Taylored Screening of potential hydropower sites in a large region using GIS and global data resources

P. Thapa
P. Schaefer
S. Palt
Fichtner GmbH & Co. KG
Renewable Energies and Environment
Sarweystr. 3
70191 Stuttgart
Germany

Introduction

Hydropower resources are garnering increasing attention due to a growing need of renewable energy sources and the increase in overall demand for energy. Hydropower is expected to continue to make a significant contribution to meeting the electricity demand in many countries. However, the hydropower potential is often unknown, or it has been determined based on criteria that are different to those of a private investor, for instance. This makes it necessary to assess the hydropower potential in large areas (country or region) and to locate the potential sites in a relatively quick, reliable and cost-effective way; and based on the specific criteria and preferences of the Client.

With the application of advanced GIS (Geographical Information System) software and the utilization of a comprehensive database, it is now possible to assess the hydropower resources in any river basin, country or region in a fairly quick, effective and efficient way.

Since 2010, a GIS-based algorithm was developed which takes different characteristics of the investigated area into account, such as topography, hydrology and infrastructure. Several procedures are performed to identify the location of potential hydropower sites in the river network of large region. At the same time the relative suitability of the site is assessed based on parameters like available flow, head, energy production, protected areas and proximity to existing infrastructures (road, rails, transmission network, substation etc). Hence, the method enables an automated screening of large areas, in order to identify and rank the potential hydropower project sites.

The development of the method is inspired by the need to provide a complete, yet time- and cost-effective way, at first step, to identify the possible hydropower project sites that are yet unexploited in the large areas for a developer before the planning for the study of the specific potential sites in more detail.

The paper describes the applied input data sources, methodology, the nature of the obtained results and their significance in terms of validity and completeness based on a case study carried out for the country of Zambia. Along with several unexploited sites, all the existing as well as the planned hydropower project sites in Zambia could be exactly identified which confirm and validate the usefulness and capacity of the input data and methodology.

1. Background

Increasing demands for energy have spurred interest in energy from renewable sources, in particular hydropower. In order to tap the potential of hydroelectric energy sources, there is a need to assess the availability of the resources spatially and to identify the potential hydropower sites within a country or a region.

The hydropower potential of a river depends on the river slope and mean annual discharge. Geographic Information Systems (GIS) are designed to manage and analyze geographically referenced spatial data, and are a common tool in a number of fields of civil engineering, including such terrain analysis (for river slope or hydraulic head) and hydrology (for river flow). The objective of this paper is to present a GIS-based time- and cost-effective methodology and its results in identifying the possible hydropower project sites that are yet unexploited in the large areas, based on a case study of the country of Zambia.

2. Methodology

The hydropower potential in a river is described by the so called "line potential", which is determined by the gradient and the discharge in the river. The primary goal here is to identify hydroelectric power potential and map their location in a river network system of the study area, utilizing global data (remote sensing etc) – a fast-track approach for the assessment of hydropower resources. To achieve this goal, the main work involved is the calculation of theoretical in-stream power potential in the considered stretch of the river course as described by the following equation:

$$P = \gamma_w \times \eta \times Q \times \Delta H$$

where,

P	=	in-stream power potential [kW]
γ_w	=	unit weight of water [9.81 kN/m³]
η	=	overall efficiency of power plant [-]
Q	=	flow in the stream [m³/s]
ΔH	=	static head or elevation drop in the considered river stretch [m]

As can be noticed in the power equation, the mapping of in-stream potential in a river system consists of two independent analysis namely, topographic analysis to calculate 'ΔH' along the river course and hydrological analysis to calculate available 'Q' in the considered stretch of the river. An overview of the methodology that has been developed to adopt in this study is shown in Fig. 1 below.

