The Utilization of Geographic Information Systems and Multi-Criteria Decision Making with Local Community Participation for Selection of Site for Micro Hydropower Project: A Case Study of Chi River Basin, Thailand

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Abstract

At the present, the situation of shortage of world energy is worsened because of many crucial problems viz., the rapid economic growth in China and India, the revolt in the world's leading trader in crude oil such as Libya, and the explosion at nuclear power plant in Japan. Accordingly, this significantly affects the socioeconomic development of all nations including Thailand, depending upon imported fossil flue, mainly. The exploration and development of renewable energy sources for generating electricity becomes a necessity and urgent. One of the interesting renewable energy sources such as micro hydropower, which requires a small investment and can be easily developed with minimum environmental impact, is considered to be an important alternative energy source for generating electrical power. This study is, therefore, to assess potential area where could be used to develop of a micro hydropower plant in the Chi-river Basin using geographical information systems together with multi-criteria decision making. It was founded that there are seventy potential areas, where could be installed the hydropower generator of more than five kilowatts. The total installation capacity of the generator of these potential areas is 23 megawatts resulting in unit of electricity of 83 gigawatt hours. The potential sites were classified into two categories: (1) the storage project of 28 sites; and (2) the in-river project of 42 sites. These sites were prioritized considering their strengths and weaknesses, in order to develop a pilot project, using multi-criteria decision making with five groups of expertise viz., engineering, economy, environment, socio-economy and community participation. From the prioritization process of community micro hydropower pilot project in the Chi river basin, the top ten ranking were: Chilong-4, Chilong-5, Kanchu-4, Lampao-Dam, Wangyang-Reservoir, Chi-1, Kuichurk-Weir, Thartnoi-Weir, Chi-2 and Chi-3. In addition, the top three ranking were chosen into the intensive community participation process, resulting that the Chilong-4 site was selected to be a pilot project for developing micro hydropower.

1. INTRODUCTION

At the present, all nations are dealing with energy crisis problems that are one of the most crucial factors impacting to economic and social developments. The main causes of the energy crisis, during this decade, was beginning with the rapid economic growth in China and India, subsequently revolting in the world's leading trader in crude oil such as Libya. Additionally, from natural hazards such as Tsunami and Earthquake, the explosion at nuclear power plant in Japan resulting occurred in 2011 causes radioactive leak. Accordingly, a number of people in Japan and many countries oppose to nuclear energy. Therefore, the exploration and development of renewable energy sources, which do not disturb global environment, for generating electricity such as hydro, wind and solar powers becomes a necessity and urgent.

Hydropower is a renewable and clean energy which has contributed least to greenhouse gas emissions (Gagnon and van de Vate, 1997). In the past, hydropower was widely developed in large scale such as big dam; however, the dam construction lead to the other problems such as environmental or ecological problems. These problems was solved by applying small-scale hydropower which could be easily developed in a short time based on local community participation. In addition, the small-scale hydropower could be used as a main energy resource for rural area as well as a supplementary for the country level. Accordingly, it is very important to discover a potential area where is able to develop the small-scale hydropower project.

Past attempts such as Rojanamon *et al.* (2009) and Supriyasilp *et al.* (2009) used geographic information systems to evaluate the potential areas, in Nan and Ping River Basin, for developing small-scale hydropower project. Additionally, Surpiyasilp et al. (2009) subsequently employed multi-criteria decision making for ranking these potential areas. It was found that the integration of GIS and MCDM can be used to analyze the potential areas in the Northern Part of Thailand effectively. However, in the past attempts, they did not bring the top rank result for practical development. Taking the Chi-river basin located the longest river in Thailand as a case study. Therefore, the aims of this study is to employ the integration of GIS and MCDM for ranking the potential areas and subsequently, to select the potential area for developing a small-scale hydropower with local community participation.

2. STUDY AREA

The Chi River Basin, a tributary of the Mekong River, is located in northeastern Thailand (Figure 1). It extends between 15°30'-17°30' N latitude and 101°30'-104°30' E longitude, covering an area of 4,912,987 ha (49,129.87 km^2). The elevation ranges from 100 to 1350 m msl. The slope varies from 20 - 450%. Relatively flat slopes (less than 20%) are found predominantly in the whole study area, while in the northwestern part in the lower part. The river bank level of main stream varies from 190 m to 100 m msl with an river gradient of 1:4200 in upper stream and 1:10,000 in lower stream. The mean annual rainfall for the area is about 1300 mm. The average annual runoff ranged from 4.0 to 9.7 liters / sec / km ²

