

Spatial Multiple Criteria Decision Making for Site Selection of Pumped Storage Hydropower Plants

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ABSTRACT: The first stage in development and design of Pumped Storage Hydropower Plants (PSHP) is finding the optimum location. In the current study we investigate the application of methods developed in the decision sciences: Spatial multiple criteria decision making using Weighted Linear Combination (WLC) with the help of geospatial data analysis in a Geographic Information System (GIS) environment. The conventional method of PSHP site selection has certain limitations and is not cost and time effective. The volume of data and the criteria for the site selection of PSHP causes a lot of difficulties for decision making. However with the help of GIS as an information technology and with its analytical ability for decision making optimization, we can overcome these difficulties. Every criterion in a GIS can be illustrated as a separate data layer and site selection can be done according to the defined criteria. Overlay is one of the spatial functions that can combine spatial data layers from different sources for the site selection applications. In the process of site selection of suitable PSHP, various factors with different importance are considered. The Zayanderud pumped storage hydropower has been investigated as a case study. The Zayanderud PSHP is located in a dry and hot zone in central Iran and uses the existing Zayanderud dam lake as the lower reservoir. During this study, sites for upper reservoir location have been defined according to the artificial upper reservoir on the bank of the zayanderud reservoir. In this case study, at first, effective criteria for PSHP site location and responsive data layers have been defined. Then, data layers have been classified and prepared with respect to main criteria. Finally, results of WLC have been evaluated. The main factors used in PSHP site selection process were; development pattern (using existing lake, rivers, sea, natural and artificial pools, etc as upper or lower reservoirs), head, conveyance length-head ratio, slope, power grid situation, roads accessibility, geology and other technical points of view. The above mentioned factors were entered in GIS as data layers. Results of this investigation indicate that by using GIS, more suitable sites can be selected and verified and the feasibility study process can be done in more precise manner. This method can save more time and cost compared to the conventional approach.

Keywords: Spatial Multiple Criteria Decision Making (SMCDM), Geographic Information System (GIS), Hydropower, Pumped Storage, Site Selection, Zayanderud.

INTRODUCTION

Hydropower is one of the most renewable, non-radioactive and non-polluting sources of energy. Construction of Pumped Storage Hydropower Plants (PSHP) is one type of hydropower developments. PSHP developments are energy-storing systems. Water is pumped from a lower reservoir to a higher one, utilizing low-cost dump power produced during periods of low demand by power plant which can be operated economically at a constant load. The water in higher reservoir is then released through turbines to produce power needed during periods of peak demand. Although there is a net energy loss in the system because more energy is expended in pumping

than can be produced by the turbines, the relative monetary value of "peak" power compared to "dump" power makes pumped storage projects economically feasible.

The most important step in the development of a PSHP is the site selection by preliminary area screening and the evaluation of their suitability according to relevant criteria, engineering design and costs. This process is difficult and complex because it requires working with large amounts of spatial data with regard to various rules and constraints. There are immense data volume and some criteria for the site selection of PSHP that cause much more problem for decision

making. It is possible conventional method omit several regions which are not accessible or visitable.

As PSHP site selection are multifactorial, a method needed to be adopted within the context of Spatial Multiple Criteria Decision Making (SMCDM) to combine membership functions for different criteria—one such method is Weighted Linear Combination (WLC). With WLC, the criteria are standardized for comparison on a common scale, weights are applied so that more important criteria are able to exert a greater influence on the outcome, and a weighted average across criteria is calculated for each pixel, giving the final suitability estimates.

Geographic Information Systems (GIS) have been used as an important programming tool for enhanced spatial visualization and data analysis. The use of a GIS for selection of sites for PSHP would be of help in finding more appropriate sites. The inclusion of a GIS site suitability analysis into the PSHP site selection process, would allow selected sites to be evaluated based on the same criteria. Furthermore, a GIS would supply a standardized tool for evaluating selected sites. All sites would be weighted against the same criteria and subjectivity judgments would be eliminated from the process. GIS procedure is helpful in managing the complex theme of landscape mapping and as a result the land-use scheming decisions are made more efficiently. In this paper, GIS have been used in selection of sites for PSHP to illustrate GIS as an applicable complement to support the decision made and to investigate its applicability in the PSHP site selection.

