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Identifying high potential locations for run-of-the-river hydroelectric power plants using GIS and digital elevation models

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ABSTRACT

The recent global energy crisis has provoked a need to explore alternate energy sources including run-of-the-river hydropower projects. To derive maximum payback for a given investment, finding the most advantageous siting of power plants is imperative. If a selection of potential sites misses some of the apparently indistinct sites with significant power potential, there is a chance of acquiring only partial benefits out of these investments. A review of the existing methods for evaluating power potential of a river is discussed in this paper with their limitations along with a new proposed approach. The new approach can be used to evaluate different installation schemes along a river to assess run-of-the-river hydropower potentials using geospatial data techniques to select sites exhibiting higher total hydropower potential. The case study of Kunhar River, located in the northern part of Pakistan, presents the applicability of the approach. Open source Advanced Spaceborne Thermal Emission (ASTER)'s digital elevation model (DEM) and regional hydrologic gauged data are used for identifying the best locations for hydropower plants, demonstrating this approach is substantially more cost effective and robust compared to other field based assessment. Replicating the proposed approach for other locations is easy following the step-by-step method presented in this paper and giving consideration to the limitations described. This study may provide guidelines for the development of cost-effective and energy efficient hydropower projects. The use of this approach is most advantageous in the preliminary assessment phase of a project to narrow the scope of the detailed study focusing only on the higher potential sites.

1. Introduction

The total hydropower potential of a river is the available energy without losses that can be harnessed utilizing natural flows at all possible river locations [1]. Many rivers of the world have an abundant hydropower potential, but so far this potential has not been optimally utilized except in a few technologically advanced countries [2]. The run-of-the-river (RoR) projects that are built within riverbeds, requiring no water storage structures, are gaining popularity nowadays for their relatively low cost per kWh, short implementation time, small site requirement, and less environmental and social impacts [3]. In a typical RoR plant, water is diverted from a water channel through a canal or penstock to the turbine. It simply allows water to pass through a facility at about the same rate the river is flowing except for passage through natural habitat. A generic RoR scheme showing its main components is presented in Fig. 1.

The United Nations General assembly adopted a dedicated *Sustainable Development Goal on Sustainable Energy for All* (SDG 7) that has five targets to achieve by 2030. The progress in the development of sustainable energy resources is still slow in meeting the targets of renewable energy, energy efficiency, and energy for all [4]. Hydropower represents the greatest source of renewable energy, contributing 16% of the total global energy consumption [5]. At the end of year 2016, global hydropower installed capacity reached 1064 GW [6], which was far less than the economically feasible 8100 TWh/year projected [7]. In different parts of the world, hydroelectric energy is being harnessed as an environmental friendly renewable energy source. In developing countries with economic constraints to purchase fossil fuels for electricity production, the increasing use of renewable sources can be regarded as an indication of energy expansion. Although the available potential on earth is said to be insufficient to fully cater the world's energy demand, this resource has a high capability to fulfill the need in energy deficit areas [8].

The number of hydropower installations is increasing worldwide

Abbreviations: AMSL, Average mean sea level; ASTER, Advanced Spaceborne Thermal Emission; DAR, Drainage-area-ratio; DEM, Digital elevation model; FDC, Flow duration curve; GIS, Geographical information system; RoR, Run-of-the-river; RS, Remote sensing

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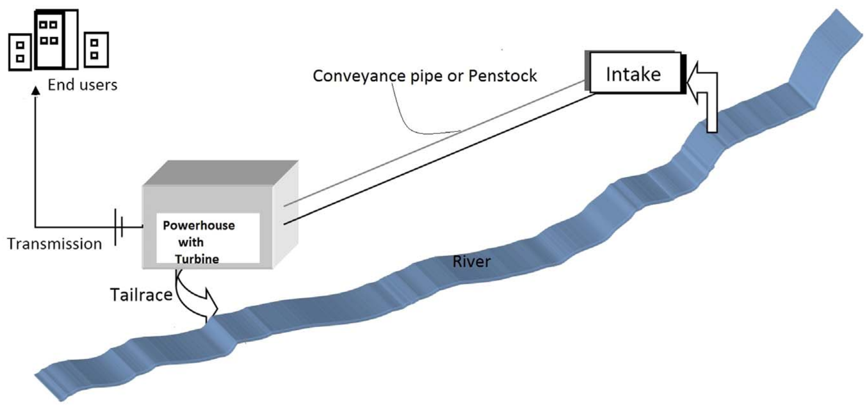

Fig. 1. Generic RoR scheme.

