GIS-based Procedures of Hydropower Potential for Tabriz Basin, Iran

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Abstract

Hydropower is a clean, renewable and reliable energy source that serves environmental and energy policy objectives. It is therefore necessary to search for this renewable, alternate and non-polluting source of energy. GIS spatial analyses have allowed developing a number of methodologies to calculate hydropower potentials. This paper discusses the application of a GIS to calculate the theoretical surface hydropower potential of the Tabriz basin in Iran. GIS based hydrological modeling is performed on equiareal raster cells using topographical and meteorological datasets. The input data was compiled and analyzed using GIS data layers, including topographic characteristics, monthly evaporation and precipitation data. The study has shown that more than half of the power potential is found in Ajei-Chai river branches while Mehran Roud river branches show the highest potentials. Moreover low power site occurs frequently and uniformly distributed over the Tabriz basin. The results of this research are important for the regional planning of the Tabriz basin in collaboration with the decision-making authorities. It may lead to actions to explicitly designate streams with high amounts of water releases and respectively potentials showing possible locations for hydro power plants.

1 Introduction

The increasing demand for energy, especially from renewable and sustainable sources, spurs the development of small hydropower plants and encourages investment in new survey studies. Preliminary hydropower survey studies usually carry huge uncertainties about the technical, economic and environmental feasibility of the undeveloped potential (LARENTIS et al. 2010). Hydropower is a clean, renewable and reliable energy source that serves national environmental and energy policy objectives. It is one of the most important renewable sources for production of electric power due to several obvious reasons. It is derived from the falling water, either from rivers or streams, flowing downhill along the river course due to force of gravity. The energy associated with this flowing water is known as kinetic energy that is released through the friction of flowing water with the rocks and the sediment in the river beds. Harnessing the kinetic energy from the flowing water for moving turbines generates hydropower (KUSRE et al. 2010). The small scale use of hydropower has been practiced since pre historic times. With the technological maturity in enhancing conversion efficiency, the large scale use of hydropower has been increased due to it is economic feasibility (KUSRE et al. 2010).

Population increases in developing and transitional countries such as Iran and using fossil fuel are placing pressure on natural resources (e.g. climate aching and air pollution), (FEIZIZADEH & BLASCHKE 2012). Thus it is necessary to search for renewable, alternate and non-polluting sources of energy which assumes top priority for self-reliance in the regional

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energy supply (RAMACHANDRA & SHRUTHI 2007). Physical characteristics indicate that the main part of Iran (85%) experiences arid, semi-arid and ultra-arid climate condition and around 2/3 of the permanent surface streams covers only 1/3 of the area of Iran (ALIJANE 2000). Due to the physical conditions and water scarcity the main part of Iran isn't suitable for extensive hydropower generation. The spatial mapping of availability and demand of energy resources would support in the integrated regional energy planning by appropriate energy supply-demand matching (RAMACHANDRA & SHRUTHI 2007). Physically based hydrologic models for watersheds are important tools to support water resources management (MELLO et al. 2008). In recent years GIS applications have been used successfully to assess environmental and economic constraints, and to select suitable locations for energy projects (RAMACHANDRA & SHRUTHI 2007, DEFNE et al. 2011). The suitability of GIS to serve for this purpose was proposed earlier (YAPA 1991), while its performance and shortcomings having been evaluated more recently (DOMÍNGUEZ AND AMADOR 2007, DEFNE et al. 2011). GIS spatial analyses have allowed to develop a number of methodologies for the extraction of drain characteristics from a DEM (Digital Elevation Model) and to calculate hydropower potential (LARENTIS et al. 2010). GIS based hydrological models are primarily used for hydrologic prediction and for understanding of hydrologic processes. It is a powerful technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers (KUSRE et al. 2010). These models generally use mathematical and statistical concepts to link certain inputs (for instance precipitation, temperature, etc.) to the model output (for instance runoff). It has become possible to integrate all the physical events leading to a better simulation of the physical world using GIS and hydrological models. The use of hydrological models has been increased due to their merit over traditional methods for water resource assessment (KUSRE et al. 2010). This paper concerns the research about hydropower survey in Tabriz basin in north western of Iran. The main objective of this study was to calculate the theoretical surface hydropower potential in order to assess the potential, water releases and storages for hydropower stations in Tabriz basin.

