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Research paper

Assessment power generation potential of small hydropower plants using GIS software

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ABSTRACT

The hydropower stations are one of the most significant sources of renewable energy. In this research, the identification of suitable locations for hydroelectric power stations installation concerning electricity generation capacity has been investigated. Small-scale hydropower can potentially be quite important in the future of the renewable energy system that may have a limited regulatory capacity in energy storage and transmission capacity. The objective of this study, to develop methods that assess the power production potential associated with suitable location schemes for a system of small-scale hydropower stations. this manuscript that regards the use of Geographical Information Systems(GIS) to assess the power generation of alternative development plans for small-scale hydropower. In this study, four plans are proposed that examining each of the plans from the aspect of their electricity generation potential and cost. A plan is selected that gives better results in terms of cost and energy production. After selecting the best plan, locations that have the potential to installation hydroelectric power stations identified. the results are obtained from the GIS software and Digital Elevation Model (DEM) map showed that decreasing watershed elevation and going along the river and outlet of the watershed, the cumulative discharge increases, thus increasing hydroelectric power generation capacity.

1. Introduction

Hydroelectric power has been used in the world for many years and is one of the popular and largest sources of renewable energy (Ajanovic and Haas, 2019; Cao et al., 2019a,b; Fei et al., 2019). The method of using hydroelectric energy is mostly related to the energy stored behind the dams. However, the lakes created behind the dams often cause climate change and sometimes social impacts for the residents of the adjacent areas (Popa et al., 2020), but there is another method for using this energy, that is the use of small hydroelectric power stations, which is used for energy generation by river flow (Mayeda and Boyd, 2020; Hoes et al., 2017b). Small hydroelectric power stations are major global electricity generation potential with few environmental problems (Khodaei et al., 2018; Liu et al., 2017a; Manafi et al., 2013). These hydroelectric power stations are located in the river flow path that flowing from the mountainous heights to the outlet of the watershed, which generates electricity by restraining the flow of the rivers (Ghorbani et al., 2020). Because small hydroelectric power stations supply electricity from natural sources, they do not cause any pollution or damage to the environment (Craig et al., 2019). In mountainous areas where the slopes of the rivers are high, in places that are topographically and geologically suitable, a diversion dam is constructed to divert water from the natural path into the water transfer system. The channel connects to forebay after a long distance in an appropriate position, at this location, the penstock, which is a tube, delivers water to the turbine blades and the pressure water rotate the turbine. As a result, hydro energy becomes mechanical energy, finally, it is redirected to the distribution network (Ghorbani et al., 2019). Fig. 1 shows a schematic of the hydropower plant.

Various researches have been conducted to assess the hydroelectric power potential of rivers, which most of them focus on traditional methods and included field inspection. Usually, high potential locations for hydroelectric power stations are placed in distant mountain areas and impassable routes, so evaluation of these locations through traditional methods in addition to the time and the cost is difficult to access these areas (Aghajani and Ghadimi, 2018).

There are areas near the river that have more potential than other parts of the watershed, which increase electricity generation capacity by developing electricity projects. In this area finding, high-potential locations for small hydropower plants are

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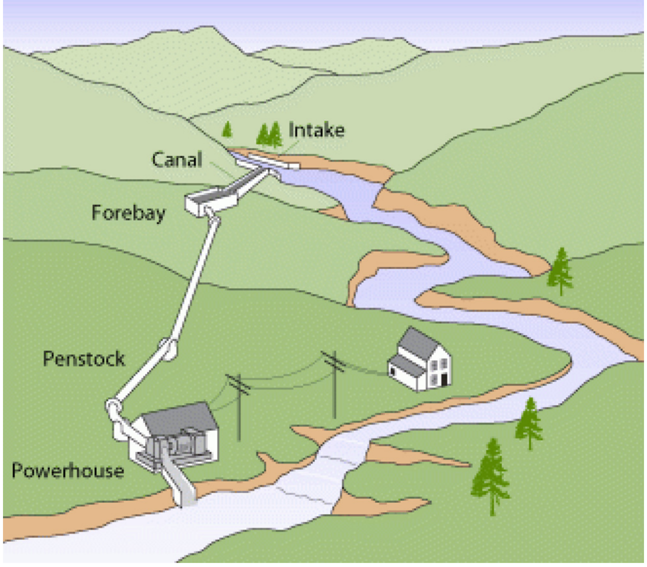


Fig. 1. Schematic of the hydropower plant (Microhydropower Systems, 0000).

necessary, but it is difficult to do with traditional methods. Therefore, some locations with higher potential may be overlooked and the error rate in finding suitable locations may increase. However, integrating Geographic Information System (GIS) and Remote Sensing (RS) may provide a convenient way to evaluate electricity (Hoes et al., 2017b,a).

Nowadays, advanced software such as remote sensing and geographic information systems are being utilized to find these areas, which can greatly overcome the limitation of the traditional methods. Latterly, GIS and RS-based methods have become more popular because of their ease of use, cost and time efficiency (Yu and Ghadimi, 2019). GIS-based tools and remote sensing are powerful tools that enable the recording, storage, and analysis of various types of spatial and geographic data in different types of the coordinate system, which can use to select suitable locations for small hydroelectric power plants, taking into account engineering, economic and environmental criteria (Liu et al., 2017b).

Based on different criteria such as hydrological, geographical, and environmental conditions in the construction of hydroelectric power plants, special analysis is very important for this type of hydroelectric power plant so that it can be defined as a process that assessment suitable locations and select alternatives, which have been fewer obstacles and more profitability for hydroelectric power plant construction projects (Gollou and Ghadimi, 2017). Given that spatial analysis is performed at an early stage, it is reasonable that used geographical and hydrological information to reduce time and cost (Hoes et al., 2017b; Mirzapour et al., 2019). With the increasing, the progress of data processing in GIS computing and access to satellite image information, the development of some methods for extracting land features, such as drainage network status, area length and slope have been made possible using the DEM model map (Firouz et al., 2016).

Recently, various studies have been conducted using GIS software to identify the power potential of hydroelectric power stations.

For example, the research of Hamian et al. (2018) that research about the use of GIS in the evaluation of water resources for the construction of hydropower stations and the result showed that 62% of potential locations as micropower stations had potential capacity 5 kW–100 kW and 38% had potential capacity less than 5 kW.

Gollou and Ghadimi (2017) analyzed the application of the Geographic Information System to estimate the hydroelectric power generation capacity in Turkey's Bilirik watershed and concluded that the flows through this river have good potential for installing small hydroelectric power plants.

Leng et al. (2018) studied the effect of river flow on power generation in the Upper Tana River watershed, Kenya. They found that decreasing rainfall and increasing temperature led to a decrease in the mass flow of the Masinza Dam, thereby reducing the electricity produced that indicated a significant relationship between power generation at power plants and dam flow, which in turn is related to rainfall and can be used to plan power supply.

