Application of Geographic Information System to Site Selection of Run-of-River Type Small Hydropower Project Based on Environmental Criteria

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Abstract

In order to implement the run-of-river type small hydropower project, the environmental impact has to be carefully considered since the project begins because water is an important natural resource. This article proposes a methodology to locate the project based on environmental criteria by using Geographic Information System (GIS). Nan province situated in the northern region of Thailand was selected as a case study.

After the literature study, the environmental criteria were created as the environmental constraints and parameters. The constraints were set up according to the regulations of Thailand government. The questionnaire based on the principle of Delphi Technique was created to verify the assigned significant score, suitability rank, weighting scale (importance), and the suitability of parameters.

Sieve Analysis was employed to select the engineering and economically feasible projects which regards to the constraints. Then the significant score was multiplied by weighting scale. Finally, the total weighted score of the selected project was determined by using Weighted Linear Combination Approach.

1. Introduction

As the world is being alert about the environmental problem and population growth, natural resources are needed and should be preserved for the next generation. The current sources of energy are mainly based on coal, oil, and natural gas which are exhaustible. The new concept about renewable and clean source of energy, which has less effect on the environment, is introduced consequently.

The run-of-river type small hydropower project is one type of small hydropower project without a reservoir. By considering the advantages of hydropower and the smaller area needed, we are convinced that the run-of-river type small hydropower project has a high potential to be a future energy source with low environmental impact.

Anyhow the project needs to construct a weir on the stream; it may affect other activities relying on the same stream. Therefore the environmental impact has to be carefully considered from the beginning of project, and the site selection stage. The optimum project should be the engineering, economically, and environmentally suitable project.

The site selection is formerly performed by selecting a possible location using a map scale of 1:50,000. A field observation should be done if needed. The selection process will be done site by site and may take a lot of time. In order to reduce the time and to make a better decision, GIS is applied. GIS is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. [1] It can display the information in the form of graphic correlated with data. Since the beginning, GIS has been important in natural resource management including land-use planning, natural hazard assessment, wildlife habitat analysis, riparian zone monitoring, and timber management. In more recent years GIS has been used for crime analysis, emergency planning, land records management, market analysis, and transportation applications.[2]

According to the Small Hydropower Technology Action Plan for the 5 year period (2002-2007), the Department of Energy Development and Promotion (DEDP), Ministry of Science Technology and Environment, there are 192 potential sites in Thailand. The highest number of potential sites is in Chiang Mai, Maehongson, and Nan with 61, 41, and 17 sites respectively.[3] Thus the proposed methodology for site selection based on environmental criteria will be applied to find the environmentally feasible small hydropower projects in Nan province as a case study. (Fig.1)

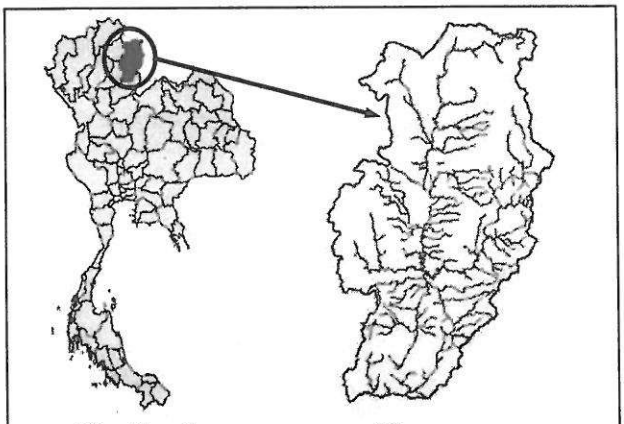

Fig.1 Nan province in the northern region of Thailand

2. Run-of-river Type Small Hydropower Project

2.1 Definition

A run-of-river project utilizes the flow of water within the natural range of the river or only a fraction of it. In the former case, inflows into the plant change as river flow changes throughout the year. Consequently, the amount of power produced by this type of run-of-river projects may vary since it depends on the river discharge. Most run-of-river plants are therefore conceived so as to provide the same power output all year long for the base demand, using only a fraction of the total river flow. [4] Fig.2 shows the project components of the run-of-river type hydropower project.