Some researchers used geographic information and decision support systems for locating potential landfill sites (Dikshit *et al.*, Lukashch *et al.*, Kao *et al.* and Daneshvar *et al.*). Ramachandra *et al.* assess micro, mini and small hydropower potential using spatial decision support system in GIS environment. PSHP have a more criteria and undefined pattern as compared to mini hydropower plants and landfill sites.

In the proposed method the existing maps are used to develop GIS database for selection of site, Digital Terrain Model data (DTM), transmission line network and access road. With the help of GIS as an information technology and effective spatial analysis tool, site selection of PSHP will be done more accurately.

STUDY AREA

The Zayanderud PSHP have been investigated as a case study. The Zayanderud river basin, with a total area of 41,542 km², is located in a dry and hot zone in

central Iran. The river stretches over a distance of 355 km and passes through the historic city of Isfahan. The multipurpose Zayanderud dam was constructed in 1970, 110 km west of Isfahan (about 23 km from Chadegan city). Table 1 shows characteristics of Zayanderud dam. Zayanderud PSHP would use the existing Zayanderud dam as the lower reservoir. Our aim is to find alternatives for artificial upper reservoir on the bank of the Zayanderud dam reservoir.

Table 1: Characteristics of Zayanderud Dam

River	Zayanderud
Near city	23 km from Chadegan
Type of dam	Concrete arch dam
Type of spillway	Gated
Construction period	1965–1970
Height	100 m
Crest length	450 m
Spillway discharge capacity	1880 m ³ /s
Effective capacity	1240 × 10 ⁶ m ³
Regulated annual water	1200 × 10 ⁶ m ³

METHODOLOGY

MCDM involves a sequence of analytical steps. This includes: 1) defining the objective(s), 2) defining the factors (continuous) and constraints (Boolean), 3) defining the relationship between each factor and suitability, 4) standardizing the factors so they can be compared, 5) defining the relative importance of each factor in relation to suitability and 6) combining each of the factors and constraints to produce a final weighted estimate of suitability for each location in the study area. We identified an additional step as being important for determining the credibility of the resultant maps: 7) validation. A GIS analysis has been done to select sites for PSHP (objective). The analysis included the following steps:

- Definitions of PSHP site selection criteria.
- Preparation of spatial data and the corresponding layer representing each criterion.
- Preparation of an analysis model.
- Selection of sites for PSHP and definition of site suitability.

Definitions of PSHP Site Selection Criteria

PSHP site selection criteria are listed based on the economical and technical considerations. The PSHP site selection criteria include:

1. Being located near a power grid situation; Produced power would be transmitted to continued power grid, so it is important that alternatives to power grid situation are located nearby.
2. Being located near an access road; Easy access to PSHP sites is required for construction, operation, etc, so it is important alternatives are close to an access road.
3. Having suitable geological condition; it is necessary to provide the required volume for upper reservoir, construct underground waterway (tunnel & shaft) and operation rooms, so it is important to have favorable geological conditions.
4. Having more head; the amount of energy produced depends on head and discharge. Produced energy can be increased with an increase in head or discharge. Head comes from topography and increasing of head is more economical, so we should try to find alternatives with more head. We can produce predefined constant energy with decreasing discharge, if net head increased.
5. Having less conveyance length-head ratio; with an increase in head, conveyance length increases too. It is an advantage when waterway length is less in a constant head. An alternative will be more economical when conveyance length—head ratio decreases.
6. Having a mild slope of natural ground surface; for construction of upper reservoir, it is necessary to make an artificial reservoir. When the ground surface is flat, cut and fill costs for artificial reservoir construction decreases. So it is an advantage for PSHP site selection when slope of natural ground surface is mild.

judgment of two expert geologists. In these regions, 38 different classes of lithology were defined (Figure 3). The various lithologies were ranked from 5–100, with 100 being the best class and 5 being the worst class (Figure 4).