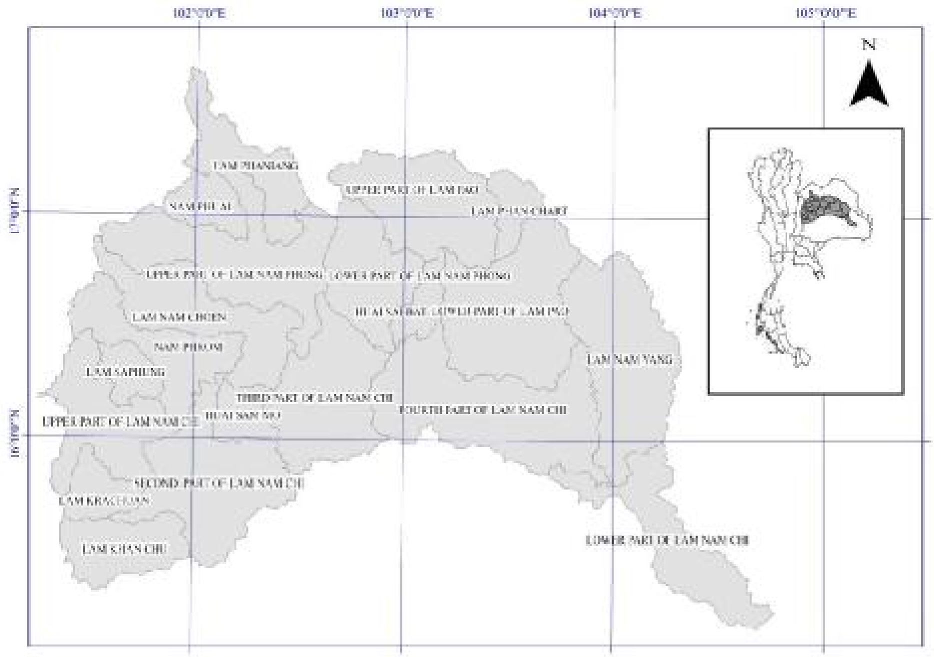

Figure 1. The study area in the Chi River Basin located in Northeastern Thailand

3. DATA AND METHOD

3.1 Preliminarily Locating the Potential Area for Developing Hydropower Project

In order to preliminarily identify the potential areas for developing small- and micro-hydropower projects, GIS data distributed by the Royal Thai Surveying Department, including a 30-m digital elevation model (30-m DEM) derived from aerial photogrammetry and a map layer of hydrographical features at scale of 1:50,000, was employed. Based on the hydrographical features, we classified the micro-hydropower projects into two categories: (1) in-river project; and (2) storage project. The technical details for assessing the potential areas for each type of projects were described as follow.

3.1.1 In-river project

This type of micro hydropower projects are designed to run in-river. In order to identify the potential area for this project type, we used hydropower formula as shown in equation (1). Using 3D Analyst and Spatial Analyst modules in the ArcGIS software, the Chi River and its tributary from the map layer of hydrographic features was used to extract their elevations along the river profile from the 30-m DEM. The water head was obtained from the elevations of river profile. An area where has the water head of at least 30 meters within a horizontal distance of 1 kilometers along the river profile was used to determined an installation capacity. In addition, hydrological data and catchment area that was derived from the 30-m DEM of the area were used to derive the basin discharge (Q). Subsequently, employing equation (1), an installed capacity for each area was estimated. The area whose installation capacity is not less than 5 kW would have been classified as the potential area.

$$E = 9.81\eta QH \quad (1)$$

Where E = Installation Capacity (kW)
η = Total efficiency losses = 0.75
Q = Basin discharge (m^3/s)
H = Net head of water (m)

3.1.2 Storage project

In the Chi-river basin, 675 medium and small reservoirs were constructed to increase the availability of water during the period of low flow or dry years. In order to determine the potential of these medium and small reservoirs for developing the micro hydropower project, a formula as shown in equation (2) was employed in estimating annual power generation using active storage of the reservoir together with its water head derived from physical structure of the reservoir (Bongerider, 2006). Subsequently, based on the assumption that generator was run twelve hours a day per three hundred days a year, installed capacity for each reservoir was determined by utilizing equation (3). Similar to the in-river project, the reservoir where has installation capacity of at least 5 kW would have been categorized as the potential area.