2 Study Area

The study area was the Tabriz basin which is a sub-basin of Urmia lake and located in the East Azerbaijan province of Iran (see figure 1). The study area is 5378 km2 in size and nowadays it is important in terms of housing, industrial and agricultural activities for the East Azerbaijan province. It is located 4175411.09 N to 4259888.02 N and 570687.02 E to 661242.81 E. In Tabriz basin, the elevation increases from 1.285 m at Ajei-Chai river bed to 3710 m above sea level in the Sahand Mountains. Agriculture is one of the main sources of income for the population. The agriculture is dependent on ground water and on managed surface runoff water resources; in particular, the three major reservoirs (MALK KIAN, AMAND & DASH ESPIRAN) are potential sources of hydropower for this region (FEIZIZADEH & BLASCHKE, 2012). The climate of this area is semi-arid and annual precipitation is about 300 mm. Daily temperatures range from 14º to 30º C in summer and 5º to 7º C in winter. The average annual precipitation for the studied area amounts to 300 mm, most of which occurs in April and May, with approximately 100 mm falling in the winter (ALIJANE 2000).

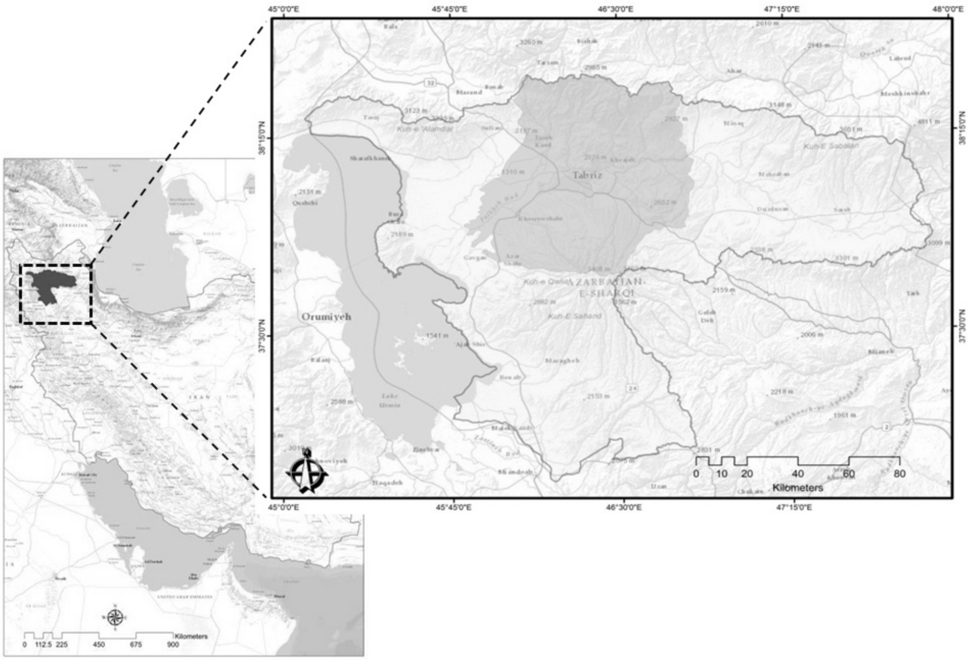

Fig. 1: Location of study area in Iran (left) and Urmia lake basin (right)

3 Methods and Data Processing

The spatial analysis at this site was assessed in order to find out about suitable locations for hydropower plants and to calculate runoff at the suitable locations for an estimation of hydropower potential in this pilot region. The hydropower potential is calculated based on the accumulation of single hydropower amounts (based on equiareal raster cells) to obtain an allover amount of theoretical hydropower potential for the specific region. Water comes down as precipitation and runs over a certain surface until it is accumulated in the lowest cells of a region. These cells are simultaneously the cells of highest potential and the locations suitable for building hydropower plants. Figure 2 shows the schema of the main steps of our research methodology to assess hydropower potential of the Tabriz basin.

3.1 Identification of hydropower sites

The methodology of this research is based on GIS hydrological model to assess the power potential. The model is based on a DEM, on monthly evaporation and precipitation data (both in mm). In the preparation phase, all necessary geometric and thematic editing was done on the original data sets and a topology was created. In the next step a DEM was derived from topographical maps with a scale of 1:25000. Subsequently monthly evaporation and precipitation raster datasets were created with 20 m resolution, based on the Inverse Distance Weighted (IDW) interpolated technique of ArcGIS taking into account data from 34 climatology stations. The model to calculate the potential starts with the filling function. It is applied on the DEM and fills sinks in order to get a smooth surface. A sink or also a peak may sometimes also be an error which results from the resolution of the dataset or from rounding of elevations to integer values. The filling function is necessary to make sure, that the basins and streams in a certain area are outlined correctly.