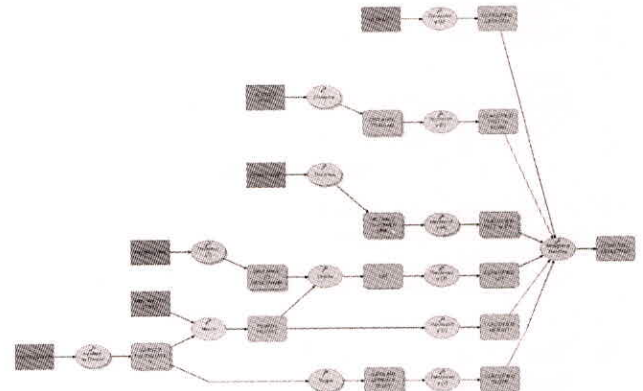


Fig. 1: GIS analysis model for PSHP site selection

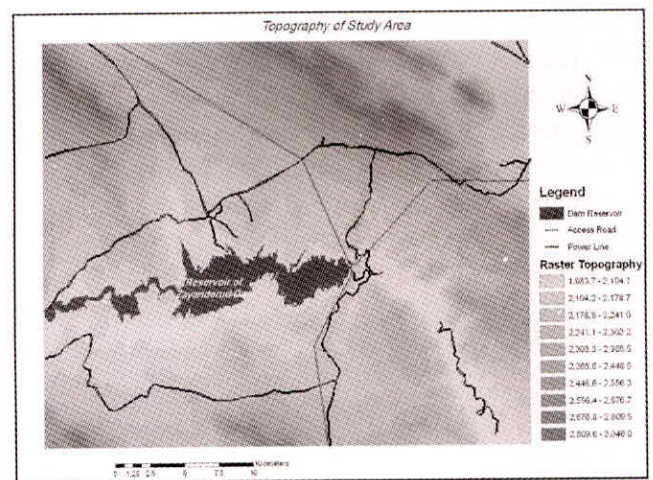


Fig. 2: Raster topography

GIS Analysis Model

GIS analysis model combines geographic data together with site selection criteria to recognize PSHP sites. A suitability analysis model (Figure 1) was created using ArcGIS9.2 in which the data sets were managed, as follows, to provide final suitability maps:

1. *Data Preparation:* Spatial data from the regions of Zayanderud dam was collected. These maps consist of region topography, power transmission line and access road distribution.
2. *Conversion of Data to Raster:* For spatial analysis, the initial data converted to Raster type. Figure 2 shows converted topography to raster.
3. *Classification of Geology Based on Their Suitability:* The classification of geology was based on personal

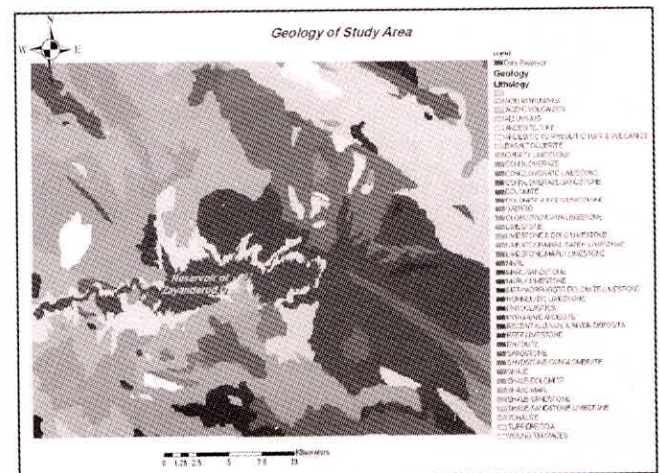


Fig. 3: Geology of study area

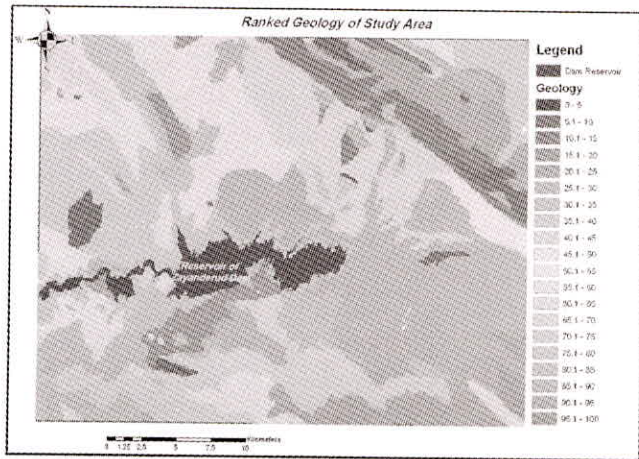


Fig. 4: Ranked geology of study area

4. *Determining the Distance to Power Line, Road and Dam Reservoir and Reclassification of Suitability Rank Values to Each Criteria:* Using spatial raster analysis tools, the distance to power line, road and dam reservoir are evaluated. To classify the criteria, the model divides areas into twenty categories. The categories each were assigned a category value (V) from 5–100, with 100 being the best class and 5 being the worst class. A linear function was used to assign rank values (V) to each class (e.g. Figure 5 and 6).