Akbary et al. (2019) worked on the impact of environmental methods on the rate of change of flow and energy generation at the hydroelectric power station and concluded that 10% and 15% daily discharge had the highest power generation and 75% discharge had the lowest energy production.

Ebrahimian et al. (2018) investigated the impact of small cascaded hydropower plants (SCHPs) on river discharge in a watershed of southern China. The findings of this study indicated that SCHPs decreased the yearly mean discharge of the river and also had a greater impact on the river discharge changes more than climate change and other human activities. Another result was SCHP's impact on the discharge of the rivers that was different from the effect of large reservoir dams and delayed (adjustable) check dam and drought in discharge rivers.

Wegner et al. (2020) studied the potential of hydropower to environmental variables and water availability in three Parana watersheds and the results showed that of the 3899 sites investigated, 3477 sites had sufficient potential for the construction of the river water power plants with a generation capacity of about 3 MW and 48 capacity sites for small hydroelectric power station with production potential between 3 MW and 30 MW.

The objective of this study is to assess alternative development plans for small-scale hydropower systems. In this research, one of the variables considered to the assessment of development plans is power production capacity. In this study, the method used identifies suitable locations in terms of power generation capacity along the river with the help of spatial data techniques. The criteria for the development plans are stream gradient and discharge. Suitable locations to installation hydroelectric power plants of each of the proposed plans are selected based on these two criteria. the method improves efficiency power production capacity by eliminating inferior plans and identifying acceptable plans and makes installation operations cost-effective. Several studies have been conducted around the world which includes extensive investment and tiresome fieldwork. Geographic Information Systems (GIS) utilized to assess the power production capacity of alternative development for small-scale hydropower. The use of Geographic Information System (GIS) tools and due to easier access to the area, quickly evaluates the power plant projects and improves the identification of suitable places to install the plant compared to other methods to develop a cost-effective and efficient method for assessing the water potential of small hydroelectric power stations and identify suitable locations along the river used of several suggested plans and GIS techniques. Using the plans in conjunction with the GIS technique, in addition to helping identify potential locations, can reduce the time, cost, and error in identifying these locations. This method helps energy decision-makers assess the potential of rivers and choose the best alternative for installing blue power plants.

2. Material and method

2.1. Study area

The study area is Khyav Chai watershed with an approximate area of 13 000 ha, located on the western margin of Sabalan Mountain, south of Meshkin Shahr in Ardebil Province, Iran.

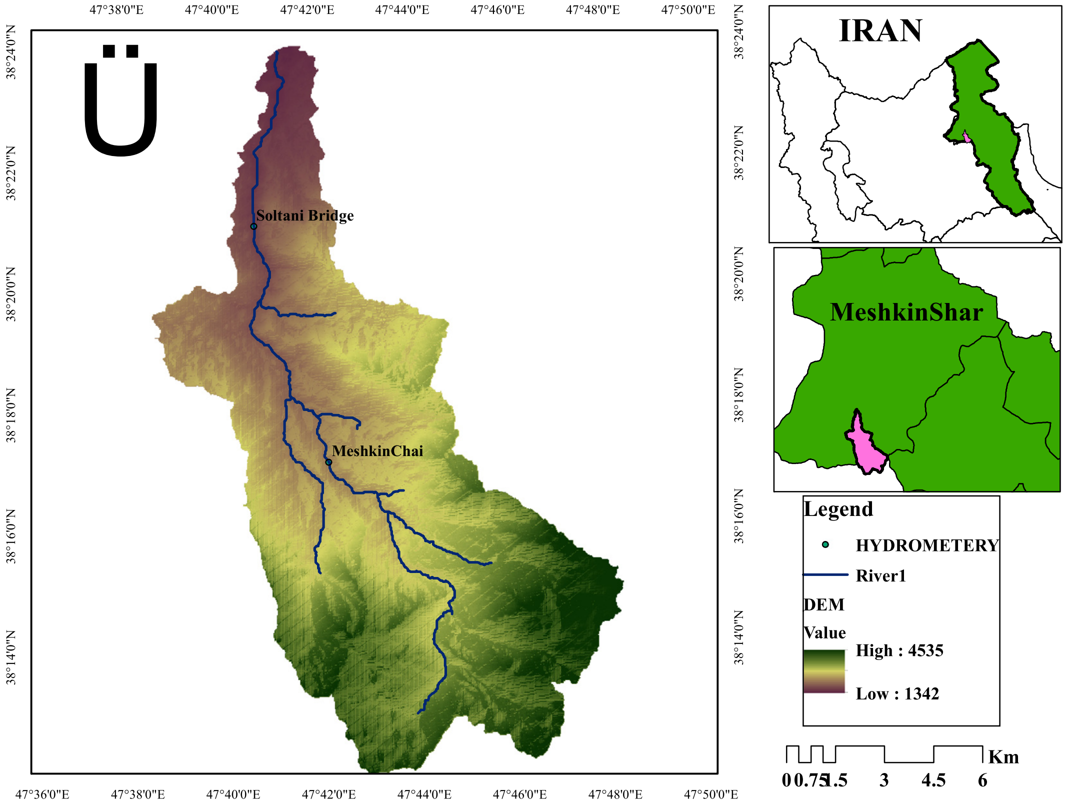


Fig. 2. Location Khyav Chai watershed.

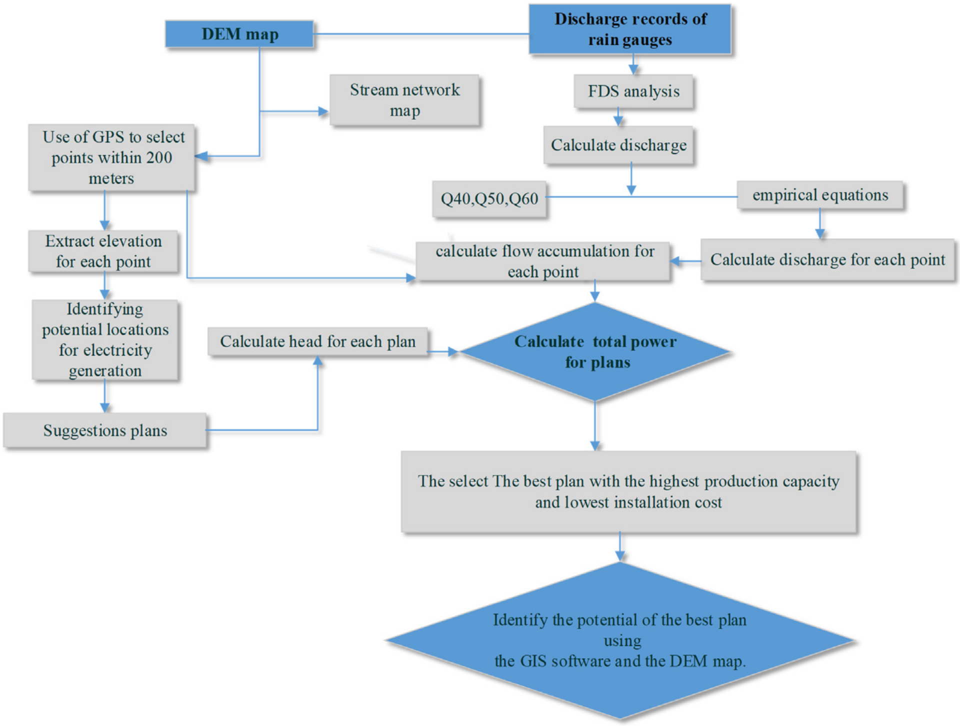


Fig. 3. Steps from the methodological framework.