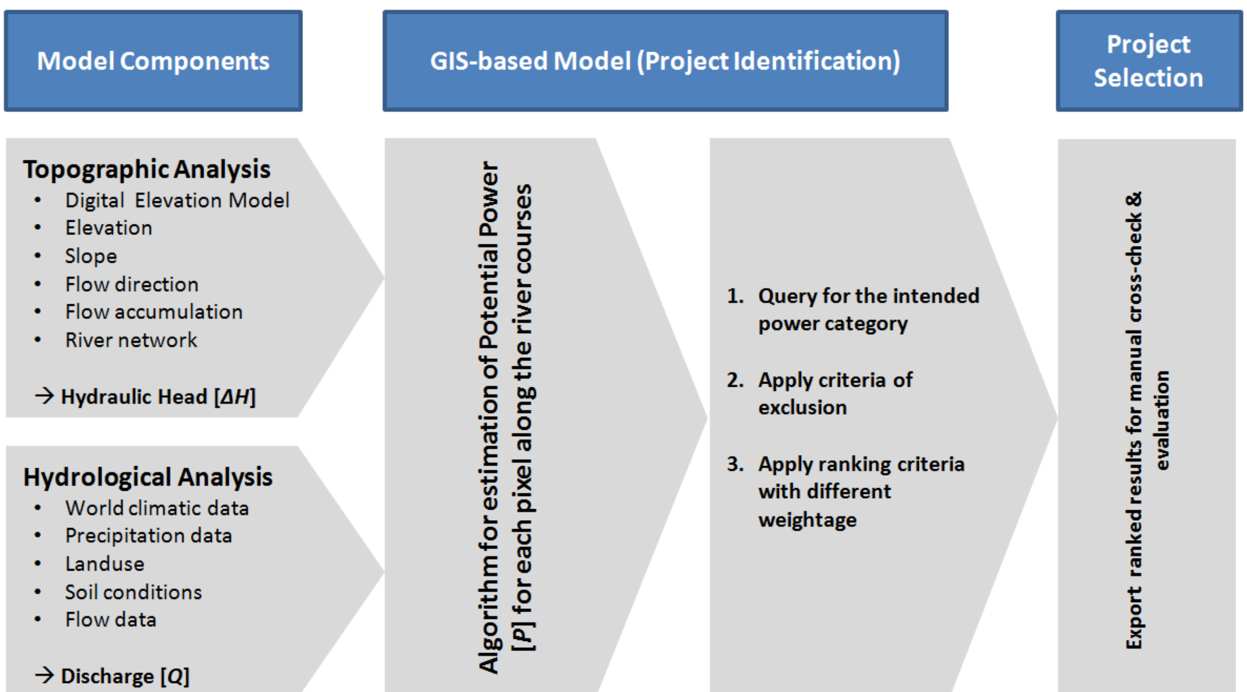

Fig. 1. Methodology for mapping of in-stream power potential in a study area and identify the suitable project location

The developed methodology allows to screen large areas throughout their extents and select the most attractive project locations using documented parameters. To carry out this methodology several data and the spatial analysis tools are needed.

The data sets that set the basis of this assessment are as follows:

For topographical analysis (i.e. estimation of river network, catchment area and head)

- *Topography* -a Digital Elevation Model (DEM)

For hydrological analysis (i.e. estimation of mean annual flow in river network)

- *Meteorology* - precipitation data
- *Hydrology* - river flow data
- *Soil Information* - data on soil texture
- *Land cover Information* - data on landuse

For project identification and selection (i.e. criteria for exclusion and ranking of project sites)

- *Protected area* - data on different levels of environmentally protected areas
- *Transmission line and Substations*
- *Roads*
- *Settlement*
- *Existing, ongoing and already planned locations*

For the analysis, the 'spatial-analyst' capabilities of the ESRI-GIS (ArcGIS 10.x) are exploited. These are the Geographic Information System (GIS) software developed by Environmental Systems Re-search Institute (ESRI) and currently are the most widely used tools for the problems needing spatial analysis. The software is equipped with different algorithms and filters, which enable to make a selection according to defined properties. These were supplemented with routines developed for the particular purposes.