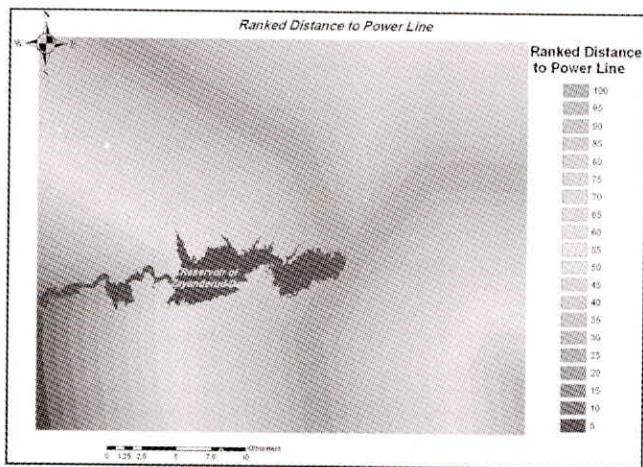


Fig. 5: Ranked distance to power line

maximum rate of change in value from each cell to its neighbors. They have been classified like the other criteria (e.g. Figures 7 and 8).

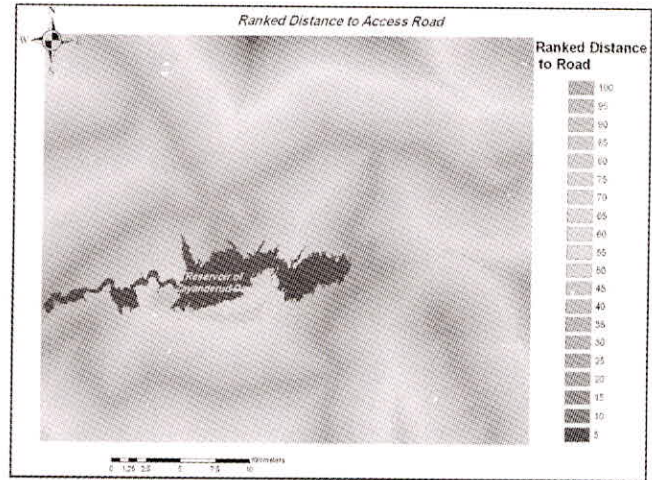


Fig. 6: Ranked distance to access road

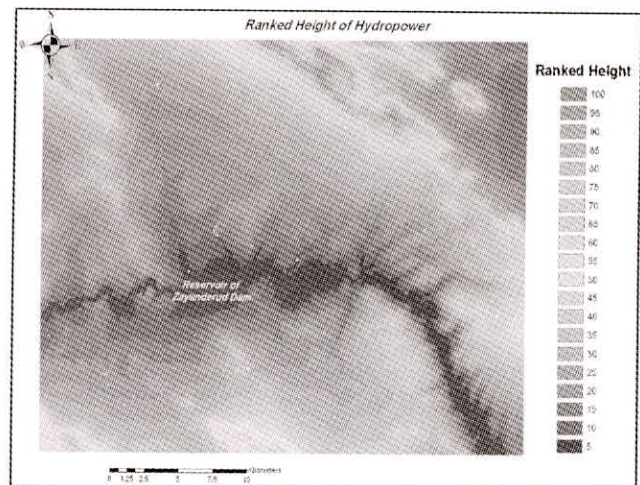


Fig. 7: Ranked head of hydropower

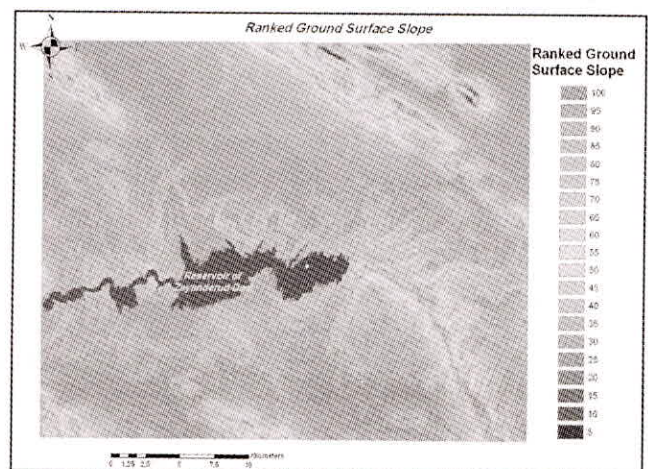


Fig. 8: Ranked ground surface slope

5. *Determining the Head of PSHP, Conveyance Length-Head Ratio and Slope of Ground Surface and Reclassification of Them:* Using spatial raster analysis tools, the head of PSHP, conveyance length-head ratio and slope of ground surface are computed. The head of hydropower in any place equals the difference of minimum water level and the cell elevation. Conveyance length is minimum distance of any cell from dam reservoir. Slope identifies the