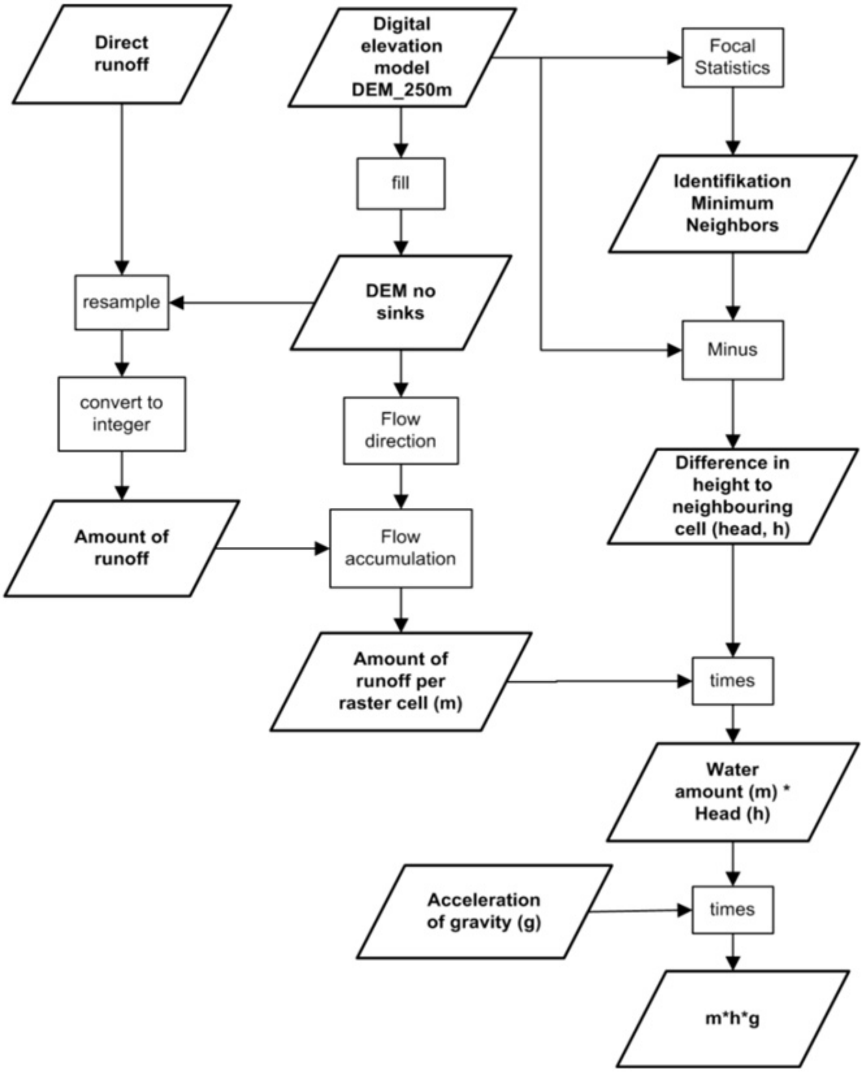

Fig. 2: Schema of the model to calculate potential energy

Subsequently to the filling step, a resample function was performed on the direct runoff dataset. The data describes the runoff[1] in a certain region considering just the surface runoff but not the subterranean runoff. The resample function in ArcGIS assigns new statistical values to an input dataset. By resampling, the ratio of the cells is changed by altering the cell size but not the extension of the cells. In the present case the direct runoff dataset is resampled according to the DEM. The result is a runoff dataset which is exactly overlapping the DEM. In this step resampled direct runoff dataset is converted to integer values in order to process it more easily and most of all faster.

Following the flow direction is calculated in order to gain information about the direction of flow from each raster cell. The input is a surface raster and the output is a raster that shows the direction of flow by encoding each cell with a value between 8 and 128, each value indicating one direction.