Khyav Chai watershed, in terms of political divisions, it belonged to the Caspian watershed with nine sub-basins in geographical range 47°67′90″ to 47°74′40″ Eastern longitude and 38°21′50″ to 38°39′80″ northern latitude. The maximum elevation of 4335 km is located at the southern elevation of the watershed and the minimum elevation of 1375 m that is located at the outlet

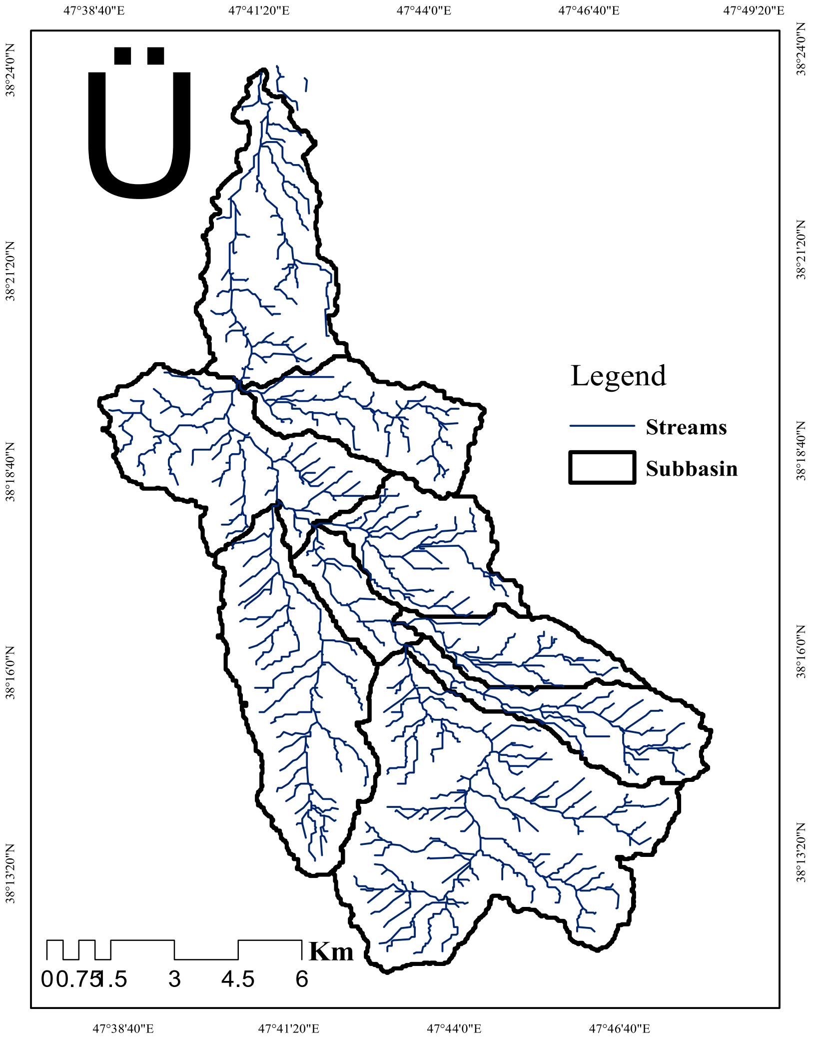


Fig. 4. Streams networks of KhyavChai watershed.

of the watershed. Khyav Chai is one of the main rivers of the area, which is one of the rivers with a large flood history, but with proper management and the use of delay dams, the water potential of this area can be utilized as suitable locations for hydropower generation. Fig. 2 shows the location for the KhyavChai watershed.

Since Meshkin Shahr is one of the mountainous areas, the installation of equipment needs for the transmission of electricity to remote and the mountainous areas which require special equipment with high costs. Therefore, using other methods can provide electricity to remote areas, such as installing small hydroelectric power stations. Since due to the mountainous and remote areas the use of traditional methods and field surveys to identify these areas is difficult and costly, modern methods like Geographic Information System (GIS) can be used to solve this problem. To provide a suitable allocation for hydroelectric power stations installation, it is important to evaluate the characteristics of water resources such as the head and the discharge in different areas of the river. Therefore, these two issues must also be considered. Fig. 3 shows steps from the methodological framework for choosing high-potential places.

2.2. Drainage analysis

In this research, ArcMap software and powerful Arc Hydro tool have been used to model streams, to determine the main river route, and to delineate the watershed drainage network. ArcMap software can analyze different geographic conditions of river and sub-basin based on the Digital Elevation Model (DEM) map with a resolution of 30 m × 30 m. Obviously, the higher the drainage networks of the river, the lower the infiltration and thus the river flow velocity increased (Awawdeh et al., 2019). Therefore, increasing the flow velocity and discharge can increase the hydroelectric power generation capacity. Fig. 4 showed streams networks of Khyav Chai watershed.

2.3. Estimating discharge for sites without hydrometric station

2.3.1. The Drainage-to-Area Ratio (DAR) method

The Drainage-to-Area Ratio (DAR) method is used to evaluate the monthly streamflow. The advantage of this method is that it is easy to use and requires little data and does not need to be developed. This method is used to measure the streamflow in areas without hydrometric stations and to estimate flow and discharge this area used statistical data from neighboring stations (Dikbas and Yasar, 2020). The drainage-to-area ratio (DAR) method is based on the theory that the flow ratio at hydrometric stations is equal to the area drainage ratio. Since there are only two hydrometric stations in this watershed, most of the locations suggested for hydroelectric power plants have not a hydrometric station. Therefore, this method has been used to estimate the discharge

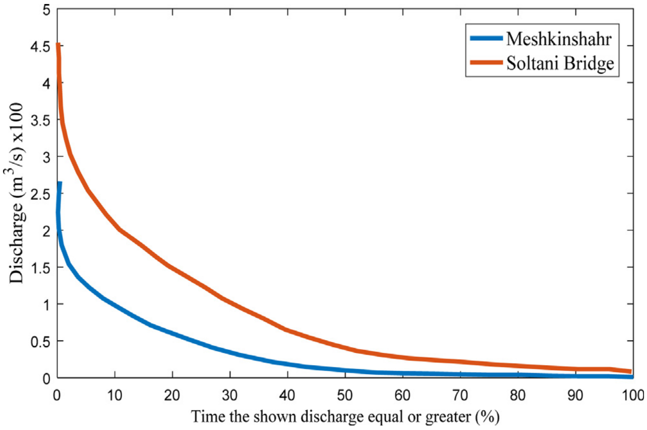


Fig. 5. Flow frequency.