$$P = \frac{9.81\eta VH}{3600} \times 10^6 \text{ kWh} \quad (2)$$

$$E = \frac{P}{12 \times 300} \times 10^6 \text{ kW} \quad (3)$$

When P = Annual power generation
η = Total efficiency losses = 0.75
V= Active Storage (m^3)
H= Net head of water (m)

3.2 GIS-based Analysis

In order to determine environmental impact and agricultural impact, the potential areas were overlaid with land use/cover map at map scale of 1:4,000 which was distributed by the Land Development Department. A map layer of national park and forestry area was also adopted in order to assess the area limited to develop by the national forestry law. In addition, we used a map layer of road network together with electrical transmission line for estimating the length of transmission line from the potential area

3.3 Ranking the potential area for developing the micro-hydropower project

Multi-criteria decision making method with analytical hierarchy process was used to analyze the advantage and disadvantage for each potential area based on five aspects, which were taken as main criteria in this study, including engineering, socio-economic, environment, stake-holder involvement, and economics. For each main criterion, it was divided by expert group into sub-criteria described as follows.

3.3.1 Engineering aspect (A)

1. Installed capacity (A1) indicates the potential for generating electrical power in each area. 2. Annual energy production (A2) indicates the potential for producing electrical energy per year.
3. Improving the usefulness of existing reservoir (A3) determined from an available of reservoir for each potential site indicates engineering feasibility, and difficulty in construction.
4. Length of transmission line (A4) indicates the distance from the electricity generating site to the electricity distribution system.

3.3.2 Economical aspect (B)

1. Annual flow (B1) is a major factor for hydropower capacity.
2. Accessibility to project site (B2) indicates the distance from major roads to the hydropower construction site is directly related to construction cost.
3. Benefit to cost ratio (B3) indicates rate of return on investment of the project identifying the economic value of investment and operations.
4. Project cost (B4) indicates the budget for set up the project.
5. Internal rate of return (IRR, [B5]) indicates the profitability of investments for each potential area.
6. Net present value (NPV, [B6]) indicates the overall present value of the micro-hydropower project for each potential area.

3.3.3 Environmental aspect (C)
1. Site location (C1) indicates legal obstacle caused by the position of the potential area situated in the areas under the supervision of the Department of National Park, Wildlife and Plant Conservation.
2. Dust and noise during site construction (C2) depending on the length of the construction period disturbs directly to an environmental impact.
3. Local community impact (C3)
3.3.4 Socio-economic aspect (D)
1. Water resource problem (D1) indicating a repetitious drought area, lack of water for agriculture, or problems related to water utilization and accessibility to water resources in the potential site.
2. Existing extent of electricity for household use (D2)
3. Poverty level (D3) was used to identify the poverty level in accordance with the Thai Government dataset.
4. Transportation condition (D4) indicates the facility convincing to develop the micro-hydropower project.
5. Unity of community (D5) indicates the availability of local community for constructing the micro-hydropower project.
6. Land tenure (D6) indicates the type of land ownership in the potential areas resulting to the chance for developing project.
7. Number of household expected to benefit from hydropower project (D7) indicates to the level of community participation in the potential area.

3.3.5 Stake-holder involvement (E)
1. Level of understanding and acceptance of the local administrative unit (E1)
2. Potential of the local administrative unit for developing and managing the micro-hydropower project (E2)
3. Local community budget for cooperating to develop the micro-hydropower project (E3)

Table 1 Weight of main criteria and subcriteria

Main criteria	Sub Criteria	Description	Type	Weight from Expert
A Engineering aspect (0.0617)	A1	Installed capacity	Quantitative	0.1961
	A2	Annual energy production	Quantitative	0.0980
	A3	Improving the usefulness of existing reservoir	Qualitative	0.5882
	A4	Length of transmission line	Quantitative	0.1176
B Economical aspect (0.1235)	B1	Annual flow	Quantitative	0.5181
	B2	Accessibility to project site	Quantitative	0.0576
	B3	Benefit to cost ratio	Quantitative	0.1727
	B4	Project cost	Quantitative	0.0740
	B5	Internal rate of return	Quantitative	0.0740
	B6	Net present value	Quantitative	0.1036
C. Environmental aspect (0.3704)	C1	Site location	Quantitative	0.2941
	C2	Dust and noise during site construction	Qualitative	0.1176
	C3	Local community impact	Qualitative	0.5882
D. Socio-economic aspect (0.0741)	D1	Water resource problem	Qualitative	0.3857
	D2	Existing extent of electricity for household use	Quantitative	0.1928
	D3	Poverty level	Qualitative	0.1286
	D4	Transportation condition	Qualitative	0.0551
	D5	Unity of community	Qualitative	0.0964
	D6	Land tenure	Quantitative	0.0643
	D7	Number of benefit household	Quantitative	0.0771
E. Stake-holder involvement (0.3704)	E1	Level of understanding and acceptance	Qualitative	0.5455
	E2	Potential of the local administrative	Qualitative	0.1818
	E3	Local community budget	Quantitative	0.2727

