes place between October and May in the whole Zab River Basin. Between March and June, melted snow joins rainfalls and cause big floods. Maximum peak discharges are observed in springtime. The precipitation runoff during other times of the year are considerably low and do not bring flood risks. Estimated maximum flood discharges in Şemdinli River Basin according to return periods of EIE 2636-2639 numbered stream gaging stations (SGS) is given in Table 2.

In Zab Basin, estimated flood discharges according to 2, 5, 10, 25, 50, 100, 200 and 1000-year maximum flood return periods were calculated utilizing the data recorded by 14 SGS of DSI and EIE. Potential maximum flow values at these return periods are of great significance for providing dam safety during the preparation of dam spillway projects. In the study, main river basin and other subbasin maximum flood peak discharges were multiplied with a particular coefficient to calculate the spillway project discharges. Drainage area of the Dam 12, which was planned on Şemdinli River for this study, was found as 1123,61 km^2 and the average of transported dam axes discharges were calculated as 24,4 m^3/s. According to these calculations, annual average water potential was found as $0,77x10^9$ m^3.

D. Determination of appropriate dam location and examination of hydropower energy production

In this study, an appropriate dam location at an elevation below 1000 m and between the coordinates of 44°19'15,355" E, 37°11'13,409" N was determined on /25

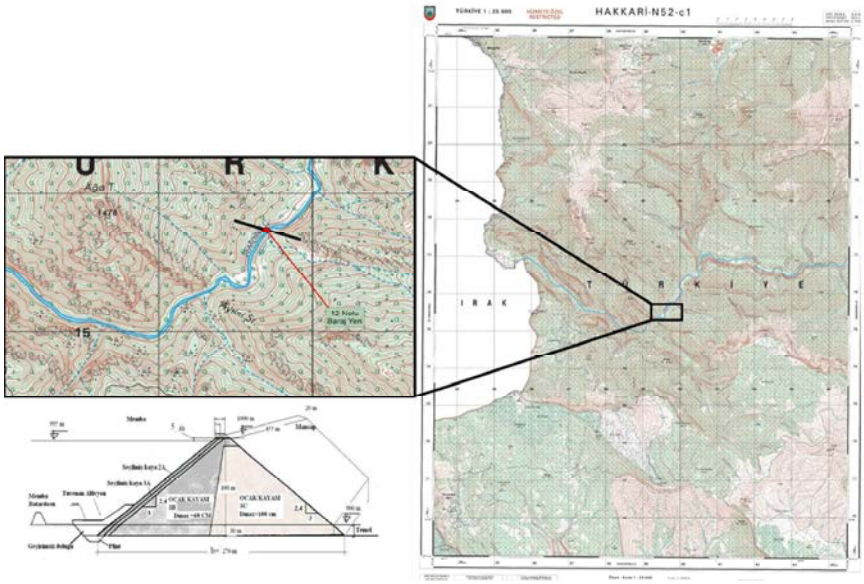


Fig. 6: Location of Dam 12 on 1/25 000 scale (Hakkari N52-c1) map.

Table 3: Location and characteristics of Dam12.

