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Addressing Climate change in the water sector: The study of Run-of-river Hydropower potential in Vu Gia - Thu Bon river basin of Vietnam

L H Nguyen[1] and K Fukushi[2]

[1]Faculty of Environmental Engineering, National University of Civil Engineering, Hanoi, Vietnam
[2] Integrated Research System for Sustainability Science (IR3S), The University of Tokyo Institutes for Advanced Studies (UTIAS), Tokyo, Japan

E-mail: huongnl2@nuce.edu.vn

Abstract. Vu Gia - Thu Bon river is the major water resource for the region with especially high potential for small hydropower development. This paper studies the potential of developing small hydropower and off-grid electricity supply for the communities within the river basin. Estimated run-of-river hydropower potential in the study area was performed using a distributed hydrologic model and flow duration curve method. The result indicates the total run-of-river hydropower potential is 277.342 MW with an average capacity factor of 40.2 %; which means the system is capable of generating 1.02 million MWh in a year.

1. Introduction

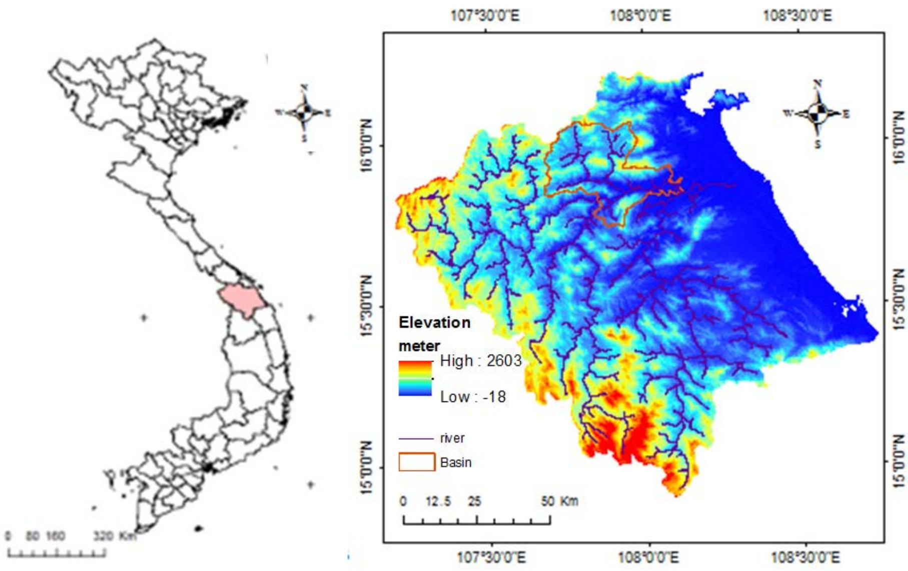
Vietnam is one of the most climate change vulnerable and disaster-prone countries [1]. Latest projection indicates that Vietnam will be hard hit by sea level rise, and intense and frequent extreme weather [2, 3]. Climate change can affect the spatial and temporal distribution of water resource as well as intensity and frequency of the extreme hydrological event [4]. Consequently, climate change generates extreme impacts on socioeconomic development and challenge on the natural resource management system of the country, especially water resource management system [5]. The climate change mitigation measures introduced aim at GHG emissions reduction; and hydropower is recognized as the most effective and affordable source for developing countries. Therefore, the development of energy sector, especially the hydropower is interlinked with water resources management and climate change mitigation. Small scale hydropower particularly run-of-river hydropower is one of the technology options to generate and supply electricity to grid off and rural applications with almost zero emission [6].

In this paper, the authors propose the development of scheme for hydropower development in order to cope with climate change in the Vu Gia - Thu Bon river basin of Vietnam. The potential of small hydropower in the representative river basin of Vietnam was analyzed. Estimated run-of-river hydropower potential in the study area was performed using a distributed hydrologic model and flow duration curve method.

2. Methodology

2.1. Study area

Vu Gia - Thu Bon river basin is one of the 5th largest river basins in Vietnam with the catchment area of over 10,500 km2. Two main rivers form the system named Vu Gia and Thu Bon, both origins from the Truong Son mountain range (Figure 1). This river basin is the major water resource for the region with especially high potential for hydropower development. The area with 75 % of hills and mountains are favoured for small and medium hydropower projects.



(a) (b)

Figure 1. Map showing location of study area (a), Vu Gia-Thu Bon River basin (b) (ArcMap 10.0)

According to the survey by Huong N. L. [7], the electricity demand at annual basis in the region for one rural household is 960 kWh, which is lower than the country's average. The total electricity demand is 0.14 million MWh/year in 2012 and estimated to increase to 2.3 million MWh/year in 2041. However, the electricity supply in this rural area is not stable, especially in dry season; and the electricity blackout often takes place. For some remote areas without access to electricity, firewood and LP gas was seen as the main energy source.