4. RESULTS AND DISCUSSION

4.1 Potential area for developing the micro-hydropower project

Based on the use of GIS and hydrological analysis, it was found that there are seventy potential areas with the total installation capacity of 23 MW which can be divide into two groups consist of: (1) the storage project and (2) the in-river project (Table 1 and Figure 1). There are 28 potential areas with the total installation capacity of 5.8 MW for the storage project whereas there are 42 potential areas with the total installation capacity of 17.2 MW for the in-river project.

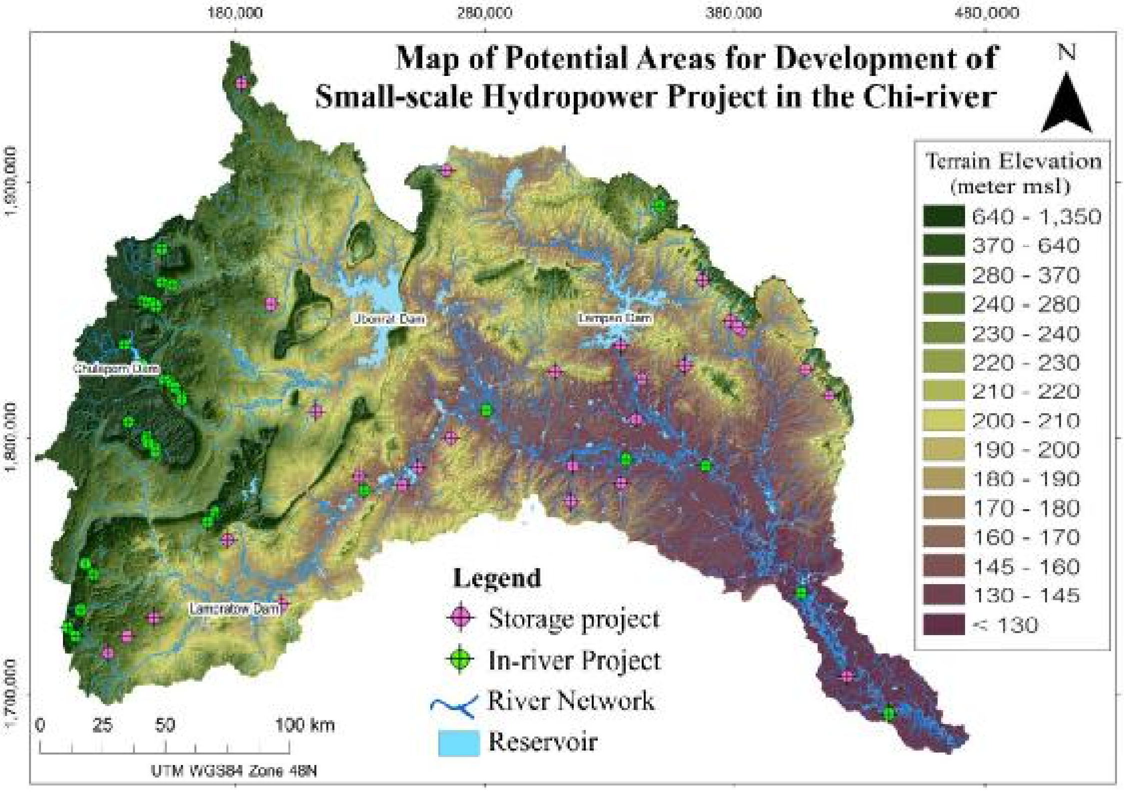

Figure 1 A map showing seventy potential areas that can be developed small-scale hydropower project in the Chi-river Basin

Table 2 The number of the potential area for each type of project

Type of project	Number of Site	Installation Capacity (MW)	Annual Energy (GWh)
Storage project	27	5.8	20.74
In-river project	36	17.2	60.97
Total	70	23.0	82.71

4.2 Assignment of weights for AHP process

An expert group for each main criteria and sub-criteria have discussed and assigned criteria weight, resulting that the stakeholder involvement and the environmental aspect are the same weight. This indicating that, in the Chi-river Basin, the stakeholder involvement and the environmental aspect are the most important aspect while the second most to the least are economics, engineering and socio-economics, respectively. In addition, the weights of the main criteria and sub-criteria can be summarized in Table 2. Using these assigned weight, the seventy potential site was ranked, indicating that the top ten ranking were: Chilong-4, Chilong-5, Kanchu-4, Lampao-Dam, Wangyang-Reservoir, Chi-1, Kuichurk-Weir, Thartnoi-Weir, Chi-2 and Chi-3. Consequently, the top three ranking were chosen into the intensive community participation process in order to select the pilot project for construction the small-scale hydropower station.