value of selected areas. To determine the discharge without hydrometric stations places (Q_{xn}), the proportion of the drainage areas of without hydrometric station (A_{xn}) and the drainage areas of with hydrometric station (A_a or A_b) is used that is called the drainage area weights and is calculated using the flow value for the area with hydrometric station (Merta et al., 2019). The specific discharge is the discharge divided into separate sections in a watershed area and contributes to the discharge of each hydrometric station. Special discharge is used to calculate the discharge at different points along the river from upstream and downstream hydrometric stations. Fig. 6 shows this simulation where there is a watershed that has two hydrometric stations named "a" and "b", which the station "a" is placed at an up of the watershed, while, station "b" is placed at a down watershed. Also, an area separated from the watershed area and the value of specific discharge are "Aa", "Ab" and "Qa", "Qb", respectively. The flow along the river in upstream and downstream of station 'a' called 'x_1' and 'x_2' respectively that the area separated of 'x_1' and 'x_2' are Ax_1 and Ax_2, respectively. Also the flow alone the river in upstream and downstream of station 'b' are 'x_2' and 'x_3', respectively that the area separated of x'_3 are Ax3 (Shah et al., 2020).

To measure the discharge Upstream hydrometric station 'a', the specific discharge at hydrometric station 'a' is used and for measuring the specific discharge at 'b' (Qb–Qa)/ (Ab–Aa) is used. The flow of Qx_1 and Qx_2 is discharged without hydrometric station locations that are formulated in Eqs. (1) and (2), respectively (Okedu et al., 2020).

$$Q_{x1} = \frac{A_{x1}}{A_a} Q_a \tag{1}$$

$$Q_{x2} = Q_a + \frac{(A_{x2} - A_a)}{(A_b - A_a)} (Q_b - Q_a) \tag{2}$$

The flow Qx3 placed in downstream hydrometric station 'b' that can be estimated as follows (Kayastha et al., 2018).

$$Q_{x3} = \frac{A_{x3}}{A_b} Q_b \tag{3}$$

2.3.2. USDA-NRCS CN method

In addition to the effect of area on the volume of discharge, also runoff elevation can affect the volume of discharge. The increase in runoff can increase discharge and the stage (level water) river, which could affect the capacity of hydroelectric power stations. There are several methods to calculate runoff elevation. One of the methods of estimating runoff is the Curve Number (CN) method, which is related to the Soil Conservation Service (SCS) (Farran and Elfeki, 2020b). The evaluation depth of runoff from rainfall can be used by the following Equation

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{4}$$

where, P is the rainfall (mm), R is the depth of runoff (mm), S is the most retention value (mm) which can be estimated as follows:

$$S = \frac{25400}{CN} - 254 \tag{5}$$

where, (CN) is the value of the curve number which is the main factor in hydrology for estimating runoff. the amount of CN is estimated based on the watershed features such as type of soil area, the hydrological status of the area, land-use condition, and primary soil humidity status. The CN is calculated by reading the standard NRCS CN Table (USDA–NRCS, 2004) (Moglen et al., 2018; Farran and Elfeki, 2020a).

After determining the runoff elevation due to precipitation, the discharge can be calculated from the following equation (Lian et al., 2020)

$$Q = \frac{0.0208(A \times R)}{0.6T_c + \sqrt{T_c}} \tag{6}$$

where, A is area watershed (km^2), R is depth runoff (mm), Q is the discharge (m^3/s) and Tc is the time of concentration (h) that is the time needed for runoff to move is from the farthest hydraulic point of the watershed to the outlet.

The California equation is used to calculate the time of the concentration, which is obtained from the following formula (Azizian, 2019).

$$T_c = (0.885 \frac{L^3}{H}) \tag{7}$$

where, Tc is the time of the concentration (h), L is the length of the longest water route in the watershed (km^2) and H showed elevation difference between the lowest and highest point of the watershed (m)

2.4. Investigating the effect of discharge and river stage capacity of hydroelectric stations

The relationship between the volume of discharge in a river and stage at a point of the river is identified as the stage-discharge relationship. This relationship between river stage and discharge is termed the stage-discharge rating curve (rating curve). The discharge-stage relationship is used for the convert the continuously measured stage (level water) to the discharge estimate (Manfreda et al., 2020). This relationship is obtained from the following formula.

$$\mathrm{Q} = \mathrm{C}(\mathrm{h} - \mathrm{a})^{\propto} \tag{8}$$

where Q is the discharge, h is the stage (elevation water of river) and C, a, α are calibration coefficients. If the effective depth of flow (h–a) is equal to 1, C is equal to the discharge. an indicates the river stage at which the discharge is zero. α is the gradient of the rating curve (on logarithmic paper). (h–a) is the effective depth of flow.

It is clear that Eq. (8) is derived from Manning's equation, and is simplified the Manning equation, which frequently is utilized as the governing equation for steady uniform streamflow problems (Abbas et al., 2020; Tuozzolo et al., 2019). The Manning's equation is obtained from the following formula

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{9}$$

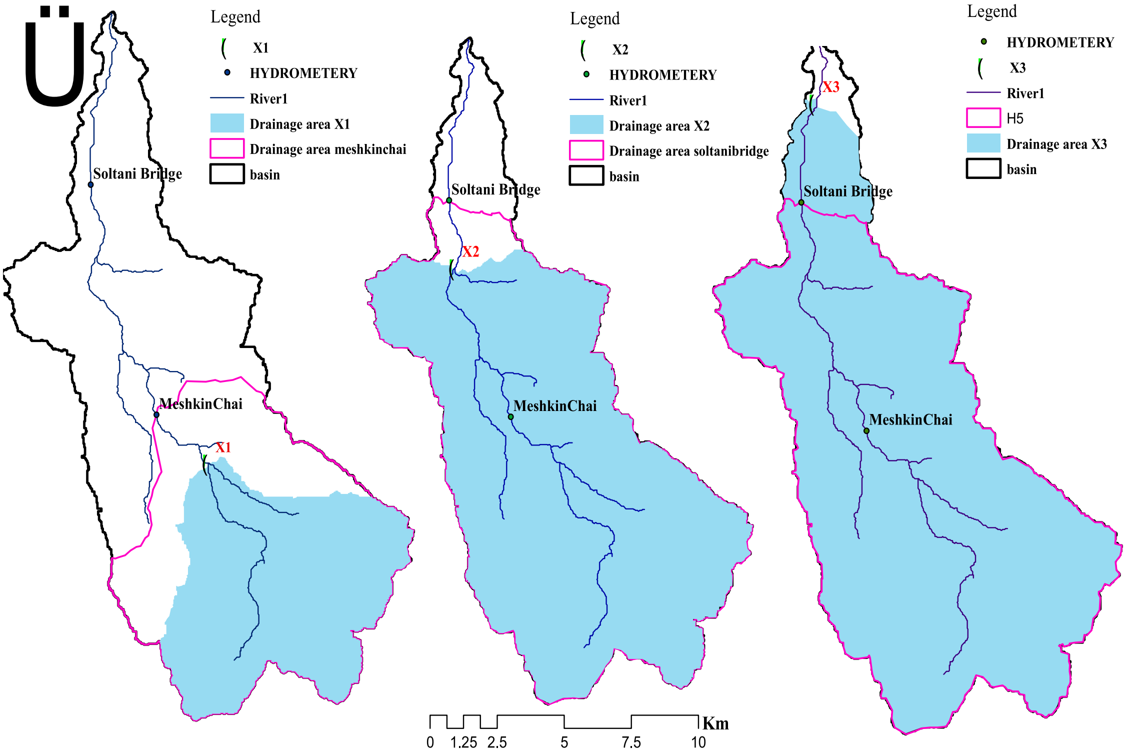


Fig. 6. Measuring relative discharge.

where n is the Manning's roughness factor, S is river slope ($\frac{\text{m}}{\text{m}}$), A is the flow Area (m^2) and R is the hydraulic radius (m).