[9]. China is the top hydropower energy producer generating 856.4 TW h in 2012 [10,11]. The second largest hydropower generating country is Brazil with 411.2 TW h production in 2012, followed by Canada [11]. Turkey, with 1% of world total hydropower potential, has one-third of its renewable energy production in the form of hydroelectric energy [12].

Numerous studies have already been done to estimate the hydropower potential of a river using a variety of methods and tools. Most of the earlier studies focused on traditional methods using field investigations or classical approaches for hydropower estimations, whereas many recent endeavors have utilized advanced tools of remote sensing and geographical information system [13–19]. The traditional methods of site surveys consume time and money that limit the scope of a study, especially if these are carried out in remote areas with difficult terrains and therefore, are limited in scope. The classical approaches or simple rational calculations provide only approximate power potential by converting river flow and elevation head at a single point, double point, or sub-drainage point [20]. In the single point method, head and discharge at the watershed outlet are considered for calculation. In the double point method, two points — centroid and outlet — are used to calculate average head and discharge of the watershed. The sub-drainage point technique has two parts: one combines elevation and flow differences at the inlet and outlet locations of a watershed, and the other part considers surface runoff by examining sub-drainage area weighted elevation values [20].

Generally, the high potential sites are located at remote inaccessible mountainous areas with rough terrain, making site survey-based potential assessments very challenging. In such situations, the use of geographic information system (GIS) and remote sensing (RS) can overcome such barriers to a large extent. Recently, GIS- and RS-based techniques are becoming popular due to their ease of use and cost and time effectiveness. A recent investigation done by Bayazıt et al. [21] cited many studies conducted worldwide using GIS for small hydropower projects. The first hydropower potential thematic GIS layers were developed and released to public domain in the USA in 2004.

The study presented in this paper is an innovative approach that differs from all other studies in its uniqueness. Dudhani et al. [13] used Indian Remote Sensing (IRS) satellite data to identify water resources of the Alaknanda River located in a hilly and mountainous district of India. Changing flows and river channel gradients were not discussed, but rather satellite derived water, forest, and inhabitant cover were presented as the main parameters in selecting hydropower sites. The approach suggested by Kusre et al. [16] for the Kopili River basin in Assam, India, used simulated flows and satellite derived DEMs and is similar to the one proposed here. The minimum elevation drop requirement of 2% and a minimum hydropower site interval of 500 m were chosen as the selection criteria. The stream network and DEMs were overlaid to identify the available elevation drop along the stream. The search for potential sites started at the watershed outlet and moved upward selecting the criteria fulfilling sites and rejecting the others. The improvement on the Kusre method by the approach presented in this paper, is its flexibility in assessing multiple such schemes by changing the starting point, which minimizes skipping locations with higher potentials. Rojanamon et al. [17] not only considered engineering aspects, but also employed economic, environmental, and social impact criteria for small run-of-river hydropower projects in Thailand. Although this study is very extensive and talks about GIS application and head difference between weirs and powerhouses for site selection, it did not present the precise methodology for site selection. Belmonte et al. [22] in a study of renewable resources of the Lerma Valley, Argentina developed watershed-based hydroelectric potential density maps, but the precise locations of hydropower plants along river channels were not identified. Another robust approach found in the literature is the GIS-based computational program *Hydrospot. Hydrospot* searches a large number of alternative sites, but it misses some of the planned projects with higher potential and overlapping of many alternatives because of the interdependence of the project alternatives [14]. Another GIS-based model developed for Scotland is *Hydrobot,* which uses 10-meter elevation data to derive surface flow model, but the model algorithms, being commercially sensitive, could not be accessed and reviewed [23].

The proposed study is an effort to develop an affordable and efficient approach to evaluate RoR hydropower potential and to identify suitable project sites along a river using open source satellite data and GIS techniques. This approach is recommended for the inception phase of a project as a part of its feasibility study. This study and other similar desk studies are not presented as a replacement for the field work, but they can help identifying potential sites for more focused investigations and thus significantly reduce cost and effort [13,14]. The proposed methodology is based on satellite and regional streamflow data and GIS tools. This method allows assessing power potential of numerous potential sites along the drainage network that would be challenging using traditional in-situ measurements due to rough and inaccessible terrains. Preliminary results from application of the proposed method in Kunhar River located in the mountainous region of Pakistan have shown the potential and limitations of the approach for providing support to the electricity sector for initial hydroelectric development planning.

The proposed approach is not an optimization problem, and therefore, did not use any optimization algorithm. The question this study addresses is not how many RoR installations are needed at a given site to produce the amount of energy required to meet a given demand; rather how this energy could be produced while minimizing the number of installations? To answer this question, it is necessary to know the suitable locations for hydro plant facility where hydropower potential can be fully harnessed. The hydropower potential at a given site is