2.2. Hydropower potential assessment

Hydropower potential is estimated from two major components: the head and the availability of flow. The flow assessment is conducted by employing Arc-SWAT model; and then the availability of flow is performed using the flow duration curve.

This study assesses only the run-of-river hydropower which is generated without reservoir construction but diverting water from streams to a bypassing pipe or channel and finally into the turbine. The low head run-of-river scheme is chosen with the head of 20m. This is done to ensure that the tail race of the upstream site is not influenced by the reservoir of the downstream site. Also, these run-of-river hydropower projects shall be located close to rural communities. Therefore only watersheds with rural settlements were selected.

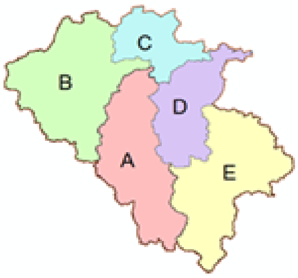
2.3. Data processing

Digital maps, DEM, land use, and soil, in raster format, are needed to derive watershed characteristics for the Arc-SWAT model input. DEM resolution of 30 m is derived from digital topographic map with scale 1:50000. The digital maps are obtained from Quang Nam Natural Resources and Environment Department. Daily rainfall data were collected for fifteen year period (from 1996 to 2007) from 16 meteorological stations established within the watershed. These data were preprocessed and checked for continuity and applicable to the Arc-SWAT model requirement. Temperature, wind, relative humidity and solar radiation data pre-processed for SWAT model were obtained from The National Centers for Environmental Prediction (NCEP). Discharge data were obtained from Thanh My station with a daily record from the year 1996 to 2007.

2.4. Estimation of flow

Flow data for each of river reaches is needed to construct a Flow Duration Curve at sub-watershed level. This study employs simulation model to obtain flow data. There are varieties of models available to choose, from the empirical and conceptual of physical models. The SWAT model (Soil and Water Assessment Tool) is chosen among some most popular models.

SWAT model calibration and validation improve the reliability of model estimates. In this study, a semi-auto calibration and validation are employed. The model performance was evaluated by comparing simulated and observed discharge data with an usage of two statistical indices: Coefficient of determination (R2)[8] and Nash and Sutcliffe efficiency (NSE)[9]. The calibration and validation process following the SWAT guidelines and [10,11].



	Sub-basin	Area, km^2
A	Thanh My	2464.62
B	Song Bung	2450.67
C	Song Con	913.43
D	Nong Son	1346.56
E	Hiep Duc	2334.06

Figure 2. Sub-basin delineation

2.5. Estimation of power potential

Run-of-the-river plants generally operate at the base of the load curve, as compared with storage plants operating at the peak of the load curve [12]. Flow duration curve analysis is a method involving the frequency of historical flow data over a specified period. From SWAT model output, flow data is extracted by daily time scale. The data is then used to construct FDCs for each of the watersheds. The hydroelectric power was calculated at the outlet of each basin to represent the optimum ROR hydropower potential at the basin scale. The water head of 20 meters was chosen as the minimum vertical flow of water from the upstream level to a downstream level that represents low head ROR hydropower stream. The dependable flows extracted from FDC data (Q95, Q25) were used to determine the power output from each watershed. These flow represented the ability of the ROR hydropower scheme to operate throughout the year, and during peak flow period.

The theoretical power potential is calculated as

$$P=\eta \rho Q g H \quad (1)$$

Where: P is the mechanical power produced at the turbine shaft (Watts); η is hydraulic efficiency of the turbine (85%);ρ is the density of water (1000 kg/m3); g is the acceleration due to gravity (9.81m3/s); Q is the volume flow rate passing through the turbine (m3/s); H is the head of water across the turbine (20m). The downstream release of 10 % is considered for environmental consideration.

3. Results

3.1. SWAT model calibration and validation

To optimize the simulation process using ArcSWAT (Figure 3), the Vu Gia-Thu Bon river basin was divided into five sub-basins using the catchment delineation tools in ArcSWAT. The outlets of these sub-basins were located according to the location of monitoring stations namely: Thanh My, Song Bung, Song Con, Nong Son and Hiep Duc (Figure 2).

Firstly, the model performs the daily simulation for Thanh My sub-basin from January 2005 to December 2007 (including five years warm-up period) for calibration. Calibration parameters from Thanh My simulation are used for model validation for the three years period (January 2002 to December 2004) at Thanh My sub-basin. Due to observation data availability, after calibration/ validation of Thanh My sub-basin was done, the calibrated parameters were applied for the remaining sub-watersheds with the assumption that the model would give similar performance.