In wide rectangular channels, the AR$^{2/3}$ conveyance function can be considered as a simpler function than water elevation. So the manning equation for a wide river is obtained from the following formula

$$Q = \frac{1}{n} B h^{\frac{5}{3}} S^{\frac{1}{2}} \tag{10}$$

Based on the explanations given above, it is clear that there is a direct nonlinear relationship between discharge and the water elevation (river stage).

$$Q \sim H^{\frac{5}{3}} \tag{11}$$

In addition to the discharge river, the river stage can also affect the production capacity of small hydropower stations. Considering the discharge equation (Kebede et al., 2020), both discharge and stage vary over time. the discharge equation is obtained from the following formula

$$Q = V \times A \tag{12}$$

where, V is the velocity of streamflow (m^2/s), A is cross-sectional area and Q is discharged (m^3/s).

Therefore, the expected value of the power can be expressed as

$$P \sim E[H(t)Q(t)] = E[Q(t)]E[H(t)] + Cov[Q(t)H(t)] \tag{13}$$

where H defined river stage (m), Q is discharged (m^3/s), E [...] denotes expected value and Cov [...] denotes the covariance.

In a wide channel, we have H ∼ Q$^{(3/5)}$, therefore, power can be represented by the following formula

$$P \sim E[Q8/5] \tag{14}$$

If for simplicity we replace 8/5 with 2, power be represented by the following formula

$$P \sim \ E[Q]2(1 + sqrt(2)[CV(Q)]) \tag{15}$$

Table 1
Locations Khayav Chai stations.

Name station	Longitude	Latitude	Altitude
Meshkin Chai	47°67′92″	38°35′02″	2845
Soltani Bridge	47°70′31″	38°28′47″	1420

where CV [...] denotes the coefficient of variation.

Since for small streams, the coefficient of variation of discharge can be quite large the covariance term could potentially at least double the estimated power potential.

2.5. Discharge calculations

Monthly discharging of hydrometric stations is obtained from the Regional Water Resources Company (RWRC) which includes forty-four years of statistical data for monthly discharging. These data are collected from two hydrometric stations called Soltani Bridge and Meshkin Chai. Table 1 illustrates the specifications of the hydrometric stations.

The Flow Duration Curves (FDCs) shows the relationship between flow frequency and amount of monthly discharge. The flow discharge data in the form of Flow Duration Curves (FDCs) are required for water resources management projects such as dams design and hydropower plants. Various factors are involved in the shape of this curve and its changes, including the climatic (the intensity of rainfall, rain duration) and physiographic parameters (area, slope).

In this study, Flow Duration Curves (FDCs) used to estimate 40th, 50th, and 60th percentile discharges that are called Q40%, Q50%, and Q40% respectively. Discharge at the 40th percentile (Q40%) which showed 60% dependable flow that we can use for generating power and is equal to or greater than 60% of the time and discharge at the 60th percentile (Q60%) which is 40% dependable flow for generating power which is equal to or greater than 40% of the time. Fig. 5 shows the Flow Duration Curves (FDCs) for

Table 2
Stations percentile discharges (m^3/s).

Percentile discharge	Meshkin Chai	Soltani Bridge
Q40%	19.2	32.64
Q50%	23.45	47.25
Q60%	28.85	73.59

Soltani Bridge and Meshkin Chai stations. Table 2 illustrates the discharges Q40%, Q50%, and Q60% for the stations

2.6. Estimation of the head at a different point of the river

The hydraulic head of the stream and discharge flow are needed to supply hydroelectric power that is obtained at each point of the river using the Digital Elevation Model (DEM) map. The most important factor for the hydraulic heads is the topography of watershed and the position of the intake and the turbine. The hydraulic head is the height difference between the two points in the up and down of the river, also the vertical height difference between the intake and the turbine is called the head. Based on the Digital Elevation Model (DEM) map, wherever the height difference between the two points is high (the slope of the area is high), the amount of head hydraulic is high, therefore according to Bernoulli's formula, potential energy is converted into kinetic energy and this converted into kinetic energy Moving downstream of the turbine increases power output (Zhou et al., 2020).

Points are recorded along the river using GPS at a distance of 200 m. These points were imported into the GIS environment using the Map Source software to produce the point layer. The height of each point was obtained using a Digital Elevation Model (DEM) and a spatial analysis tool of ArcGIS. These data are used to compute the height difference the intake and the turbine for all proposed places.

2.7. Developing plans

One aspect of assessing alternative development plans in terms of their production capacity is the use of methods that are to more accurately identify potential locations for small hydropower plants. To make a more accurate selection of locations with high energy production potential, several suggested plans are presented. The "plan" shows the number of hydroelectric power stations located along the main river. In this study, four plans utilized to identify potential power locations to installation small hydropower plants. All four proposed plans with different heads relative to each other are located in the width of the river. The position of each plan varies with the position of the other plans based on their location the river, so their heads are different. Based on the width of the river, which is calculated using the Chang formula (Chang, 1980), the mean width of the river approximately 816 m, therefore, each plans are located at a distance of almost 200 m from each other.

$$W = 4.17[\frac{S}{\sqrt{D50}} - \frac{0.00238}{Q^{0.251}}]^{0.5} \times Q^{0.5}$$

where, W is width of the river, Q is discharge (m^3/s), S is slope river, and D_{50} is the average size of riverbed particles.t

The best method to determine the head is to use the slope of each point of the river, which can be obtained from the following formula (Thin et al., 2020).

$$H = \tan(\alpha) \times L \tag{16}$$

where, H shows head (m), α is river slope in degrees and L is the average length of the diversion dam (m). to obtain the average length of the diversion dam, studies conducted in the United States (Kumar et al., 2017) are used, which in this study, considering the mountainous conditions of the region, the average length of the diversion dam is considered to be 1500 m.