Using these data, several analyses (pre-processing, processing and post-processing) is carried out using the ESRI-GIS system (Arc-GIS) in the spatially distributed manner (pixel or gridwise). The terrain analysis of the DEM provides the slope, flow-direction, flow-accumulation, river-courses and catchment boundaries in the study area. The potential runoff coefficient is, then, calculated for each grid based on the terrain slope, land use and soil-texture of that grid using a "modified runoff coefficient method" as adopted in WetSpa model (A GIS-based distributed watershed model developed in Vrije Universiteit Brussel, Belgium). Using these spatially distributed runoff coefficients and the mean annual precipitation, the mean annual runoff (MQ) for each grid is calculated. The MQ produced by each grid is, then, accumulated following the flow direction grid along the drainage path within the catchment boundary towards and into the river courses. This results into the output grid which provides the mean annual flow (MQ) potentially available at each river grid cell of the study area. It is then cross-checked, calibrated and validated with the available measured flow at gauging stations.

On the other hand, using geo-processing tools in GIS, the DEM is clipped with the extracted river network to obtain a DEM for the river network only. This River DEM is the basis for estimating the elevation drop or the static head (ΔH) along the river courses which is calculated successively for each river grid using Neighborhood Operations', that utilizes the spatial-analyst capabilities of GIS.

By knowing the available flow (MQ) and the static head (ΔH) at each river cell along the stream network, the potential power production along the river courses is then estimated. Based on these results, the hot-spots or the most promising theoretical potential locations can already be observed.

In a next step the exclusion criteria or hard criteria are applied to eliminate the locations that lie inside no-go zones. Such no-go zones are specified according to the specific needs of client or intended user, for example, which type of protected areas needs to strictly excluded, etc.

Then individually selected ranking criteria or soft criteria are applied, with custom weightage for the different criteria, to finally identify the relatively best locations for the hydropower sites in the study area. Such criteria are basically potential power, available head, distance to transmission line/substation, distance to road, intra-annual variability of flows or plant factor, located in international trans-boundary river, etc..

Such identified sites are then cross-checked and validated with the known locations of the already existing and already planned HPP sites in the study area. The remaining, yet unexploited, ranked locations are then exported to software such as Global Mapper for manual evaluation. A tentative layout and corresponding technical parameters, although at preliminary level, (e.g. installed capacity, waterway length etc) are estimated for each possible project site.

3. Results

All the required data was gathered for the country of Zambia and the methodology was applied as described above. After completing the initial basic screening process/steps, the possible hydropower locations are searched, in this case with the criteria of at least 10 MW potential in at maximum 5 km stretch of the river. Altogether 190 such locations are identified in the river network of the Zambia. An example of such identified locations is shown in Fig. 2 below.