Nash - Sutcliffe Efficiency (NSE) and Coefficient of determination (R2) values obtained from calibration of Thanh My sub-basin was 0.61 and 0.50 respectively. While in the validation phase, the values were 0.60 and 0.53 respectively. These values indicate that there is a good agreement between simulated and observed discharge at Thanh My station (Figure 4).

The calibrated parameters were used to validate the remaining sub-watersheds. The result of mean annual flow shows that there are two distinct seasons namely flood season and low flow season. The flood season starts from September and ends in January with the flow accounted nearly 70% of the total flow and peaks in October with over 20% of total annual runoff. The dry season comprises only 30 % of total annual flow. The driest month is April. It is exceptional in May and June; there is the secondary rainfall peak in a year, which forms a Tieu Man flood period in the river.

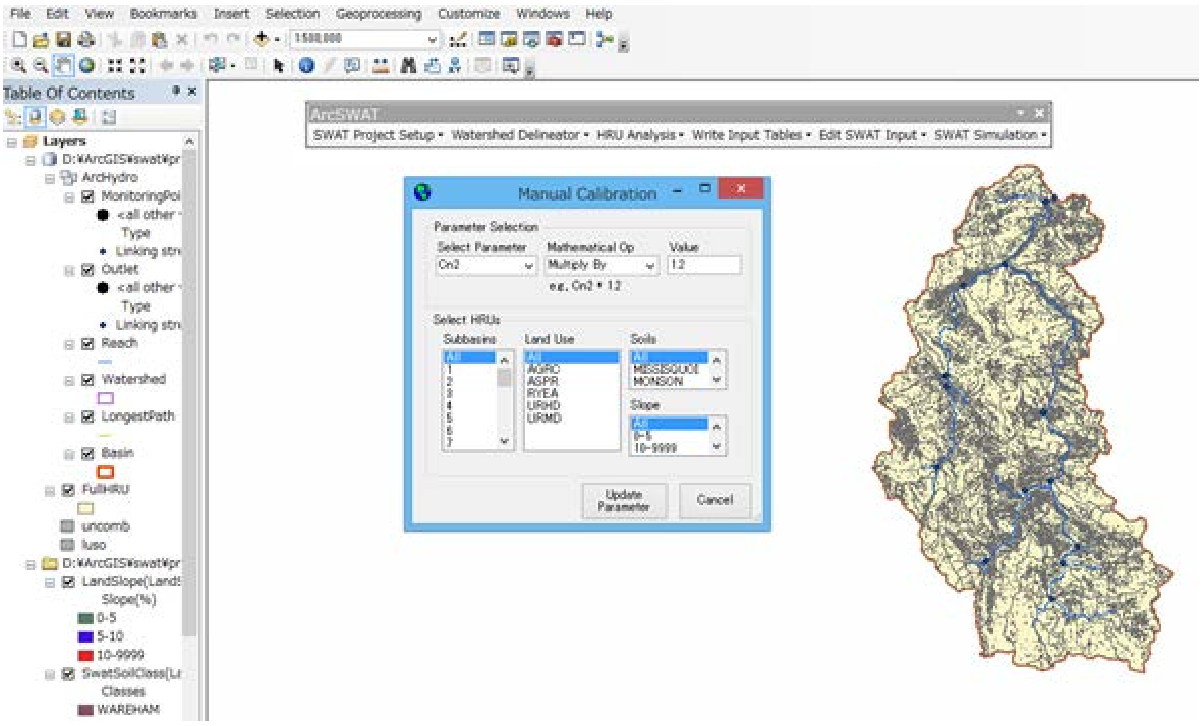


Figure 3. Screen capture: Model calibration for Thanh My sub-basin using Arc SWAT: Model calibration was performed by editing the model sensitive parameters within the recommended ranges to best match with the observed data at the selected outlet.

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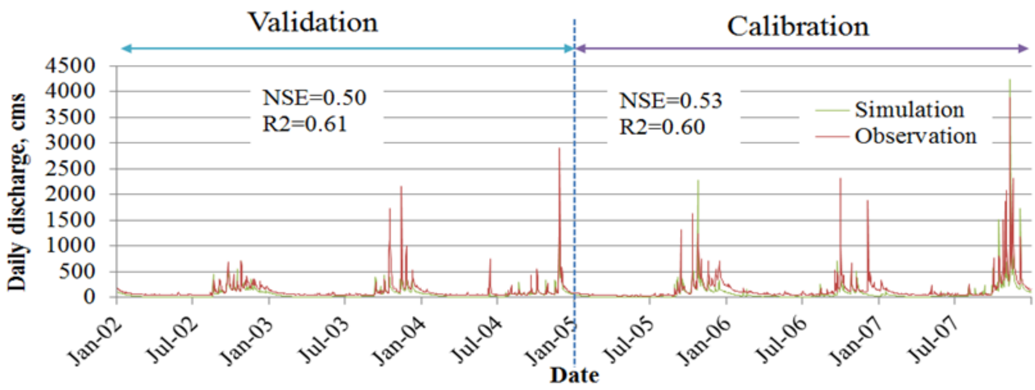