4.3 Selection of pilot project

The first two rank of the potential areas is the Chilong -4 and 5 situated in Huay-ton sub-district Muang District of Chaiyapoom province. and The third rank is the Kanchu-4 located in Banrai sub-district Dhepsatit District of Chaiyapoom province. In order to select the most suitable site for developing the pilot project, these top three ranking were studied about the availability of the community and their local government organization which here refered to "Subdistrict Administration Organization". In this stage, the criteria for deciding on the pilot area are considering from their installation capacity and contribution budget obtained from their Sub-district Administration Organization. As a result, the Sub-district Administration Organization where these potential sites located have demonstrated the potential for supporting the pilot project by cooperating their contribution budget. The Sub-district Administration Organization of Huayton sub-district located the Chilong - 4 and 5 support the contribution budget of nine hundred thousand baht while the Sub-district Administrative Organization of Banrai sub-district located Kanchu-4 support the contribution budget of five hundred thousand baht. This imply that these two sub-district administration organization are agree to contribute their budget to develop the pilot project. Additionally, within these potential sites, the Chilong-4 has the most installation capacity. Therefore, based on these two criteria we select the Chilong-4 as the pilot site for developing the hydropower project.

4.4 Feasibility study of the Chilong-4 hydropower project

In this stage, based on the use of local community participation process, the detail design of the Chilong-4 hydropower project has been done, resulting that this pilot site has the maximum installation capacity of 60 kW but the local community together with the Sub-district Administrative Organization of Huayton sub-district and the National Park of Thadtone agreed to use the actual installation capacity of 40 kW because of environment and ecosystem aspects. In addition, according to comments from the community and the National Park officers, we decided to install intake station by modifying an existing weir situated along the stream as well as located the power plant outside the boundary of National Park with a two unit of 20-kw hydro turbine. The total cost of pilot project construction is approx. 9.5 million Thai Baht. Subsequently, based on the detail design in the stage, the economical analysis has been done, indicating that, this project could produce a total energy of 0.3 million unit and earn about 1.25 million Thai Baht when they sale the generated energy the Provincial Electricity Authority with a unit price of 4.5 Thai Baht derived from a basic unit price of 3 Thai Baht plus a unit adder of 1.5 Thai Baht. Additionally, using a discount rate of 5 percent with a project life cycle of thirty years, the benefit to cost ratio of 1.24 and a return period of 18 years could be obtained. From these reasons, this pilot project is very interesting for investment. Moreover, if the Thai Government would have increased a unit adder to be 3.5 Thai Baht equal to a unit adder that they give to electrical power from wind, this pilot project would earn a annual income of 2.08 million Thai Baht and the benefit to cost ratio would change to 2.08 with a return period of 8 years. This result implies that the Thai Government should increase a unit adder for the hydropower at least equal to wind power. Therefore, the suitable adder for micro hydropower should be 3.5 Thai Baht.

5. CONCLUSIONS

An assessment of potential area for developing small-scaled hydropower, which has installation capacity of at least 5 kW, has been done, resulting that there are seventy site that can be used to develop small-scale hydropower project. Analysis of the advantages and disadvantages for each potential area has been conducted and subsequently its results was employed in ranking these seventy potential sites using multi-criteria decision making (MDCM) with analytical hierarchy process (AHP), indicating that the top three rank were: Chilong-4, Chilong-5 and Kanchu-4. Based on the community participation process, the Chilong-4 was selected to develop the pilot project. In addition, the detail design for this pilot project has been done by integrating with comments from the local community and then the economical analysis has been conducted, resulting that the Chilong-4 hydropower project is cost-effective as well as has been greatly accepted from the local community and local administrative office. Furthermore, in order to develop the small-scale hydropower in the future for the other potential areas, we can used knowledge and experiences obtained from this study. In addition, this study demonstrated that, based on the community participation process, medium and small reservoir under the supervision of local government office could be utilized for generating electrical energy which could be used to strengthen the energy security of the country.

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