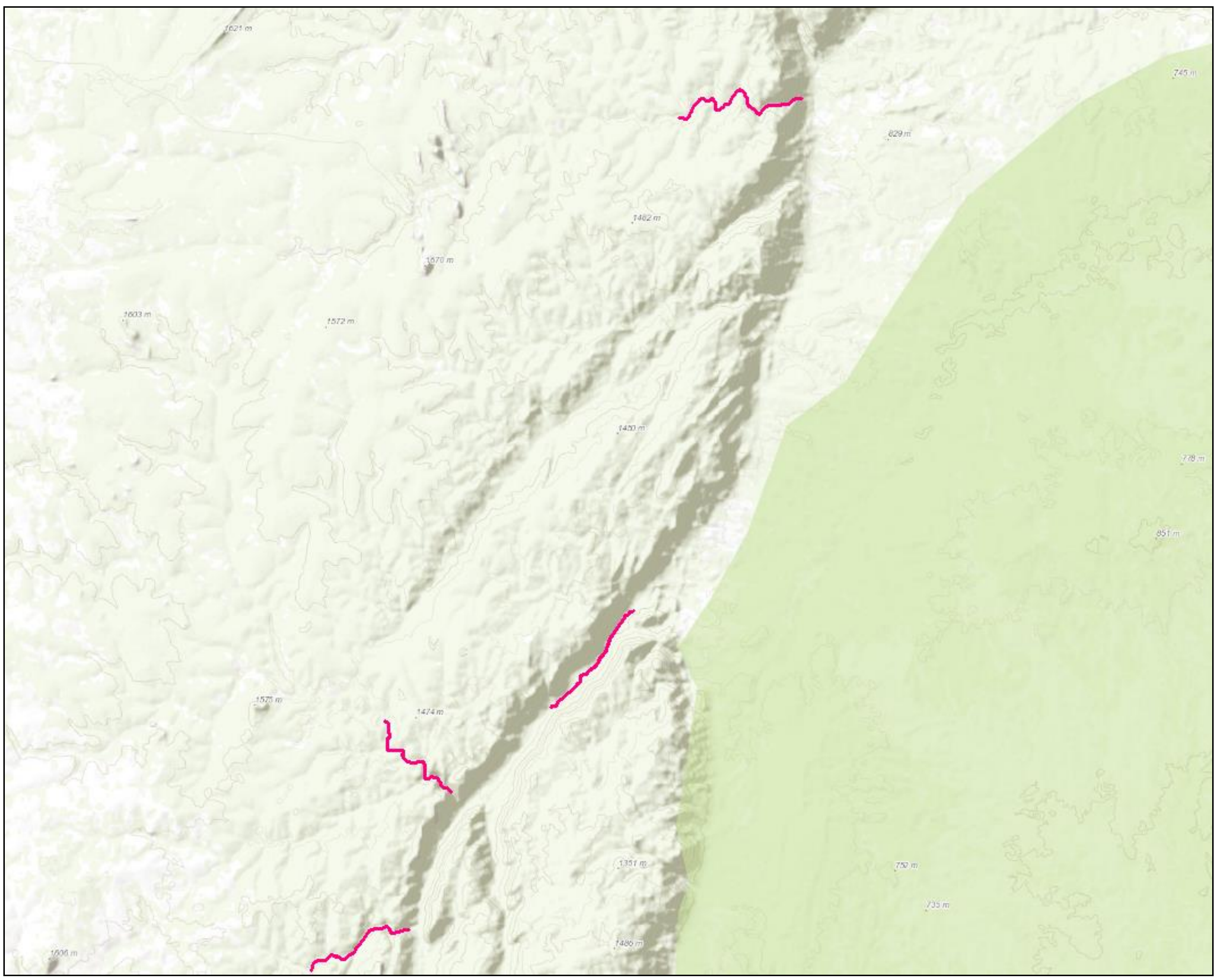

Fig. 2. Results of screening - an example location of potential river stretches in Zambia with at least 10 MW in at maximum 5 km river length

After applying the hard or exclusion criteria and the soft criteria with different weightages, 60 possible locations for the hydropower project remained in the country, which, based on the ranking, are exported for manual evaluation. A preliminary layout along with the corresponding technical parameters, are estimated for each possible project site. As an example, one such estimation is shown in Fig. 3, below.

Technical Parameters:

Project code	[-]	P109
Hydro power type	[-]	run-of-river
Gross head	[m]	205.00
Design flow	[m³/s]	10.50
Installed capacity	[MW]	17.95
Weir crest	[masl]	832.00
Weir fundation	[masl]	815.00
Channel elevation	[masl]	830.00
Channel length	[Km]	0.97
Penstock length	[Km]	0.279
Distance to tranmission line	[Km]	7.00
Tranmission line - Grade	[Km/MW]	0.78
Distance to access roads	[Km]	9.00
Access-Grade	[Km/MW]	0.50
Protected Areas	[-]	outside