Figure 4. Calibration and Validation of ArcSWAT Model at Thanh My Station

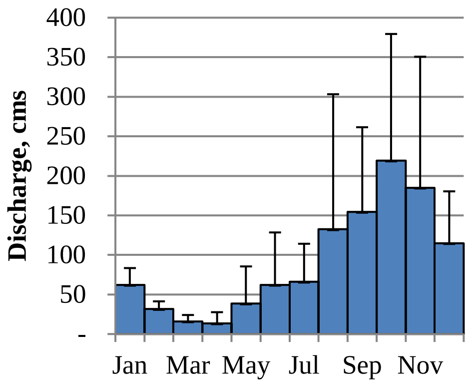

Figure 5. Mean monthly discharge at Thanh My outlet

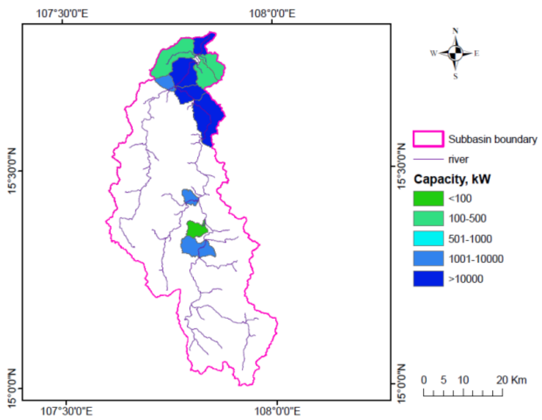

Figure 6. Thanh My run-of-river hydropower potential

3.2. Hydropower potential estimation

Daily discharge data from each of the watersheds is extracted from SWAT output files for ten years period (from 1998 to 2007). The representative result of Thanh My sub-basin is shown in Figure 5 and Figure 6. The daily flow obtains from the model output is then computed into FDC's curves for each of the sub-watershed as shown in Figure 7.

The constructed FDCs for each watershed will give the information of the flow availability throughout the year. For hydropower project, the percentage of flow exceedance at 25% is used to design plant capacity this is to ensure that there is enough flow of 25% time for hydropower generation.

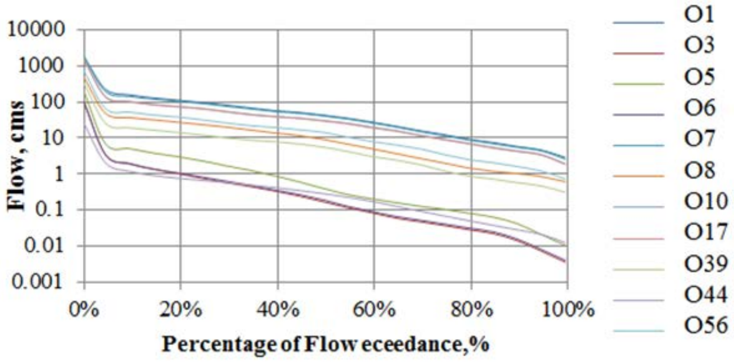

Figure 7. Flow duration curve for Thanh My Sub-basin (1998 to 2007)

The total potential ROR hydropower in each sub-basin is calculated using equation [1]. The total number of potential outlet for run-of-river hydropower installation point was 103 computed using ArcGIS. The total theoretical ROR hydropower for the Vu Gia - Thu Bon river basin potential is 277.342 MWh.

Hydropower potential was categorized according to size from micro (5kW-100kW), mini (100kW-1MW), small (1MW-10MW), medium (10MW-100MW). The majority number of the power plant is mini size ROR hydropower plant with 62 sites. With this size, it could able power 6200 to 62000 households with an average annual electricity consumption of 3,500 kWh.

4. Conclusions

The technical ROR hydropower potential was estimated using ArcSWAT, flow duration curves and energy duration curves. The hydrological models for the five sub-basins of the Vu Gia-Thu Bon River basin were developed by SWAT. The model simulated quite good especially in the dry season, but slightly under-predicted the discharge during monsoon season. The dry season flow or low flow in rivers is fundamental for hydropower development projects. Hence, the model shows good simulation in dry period, which indicates the suitability of SWAT to perform flow prediction for hydroelectric power generation on the daily basis. According to this study, the total run-of-river hydropower potential is 277.342 MWh with an average capacity factor of 40.2 %, which means the system is capable of generating 1.02 million MWh in a year. The ROR hydropower potential estimated in this paper provides fundamental information to the government and developers as well as the community to formulate plans and policies to develop small hydropower in the river basin.

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