The output of the flow direction calculation together with the direct runoff dataset (integer) serve as input data for the calculation of the flow accumulation of ArcGIS. This function delineates stream networks in elevation models. The tool calculates the accumulated flow as the accumulated weight of all cells "flowing" into each raster cell. Cells with high flow accumulation values represent sinks in a certain area; cells with low accumulation values represent highs. In this case the accumulation raster is weighted by the amount of available water in the area of interest which is represented by the integer dataset of the direct runoff data. The output from the flow accumulation function is the sum of water accumulated in each raster cell which is equivalent to the mass of water m (= $\text{density of water} \times \text{runoff}$).

On the digital elevation data also a focal statistics function is applied. This is a function that calculates statistic for the neighbouring cells of each cell such as minimum, maximum, sum of all values etc. In the present case the minimum function is applied to a 3×3 cells rectangle around each cell in order to find the minimum cells around each raster cell (lowest neighbouring cells).

The minimum neighbours' dataset is afterwards subtracted from the DEM in order to find out about the drop of elevation of each cell to its minimum neighbours. The output is the height value "head" which is then used in the equation to calculate the potential energy. With the gained outputs, mass m, head h and the constant describing the acceleration of gravity g, the potential energy E can be calculated from equation (1), while the value for the acceleration of gravity is 9.81 m/s² (STADLER 2009).

$$E = m \times g \times h \qquad (1)$$

The unit of the output is Joule which has to be transformed to kWh resp. MWh by the calculation factor $\frac{1}{3{,}6*10^{12}}$

[1] Note: for the use in the equation to calculate the potential energy the unit of the direct runoff needs to be kg.

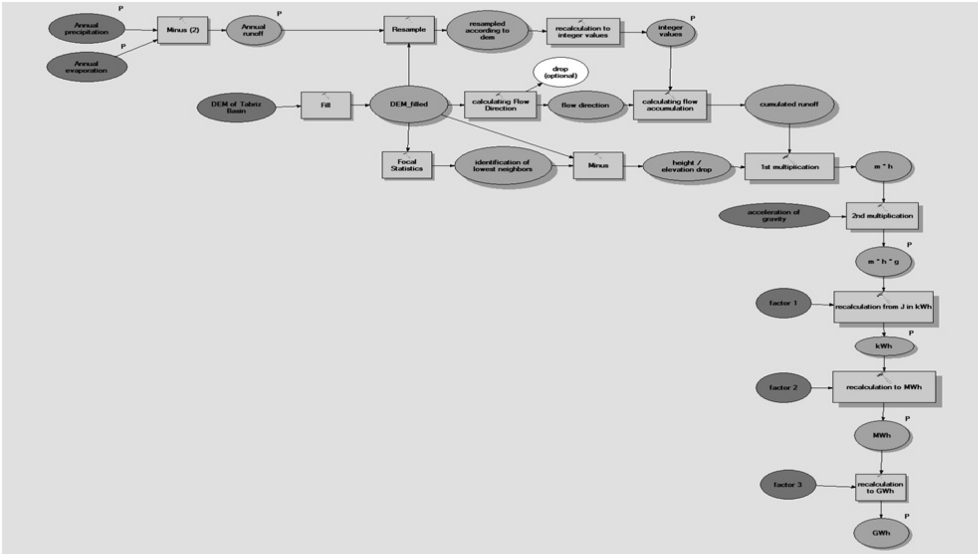

Fig. 3: Model from ESRI Model Builder according to schema in figure 2

4 Results

The results of hydropower potential for the Tabriz Basin are shown in figure 4. In this map the blue squares indicate where water is mainly accumulated and so where raster cells with high potential can be found. Summing the estimated power potential of all cells the total power potential of the Tabriz basin can be estimated. In general stream segments that show a power potential of more than 10 MWh are potentially suitable to establish hydropower station. Results indicate, the gross hydropower potential in the Tabriz basin might not be the maximum values calculated. Maximum values (around 10 to 18MWh) are found on Ajei-Chai river branches which is located in north of Tabriz city and feeds Urmia Lake. While moderate values (5-10MWh) are found on Mehran-Roud river. However low values power sites are sufficiently numerous and uniformly distributed over the case study area. The study shows that the combined amounts of available high head/low power and low head/low power potential in the study area constitute 30% of the total available potential. However, realizing nearly two-thirds of the low head/low power potential would require unconventional systems or micro-hydro technology requiring significant turbine and system configuration research and development. The fact that this source of distributed power could be realized without the need for water impoundments is a positive attribute. The greatest sources for additional hydropower lie in the combination of high power sites, high head/low power sites, and part of the low head/low power potential sites, constituting 90% of the total available power potential. This potential could be realized with conventional turbine technology, but perhaps in new configurations not requiring impoundments to be determined by future research and development.