6. *Data Weighting Based on Their Significance in PSHP Site Selection:* Several criteria were used to select suitable sites. The effect of these criteria in PSHP site selection is not equal, so the various ranked data have been weighted and used for site selection. The weight of each factor indicates amount of its cost and value as comparing with the other factors. Correct weights can help finding convenient location for PSHP. Data weighting have been done using Knowledge Driven Weighting method. In this method, data are weighted in a definite range using expert experience about application. First, different ideas are collected and their dimensions are uniformed. Then, weights are normalized in the defined range using an appropriate scale. The weights of all criteria have been presented in Table 2. These weights have been used in the analysis.

Table 2: Weight of Criteria

Criterion Number	Criteria	Weight (%)
1.	Being located near a power grid situation	10
2.	Being located near an access road	10
3.	Having suitable geological condition	25
4.	Having more head	15
5.	Having less conveyance length-head ratio	25
6.	Having a mild slope of natural ground surface	15

7. *Ranking and Weighting of the Overlay Criteria to Produce Final Suitability and Preference Maps:* The final step in the GIS analysis model is summing up the six ranked criteria to determine the total suitability value of any region. The overlay function calculates the values across each region, resulting in a single priority or suitability number for each site. Final average priority and suitability rank values are divided into 20 categories to identify areas most suitable for PSHP. The final suitability and priority maps are presented in Figure 9. This map presents the overall suitability values for potential PSHP sites and identified areas with suitability rank values ranging from 0–100. In this scale, a value of 100 indicates that a site is most suitable for PSHP and it means that the site met all of the criteria to a good extent. A value, 0 indicates that a site is not suitable and did not meet any of the PSHP site selection criteria. This map shows overall suitability for PSHP regions ranged

from 32.0 to 84.8, indicating that no sites fully matched all criteria. PSHP sites that received more than 80% of the possible 100-point suitability value were recommended to be included in PSHP list of selected sites. The sites with suitability value more than 80 have been shown in Figure 9 with black color. It is identified that suitable regions are located near to dam position in the right and left bank that have been called ZPR (right bank region) and ZPL (left bank region). They are potential areas that decision must be made on them based on their priority. Table 3 shows the characteristics of these suitable sites.

Table 3: Characteristics of Potential Sites

	ZPR	ZPL
Area - Km ²	2.29	1.47
Heat of PSHP (H) - meter	110~160	110~200
Length of conveyance system (L) - meter	200~1000	200~1000
L/H	2~6.5	2~5
Slope of ground surface (S) - %	5~15	5~20
Geology (Lithology)	Rhyolite	Rhyolite—Bazalt dolerite
Distance to access road - meter	0~1250	0~1250
Distance to power line grid - meter	0~1000	0~1000

Presented results in Table 3 show ZPL Site has better economic and facilities conditions than ZPR site, because ZPL Site has more head and less conveyance length-head ratio. Therefore, ZPL site is proposed as an optimum region for upper artificial reservoir construction.

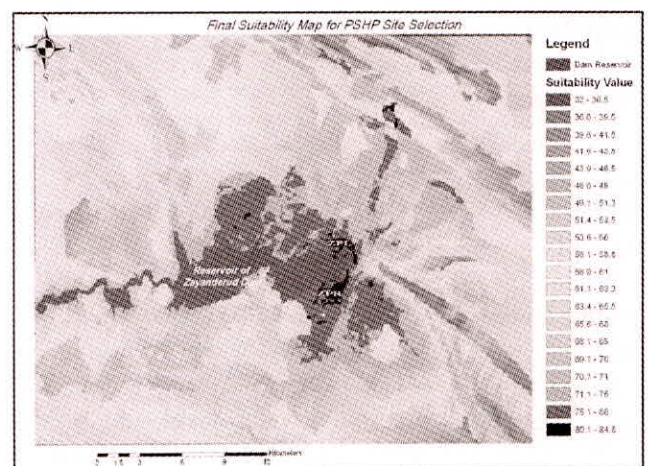


Fig. 9: Final Suitability Map

Validation

Figure 10 shows result of PSHP site selection using conventional method [9]. The selected site located in left bank of dam reservoir about 2 kilometers from dam position. The mentioned site have been located in ZPL region. Perhaps ZPR rejected with more studies, site visit and other problems.