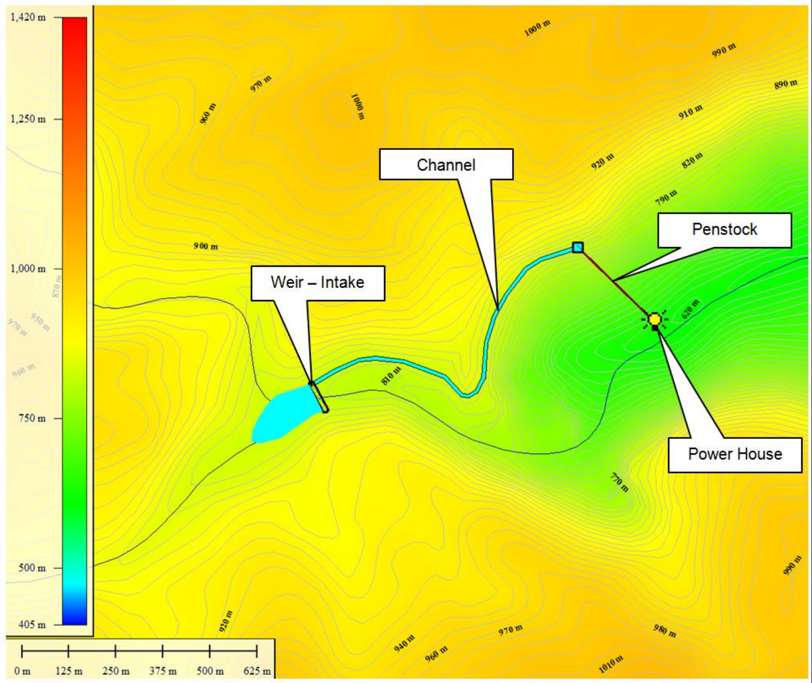

Fig. 3. Results of screening - an example of identified project

3. Summary and Outlook

The results in Zambia could capture all the locations of already existing and already planned HPP sites in the country. Similar results/conclusions are obtained when applied for several other countries like Mozambique, Malawi, Zimbabwe, Ethiopia, Guinea, Malaysia, Bhutan, Peru etc. This justifies and validates the adopted methodology and the used databases for the intended purpose.

Hence, the method based on a GIS-model driven by a comprehensive database, as presented in this paper, has proven to be a useful tool to identify the most promising, yet unexploited sites for the hydropower projects in large areas. The developed tool can be applied any place of any size in the globe by adjusting the parameters/criteria according to the specific needs.

Future developments may include the possibility to incorporate some level of financial analysis of the project to have a preliminary indication idea of the project's feasibility beforehand.

The Authors

Dr.-Ing. Pawan Thapa is a Civil Engineer, Hydrologist and GIS-Expert in the Hydropower Department of Fichtner Consulting Engineers, Germany. After graduation in Civil Engineering at the Birla Institute of Technology, India, and MSc in Water Resources Engineering, his PhD thesis at Stuttgart University, Germany, addressed Physically-based distributed hydrological modelling for soil erosion estimation with the application of GIS. Besides involving in the hydrological aspects of numerous

worldwide medium and large hydropower projects as well as flood protection and groundwater recharge projects, he is a GIS-expert for the application of the GIS-system for hydrological analysis as well as for project identification purposes.

Dr.-Ing. Patrick Schäfer has completed his Diploma in Civil Engineering at the Technische Universität München in 2000 and obtained the degree of Dr.-Ing. at the Institute of Hydraulic and Water Resources Engineering of the same University in 2006. In 2006 he joined Fichtner Consulting Engineers and since then contributed to a number of small and large hydropower projects, mainly in the stage of Feasibility Studies in Europe, Latin America, Africa, Southeast and Central Asia. He is specialized in hydraulic engineering, hydraulic structures and hydropower development. Since 2013 he is the Director for the Hydropower Studies Department at Fichtner.

Dr.-Ing. Sebastian Palt graduated in Civil engineering at the University of Karlsruhe in 1996. From 1996 to 2001 he completed his PhD thesis addressing sediment transport and its impact on hydropower development in mountainous regions at the University of Karlsruhe and was awarded with the Senator Huber award in 2002. In the same year he joined Fichtner as project manager and worked for various projects in Europe, Asia, Africa and Latin America. Between 2007 and 2010 he worked for project development in the International Development Department of E.ON Wasserkraft, where he was active mainly in the Balkan area, Turkey, Romania and France. Since 2013 he is the Executive Director of the Hydropower Department of Fichtner, Germany. He has worldwide experience in hydropower and development of reservoir sedimentation management approaches to ensure sustainable development. He was the principal in charge for development of the RESCON2 approach and software.