Based on this equation, it can be concluded that the steeper the slope, the elevation the head increase, and increasing the power production capacity of hydropower station. Therefore, the plan that has a higher head than the other plans, it has more capacity in production power. In this study, the position of the plans across the river is such that head plan D is higher than head plan C, head plan C is higher than head plan B, and head plan B is higher than head plan A. Therefore, plan D has a higher power generation capacity than other plans because has higher head.

The small hydropower stations of each of these plans are installed along the main river. To choose the proper place for the installation of hydropower plants, two criteria of river slope and river discharge are considered, and only the areas where yearly average discharge is more or equal to 0.3 cubic meters and the areas their slope is more or equal 60% as a place suitable for hydroelectric power plants are selected. According to Fig. 7 that show the area under study slope map.

The relationship between discharge and the stream slope can also be obtained from the Manning equation mentioned below (Welahettige et al., 2019).

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{17}$$

$$Q \sim S^{\frac{1}{2}} \tag{18}$$

Often headwater streams are steeper than major rivers on flood plains, therefore, the discharge generally decreases with slope. As a result, as the slope of the river decreases, the river's discharge increases, especially in down streams, so the power generation capacity increases in hydropower stations of these areas. Based on the Eqs. (17) and (18) discharge and slope criteria can impact on power generation potential of hydropower stations in each of the proposed plans.

Fig. 8 shows a schematic form of plans.

2.8. Hydropower potential

When water flows through the turbine, the turbine rotates and the generator connected to the turbine generates energy. In the process, the kinetic energy of the moving water is converted into energy (Tapia et al., 2020). This energy produced by the turbine has a fast flow velocity of water and specific gravity and weight per unit volume and hydraulic head. The power produced has a direct relationship with flow velocity and head, which increases power produced with increasing flow velocity and discharge (Tapia et al., 2020). The power output of the hydropower plants depends on the amount of discharge and head, which was discussed in the previous sections on how to calculate the amount of discharge and head. The measured value of power accessible from each location that can be calculated by the following Equation (Chuenchum et al., 2020).

$$p = \eta \rho g H Q \tag{19}$$

where, P is hydropower produced in watts and η is the turbine and generator efficiency that is between 1 to 100 in percentage and ρ is the density of water that is 1 kg/L and Acceleration due to gravity is 9.81 m/s^2 and Q *is* Discharge in m^3/s and H is the hydraulic head that is difference between the upstream water level (before the penstock) and the water level downstream of the draft tube.

Eq. (19) is used to measure the power of P40, P50, and P60 for Hydroelectric power stations along the rivers that have been computed for all four suggested plans. The different plan has

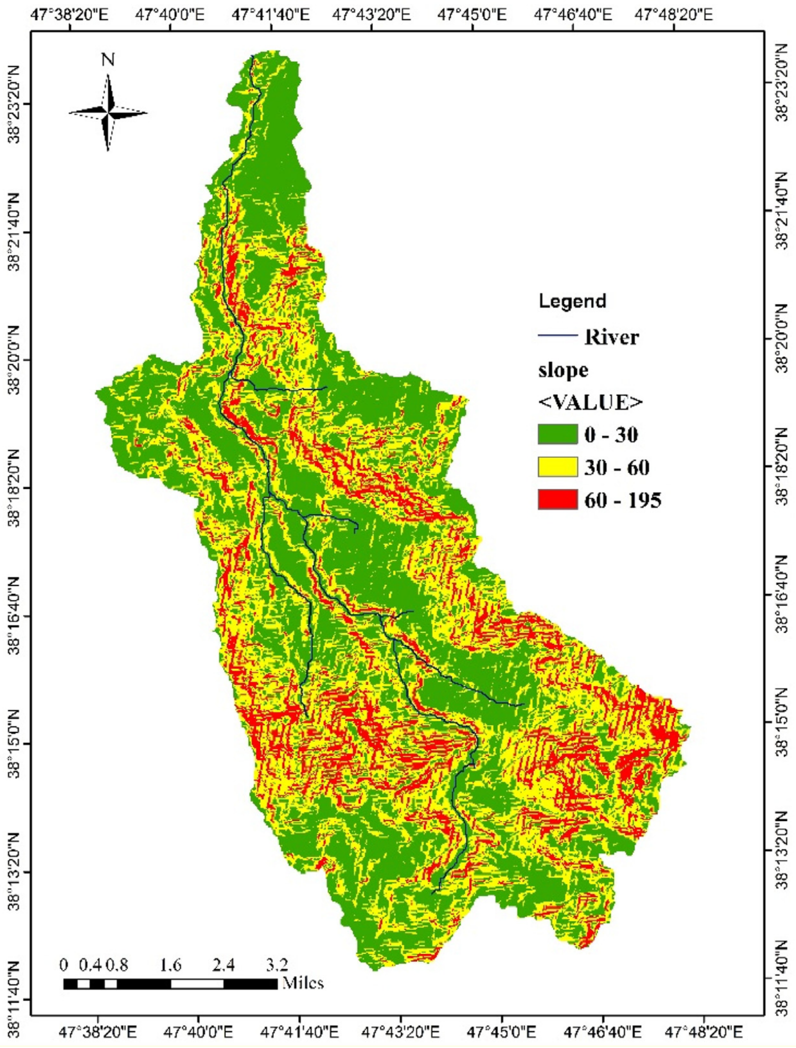


Fig. 7. Slope map of the area under study.

Table 3
Power generation classified in megawatts.

Class	Power (MW)
A	11–13
B	8–10
C	4–7
D	0–3

Table 4
The value of the power produced in each of the suggestion plans.

Plan	Power generation (MW)	Number stations
A	325.843	182
B	305.352	179
C	319.127	180
D	330.810	171

different production potential along the river, so according to the capacity of each hydroelectric power station, the generation capacity is classified in the region. Each of the plans has different potentials in production power, so to identify the capacity of each of the suggested locations, Hydroelectric power station is classified according to their generation capacity. Table 3 presents the different types of hydropower plants according to their production capacity.