Dam Name (No)	Related Basemap	Site Of Dam 12	Coordinates of the Dam	Estimated Crest Elevation (m)	River Thalweg Elevation (m)	Approximate Dam Height (m)	Crest Length (m)	Precipitation Area (Drainage Area) km^2
Dam 12	1/25000 Hakkari N52-c1	1,70 km downstream of Beyazsu and Yeşil Creeks	44°19'15,355"E-37°11'13,409" N	Dam crest: 1000 Max. reservoir elevation :995 m	900	From thalweg, 100 m From foundation 130 m, Upstream height 95 m	Crest lenght: 455 m Crest widht: 20 m Ground width 270 m	1123,61
Dam Location	The dam is located in Hakkari map, N52-c1 map. It is on 1,70 km downstream of Beyazsu ve Yeşil Creeks junction. Planned dam elevation is 900 m.							
Geology of Dam and Reservoir Locations	Şemdinli River dam site is located in a narrow valley and on Neritic limestone area. It is considered that water loss from the dam reservoir will be high. Turbine location is on the downstream of the dam.							
Dam Type	Due to valley form, dam type may also be determined as either arch or arch gravity dam. However, at this location, concrete face rock fill dam construction is suggested.							
Material	Necessary construction material can be provided from the neighbouring environment.							
Turbine Location	The dam site is located on Neritic limestone formations. The turbine location will be on this mentioned geological formation. The elevation of the turbine is 900 m.							
Hydrology	Previously, EIE-2629 numbered SGS was established on Kayalar Creek of Şemdinli River, but it was closed. Instead, EIE-2636 numbered SGS was established. However, it was, too, was replaced with EIE-2639 numbered SGS 4 years later, at the end of 2005, on Şemdinli River - Olgunlar. The average, maximum and minimum discharge values of Şemdinli River between 2001-2005 were found as 10,7, 152 and 1,75 m3/s, respectively. When examined, the correlation between EIE-2639 and EIE-2627 is considered good (r=0,975657). For the flow values of planned Dam 12, EIE-2627 MOS flow values are transported to the determined dam axis by area-ratio method. The coefficients between the two stations are K=1,0127; ϕ=n=0,7478. The minimum, average and maximum average discharges at the dam locations are respectively 17,7 m^3/s, 24,4 m^3/s and 35,10 m^3/s. Besides, Flow Duration Curve (FDC) is also given in the figure. For the construction of the diversion tunnel of dam 12, 25-year return period discharge is taken as 2x205,9=411,8 m^3/s. Spillway project discharge is taken as 4x378,7= 1515,4 m^3/s. Volume of the reservoir at the elevation of 995 m is 104,794x10^6 m^3, while the dam reservoir area is 3,53x10^6 m^2.							

Table 4: Project characteristics of dam 12.

SIMAHPP Results ...

Project(s) Characteristics :

Project Characteristics	baraj12
Net Head (m)	95.000
Design Flow (m3/s)	45.940
Design Time of Operation (%)	21
Power Production(kW)	42813.783
Energy Production (kWh/Year)	78760235.207
Energy Revenue (EUR/Year)	8225403.924
Emission Reduction (tCo2/Year)-Coal	47256.141
Emission Reduction (tCo2/Year)-Gas	15752.047
Emission Reduction (tCo2/Year)-fuel	25203.275
Carbon Market (EUR/Year)-Average of A	294038.210
Investment Cost (EUR)	43482298.797
Investment Cost/kW (EUR/kW)	1015.614
Investment Cost/kWh (EUR/kWh)	0.552
O&M Cost (EUR/Year)	434822.988
NVP: Net Present Value (EUR)	183533046.000
IRR: Internal Rate of Return (%)	18
Payback Period (Years)	5.581
Amortization Plan (Yearly)	1548520.000
Suggested Turbine Type	Pelton/Turgo
Exchange Rate (09.06.2011), 1 EUR =	1.000000 EUR

Dam 12 on Şemdinli River:
Design discharge: 45,94 m^3/s
Installed power: 42,813 MW
Annual energy production: 78,76 GWh/Yıl,
Annual profit of the energy: 11,674x10^6 USD
Investment cost: 61,716x10^6 USD
Investment cost per kW: 1441,516 USD
Amortisation time: 5,581 yrs

000 scale map of Şemdinli River (Hakkari N52-c1). The appropriate location was designated at an elevation of 900 m comprising a considerably narrow valley (Figure 6). The general characteristics of Dam 12 are given in Table 3.

Dam height and transported discharge data were used for the calculations of hydropower energy calculations of Dam 12 in Simahpp software. The project characteristics of Dam 12 are given in Table 4.