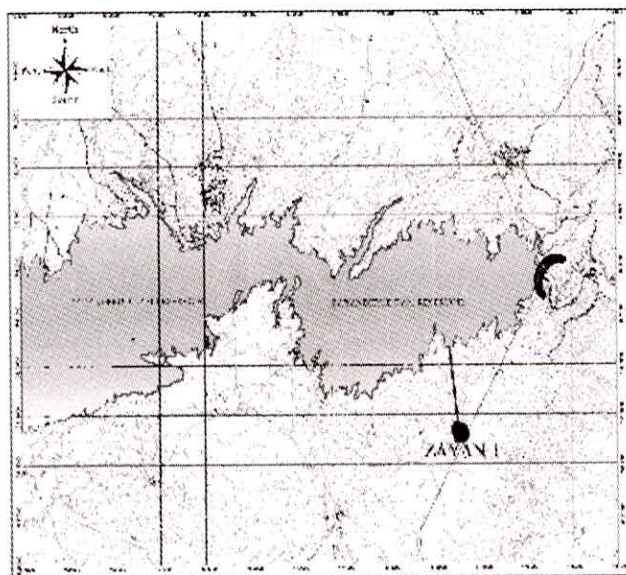


Fig. 10: Selected site—Conventional method

DISCUSSION

The GIS suitability analysis-model approach to PSHP site selection and prioritization (demonstrated in this paper) can act as a complement to conventional decision making procedures to create a comprehensive site selection and prioritization process and serve as a useful tool for improving the current consensus in site selection approaches. This method can incorporate all criteria for selecting and prioritizing sites into the priority list. It can identify remote areas of critical ecological importance that may be overlooked by the conventional decision approaches.

To incorporate GIS into the conventional PSHP site selection processes, spatial data availability for PSHP must be considered. For many of the PSHP criteria, spatial datasets for PSHP site selection might be non-existent, incomplete, or unavailable for interagency or public distribution, for example: land ownership and managed areas.

Spatial data from different organizations must be put together to create complete datasets. The difficulty in accumulation of data is the result of limited accessibility to the data available among different organizations.

The use of a GIS to select PSHP sites requires specific standardized criteria to be set. A system must be designed so that all selected sites are measured against the same standards and criteria. Small changes in parameters such as criterion weight can meaningfully change the results of the analysis. The PSHP Site List could serve as a useful tool, with flexibility to shift priorities as new sites are added and updated data is collected. As previously discussed, the use of a GIS to select sites for PSHP requires complete and up-to-date spatial data for the study area to produce the most reliable results.

Given the constraints of limited data availability and use of non-standardized criteria, The GIS analysis demonstrated in this study, accurately selected suitable PSHP sites.

The GIS analysis has laid the basis for further studies of these sites. Information about these sites collected from site visits would complete this study and approve or reject the conclusion that these sites should be added to the preference list.

CONCLUSIONS

PSHP site selection is one of the development goals that are very important for each country hydropower development. In order to obtain a clearer estimate of the degree of potential power that can be feasibly developed to determine which sites are feasible and to rank their priority, it is necessary to intersect the locations of potential with context parameters that demonstrate their feasibility for development. All the data presented in this paper are geo-referenced; therefore using GIS tools are very important and would affect the result of our investigation.

Through development of a GIS and various GIS analysis of PSHP sites, we selected a study area for deployment of a PSHP at the center of Iran which is located in the Zayanderud reservoir banks. Several criteria were defined for the site selection process. A GIS model was created and by executing the model, the optimum location for PSHP construction was located. In this case study we tried to prove that GIS, by successfully running and implementing PSHP site selection models, is capable of acting as an efficient decision making tool for PSHP site selection.

GIS technique is found to be suitable and time and cost effective for the identification of PSHP development sources, mapping suitable sites and ranking of the hydropower projects. Integrating GIS with conventional planning would prove beneficial to the

PSHP site selection procedures. Additionally, site selection will be done in the same manner and based on the same criteria for all of regions and the effect of Personal and subjective judgments will decrease.

It should be noted that implementation of a GIS-based approach to PSHP site selection would require collecting spatial data for the region and developing standardized criteria for selection of PSHP sites.

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