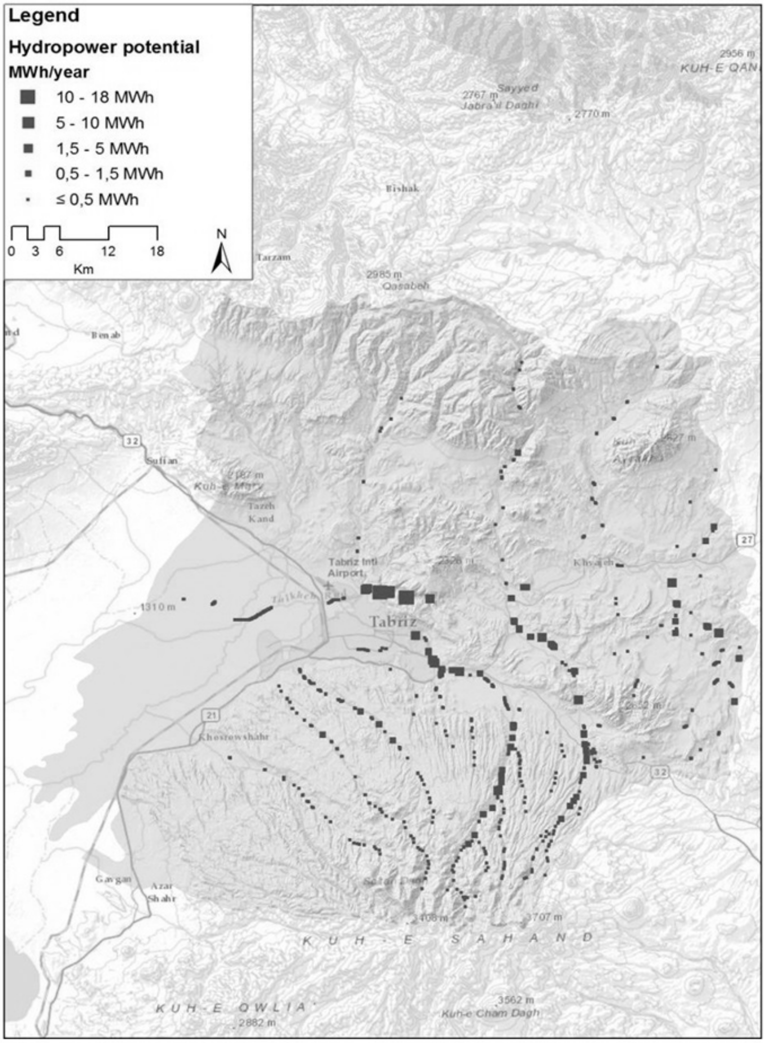

Fig. 4: Output of the model calculation: raster-based annual hydropower potential of the Tabriz Basin /Iran

5 Conclusion and Outlook

This study has demonstrated that it is possible to estimate the theoretical hydro power potential of the Tabriz basin as surface potential, i.e. a virtually placement of reservoirs all over the study area. In Ajei-Chai and Mehran Roud river branches the highest potentials can be found. The estimates of available power potential produced by this study are sufficiently large to warrant further research toward realizing these energy resources. Such research should include a refinement of the available power potential model and investigation of possible locations for siting additional hydroelectric units. Based on result of this research low power sites are sufficiently numerous and uniformly distributed over the study area to offer significant sources of distributed power without the need for reservoirs. In order to obtain a more detailed estimate of the amount of power potential that can feasibly be developed and determine which sites are feasible, it is necessary to intersect the locations of potential with context parameters that govern its feasibility of development.

Results of this study are great important to decision-makers and, in particular, to government departments such as the Ministry of Agriculture, the Ministry of Water Resource Management, and the Ministry of Natural Resources for the East Azerbaijan Province of Iran. Following the receipt of this information by these ministries, discussion was triggered on how to further enhance the detail of information portrayed in the hydro power potential maps. This enhancement will be carried out for Tabriz basin in collaboration with the decision-making authorities. It will include actions to explicitly designate streams in which the potential of hydropower and water releases is high and storages for hydropower stations can be built. However, in cultural landscapes the "ecological and socio-economic realms are intricately linked" (BLASCHKE 2006) in order to provide transparent and reliable regional planning in Tabriz basin.

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