RESULTS AND DISCUSSION

In this study, hydropower energy potential of Şemdinli River Basin, one of the unexploited rivers in Turkey, was investigated. Accordingly, a reservoir dam was planned on the river. Basin characteristics and geological formation of the area was determined using digital maps and satellite images. Total costs and benefits of Dam 12 were calculated in Simahpp program. According to these calculations, total dam costs were found as $61{,}716 \times 10^6$ USD and total installed power was calculated as 42,8 MW. Annual hydropower energy production was found as 78,76 GWh. It is possible to realize similar projects in other countries so that unexploited rivers will be kept under control and used to produce environmentally friendly energy.

However, it is of significance to notify that the calculated values for costs and energy production are only estimations. The actual values may vary depending on the precipitation and similar factors. Correspondingly, the mentioned values should not be totally adopted. Still, the current dependence on foreign energy resources of the country makes it necessary to develop methodologies to investigate the hydropower potential in Turkey. Regarding the limited number of the office and field researches within the study area, especially due to security restrictions, GIS and RS applications become even more important to carry similar projects on hydropower investigations. The scope and the method of this study is therefore highly believed to be a pioneer to encourage similar projects and enhance the opportunities to benefit from unexploited water resources in the country.

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REFERENCES

1. IEA, 2010. Turkey 2009 Review. Energy Policy of IEA Countries, Publication of International Energy Agency (IEA), www.iea.org/about/copyright.asp, pp: 108.
2. Bakış, R., S. Göncü and E. Gümüşlüoğlu, 2012. Investigation of Hydropower Energy Potential of Zab River Basin (in Turkish). Scientific Research Project (Project No: AÜBAP 090234, Proje Coordinator: R. Bakış), Eskişehir.
3. Erkan, C., M. Mucuk and D. Uysal, 2010. The Impact of Energy Consumption On Exports: The Turkish Case. Asian Journal of Business Management, 2(1): 17-23.
4. Yüksel, I., 2008. Hydropower In Turkey For A Clean And Sustainable Energy Future. Renewable and Sustainable Energy Reviews, 12: 1622-1640.
5. Altınbilek, D., 2000. Hydroelectric Development Plans in Turkey. State Hydraulic Works (DSI), http:// www.dsi.gov.tr, 2000.
6. Ersdac, 2003. ASTER Reference Guide (Version 1.0), Japan.
7. Anonymous, 1992. Grid Commands References. Arc/Info User's Guide, Environmental Systems Research Institute (ESRI), Inc., USA.
8. Anonymous, 1992. Cell-Based Modeling With Grid. Arc/Info User's Guide, Environmental Systems Research Institute (ESRI), Inc., USA.
9. Elshorbagy, A.A., U.S. Panu and S.P. Simonovic, 2000. Group-Based Estimation Of Missing Hydrological Data: I. Approach And General Methodology. Hydrological Sciences-Journal-des Sciences Hydrologiques, 45(6): 849-866.
10. Asquith, W.H., M.C. Roussel and J. Vrabel, 2006. State Wide Analysis Of The Drainage-Area Ratio Method For 34 Streamflow Percentile Ranges In Texas. U.S. Geological Survey Scientific Investigations Report 2006-5286, pp: 34, 1 appendix.
11. Emerson, D.G., A.V. Vecchia and A.L. Dahl, 2005. Evaluation Of Drainage-Area Ratio Method Used To Estimate Stream Flow For The Red River Of The North Basin, North Dakota And Minnesota. USGS Scientific Investigations Report 2005-5017, U.S. Geological Survey, Reston, Virginia.
12. Çabuk, S.N., R. Bakış, S. Göncü, E. Gümüşlüoğlu and A. Çabuk, 2013. Investigation of Hydropower Energy Potential of The Zab River Basin Using Geographical Information Systems and Remote Sensing Methods. Journal of Renewable and Sustainable Energy, 5: 063131-1.