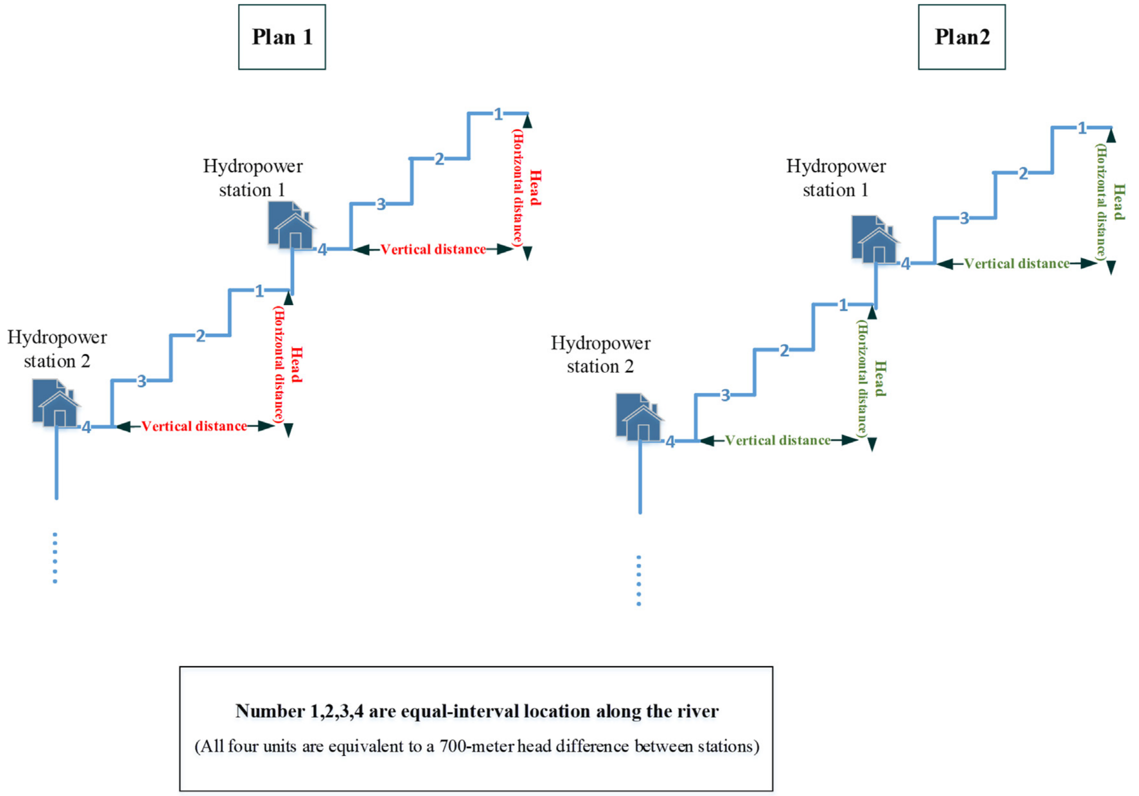
3. Results

3.1. Choose the most appropriate plan

The capacity of Power (MW) of the Khyav Chai river is computed for all four suggested plans for Q40, Q50, and Q60. guidelines issued by the Ministry of Electricity Development, Nepal (Koirala et al., 2020; Samboko et al., 2020) use 40% of reliable flow (Q60%) to estimate power production, but at this study, the result of 60% of reliable flow (Q40%) was used for showing the most conservative evaluation. Based on Table 1, the flow amount in Q40%, although lower than those in Q50% and Q60%, but is relatively stable throughout the year. Therefore, in this study used of this discharge. Table 4 shows the calculated power values for all four plans using discharge 40%.

The results of Table 4 show that among four plans, the fourth plan with the capacity power of 330.810 MW for 171 stations has the most power production.

The results obtained from the suggested plans can be used by the managers to identify energy potential locations and helps them to choose suggested plans that had the lowest electricity demand with the least capital. For example, suppose demand is 150MW, each of the four plans to supply this demand represents a different number of hydroelectric power stations. Because the



Number 1,2,3,4 are equal-interval location along the river

(All four units are equivalent to a 700-meter head difference between stations)

Fig. 8. Impact of hydropower plant placement on power potential.

Table 5
The number of stations required to supply the 150 MW demand in each plan.

Stations sorted for the wanted power	Cumulative power generation plans (MW)			
Number of stations	Plan (A)	Plan (B)	Plan (C)	Plan (D)
1	11.123	10.048	11.621	10.826
2	21.312	20.94	21.721	21.806
3	31.482	31.43	31.821	32.786
4	41.648	41.92	41.921	43.766
5	50.886	51.42	51.02	53.945
6	60.286	60.42	60.12	64.126
7	69.686	69.92	69.221	74.306
8	79.086	79.42	77.321	83.486
9	87.286	87.42	85.221	92.586
10	95.586	95.75	93.121	100.686
11	103.786	104.02	101.021	108.786
12	111.386	111.82	108.921	117.886
13	118.986	129.62	115.721	124.086
14	126.586	127.42	122.521	132.286
15	131.586	135.32	129.321	141.486
16	136.786	140.42	137/121	**150.98**
17	141.986	145.51	141.921	157.985
18	146.086	**150.62**	144.721	161.784
19	**150.186**	155.72	146.213	167.181
20	154.286	160.62	**150.932**	171.184
21	157.486	165.52	153.264	175.784
22	160.686	169.72	157.021	179.384
23	163.886	173.92	161.045	183.984
24	169.086	177.32	163.842	186.584
25	171.286	179.62	165.214	186.686
26	173.386	181.92	166.524	191.782
27	175.486	183.52	168.263	193.882
28	176.986	185.12	170.063	194.282
29	178.486	186.32	171.563	195.385
30	179.986	187.92	173.598	196.482

head of each plan different with the head of the other plan based on their location the river. Table 5 shows the number of hydropower stations needed to supply this demand.

Plan A, B, C and D supply this demand by installing 19,18, 20, and 16, respectively. Plan (D) is identified as the most economical plan by installing 16 plants and with the most power generation

Table 6
Features of hydroelectric power stations selected in plan (D).

Number stations	Attitude	Longitude	Latitude	Head hydraulic	Discharge	PowerQ40
1	2136	47°70′28″	38°29′82″	21	13.17	4.7
2	1984	47°70′26″	38°29′75″	25	18.8	6.4
3	1901	47°70′24″	38°29′64″	18	29.35	7.5
4	1835	47°70′19″	38°29′38″	25	20.51	7.8
5	1792	47°70′12″	38°29′29″	42	21.65	8.6
6	1712	47°69′73″	38°30′78″	51	22.39	9.64
7	1623	47°69′61″	38°30′55″	26	28.83	10.9
8	1574	47°69′58″	38°30′42″	18	21.62	9. 36
9	1489	47°68′44″	38°31′63″	16	24.82	9.93
10	1300	47°68′11″	38°31′45″	20	21.34	8.18
11	1218	47°68′07″	38°32′62″	24	21.67	8.62
12	1078	47°67′90″	38°32′36″	41	22.68	9.8
13	1012	47°67′79″	38°32′23″	45	32.72	11.94
14	983	47°67′50″	38°32′18″	16	33.61	12.76
15	642	47°67′42″	38°32′12″	24	31.53	11.91
16	521	47°67′32″	38°32′09″	18	33.72	12.94
						150.98

Table 7
The whole power produced using plans for 16 stations for a specific budget.

Plans	Power (MW)
A	135.452
B	131.540
C	127.168
D	139.350

about 150.98 MW. Since plan D is located at a higher head than plan C, B and A. Therefore, total fall height and discharge increased, and consequently, power production capacity this plan are greater than plan A, B and C, as the results of Table 5 show.

The exact location and characteristics of these hydropower stations are shown in Table 6.

Considering a specific budget and identifying places with high energy generation capacity for that specific budget can be the best choice of plans. An example is presented in Table 7, which shows the power generation capacity of 16 power stations in each of the four plans and assumes that the budget is dedicated to the establishment of only 16 hydroelectric power stations.

The results of Table 7 show that plan (D) is the most economical plan with the highest production 139.530 MW at the 16 installed stations and plan (C) has the least production capacity.

Therefore, it can be concluded that among the suggested plans, the plan (D) had the highest electricity generation with the lowest number of hydroelectric stations and the lowest cost for installing these stations is selected as the best plan.

3.2. Identifying the suitable site to install hydroelectric power plants in plan (D)

Based on the results, it was found that plan (D) was the best option to produce the maximum power potential among other plans. Therefore, after selecting the best plan, locations that have the potential to build hydroelectric power plants should be identified. In this study, the GIS software has been used to calculate productive power in hydropower plants along the river, which for this purpose was used of the Digital Elevation Model (DEM) to identify the physiological status of the watershed for the installation of hydropower stations. Moving to downstream of a watershed, elevation decrease whereas the discharge increases, so that, the outlet watershed has the highest discharge. Depending on the location of each point, the potential values of the power generated for each point along the river differ. Fig. 9 shows the places and calculated power potential for the plan (D) hydropower stations.

4. Discussion

To predict the fluctuations in the flow, the use of long-term data is better than short-term data because the use of short-term data increases the likelihood of error in predicting flow fluctuations and may cause errors in the calculation of power produced. In this study, two potential factors of power generation and several power stations have been used to identify potential locations of power plants. Of course, other factors, such as environmental and social factors, can also be effective in this identification. These include roads and issues related to watershed residents and residents' energy demand, settlements and land ownership, water quality, availability of other energy sources, and more. Also, other economic considerations, including the cost of installing and maintaining each power plant have been studied. In this case study, 44 years of discharge data are used. Therefore, it is advisable to use this method for other locations using data older than 40 years. The head estimation depends on the resolution of the DEM. The 30 m DEM spatial resolution is not suitable for low-slope areas, even if the river streamflow is high. But in mountainous areas with a high slope and expected to be accurate and reasonably accurate, the 30-m digital model map is expected. The failure of low-resolution DEMs to accurately compute the head in low-slope zones can limit the use of the proposed method. It is also significant to note that the algorithm selection is not based on the optimization method and the maximum potential of the calculated hydropower along the river cannot be the optimal power potential, while this study may yield better results using the optimization procedure.

5. Conclusions

Using traditional methods to calculate river water potential is time-consuming and costly and error is probable in identifying potential locations. In this paper, GIS software was used to calculate the total potential to identify suitable sites for power station costing. This method takes less time and gives better results toward the traditional techniques. Four different plans were utilized to selecting the best plan in terms of cost of installation, and the generated power and finally the best one is selected for the installation. The proposed technique based on the power sector can be used to make the best use of available resources in choosing the best locations for hydroelectric power stations with high energy capacity in a cost-effective way. Identification of suitable locations using GIS revealed that the downstream areas due to the large volume of discharge were more productive than upstream. Evaluating the potential of small hydroelectric power stations using Remote Sensing and GIS software in this study is an effective approach not found by the authors in the literature.

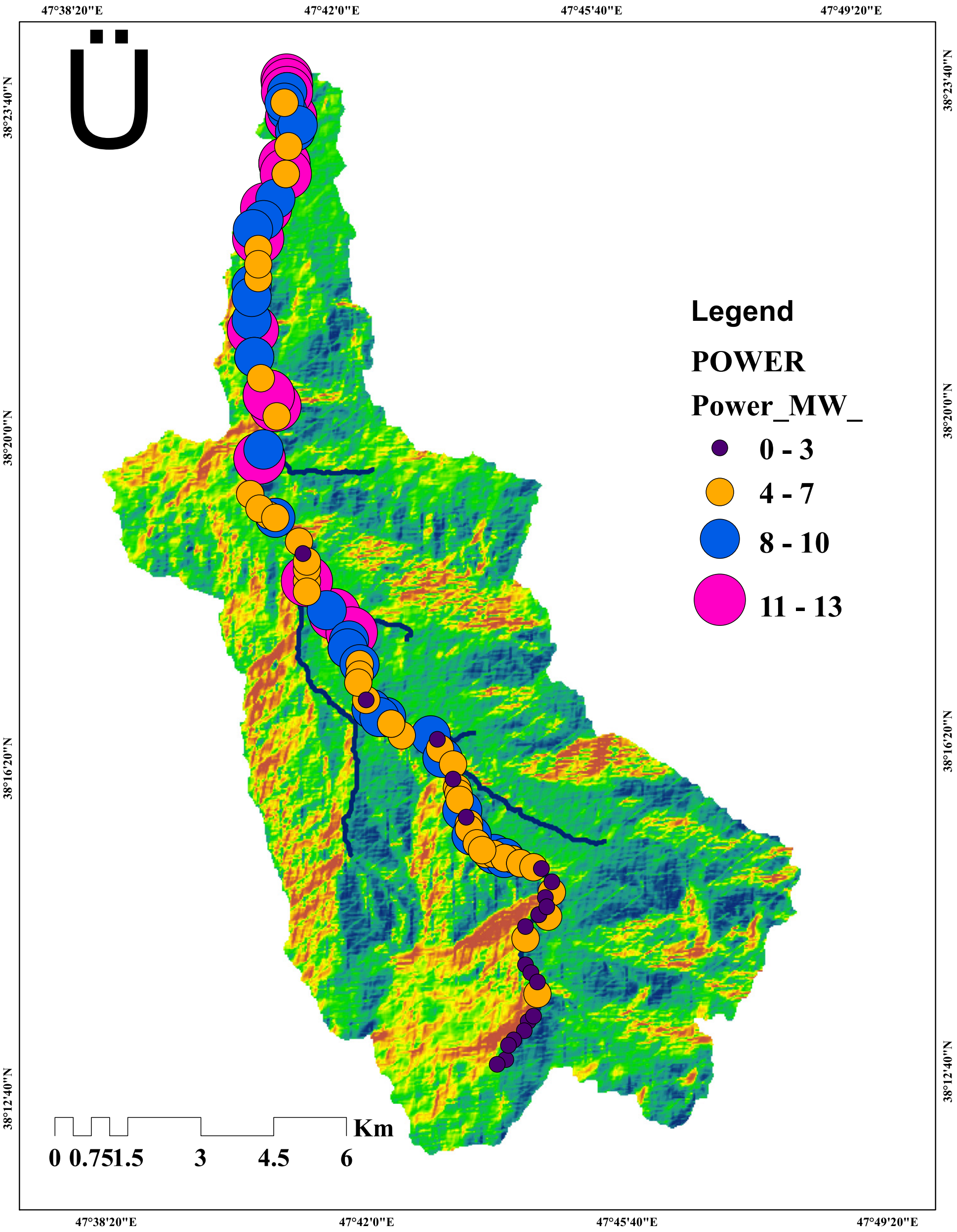


Fig. 9. The calculated power potential for the plan(D) hydropower stations.

CRediT authorship contribution statement

Yizhi Tian: Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Feng Zhang:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Zhi Yuan:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Zihang Che:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Nicholas Zafetti:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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