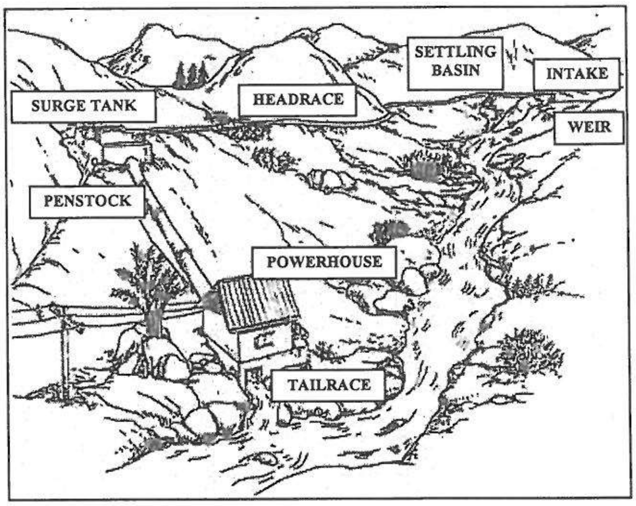

Fig.2 Components of run-of-river type hydropower project [5]

Small-scale hydro is in most cases 'run-of-river'; in other words any dam or barrage is quite small, usually just a weir, and generally little or no water is stored. The civil works purely serve the function of regulating the level of the water at the intake to the hydropower plant.[6] The project process begins with the water flowing over the weir, it will be conveyed by the intake to the settling basin. In this area the water will flow slower, which makes the suspended sediment to settle, before passing through the waterway route. The waterway route composes of a headrace, surge tank and penstock. Finally, the water will flow through turbine in the powerhouse before it returns to the stream by tailrace.

In Thailand, small mini and micro hydropower project have installed capacity of between 6001-15,000 kW, between 201-6,000 kW, and below 200 kW respectively. [7] The run-of-river type small hydropower project in this study has the installed capacity between 1MW to 6 MW, which is a small-scale project.

2.2 Environmental Impact

Even the run-of-river type hydropower project causes relatively small environmental impact due to the size of project and no reservoir. There are environmental impacts resulting from three main factors: changes in the river flow characteristics, changes in the ecosystems of land inundated, and erection of barriers which interfere with the natural movements of fish and wildlife. [8]

Most potential impacts will be minimal and temporary, and ecosystems should recover quickly if care is taken during the activities. The visual impact of small-scale hydro schemes can be minimized by careful site selection, good design and various amelioration techniques. Overall, the impacts of small-scale hydro schemes on aquatic ecosystems are likely to be extremely small and localized. Exceptions to this may occur where bad practice means insufficient care is taken in mitigation measures.[8]

3. System Analysis

3.1 Framework

Firstly, the secondary data, 1:50,000-scale map, digital map, and the environmental criteria data, were collected. The engineering and economic criteria were applied to find the potential site by using the site selection methodology of C. Kupakrapinyo (2003) [9], [16]. Then the six environmental criteria and the suitability rank for each criterion were created based on a literature review for the criteria setting which was supported by expert opinions. The geographical data of Nan province (1997) was used due to the data availability. Two set of questionnaire were performed. The first set was used to approve that the suitability rank which can be used in the next step. The second set was used to measure the expert opinion on the importance of each criterion using the 5 point rating scale. Finally the environmental criteria were applied to create the suitable site for the hydropower project. The framework of site selection is shown in Fig.3.

3.2 Environmental Criteria

According to the study of environmental impact from run-of-river type hydropower project, the environmental criteria used in this study are watershed class, national park and wildlife sanctuary, land use type, population density, mean annual sediment yield, and heritage. They are used in the term of constraints and the environmental parameters.

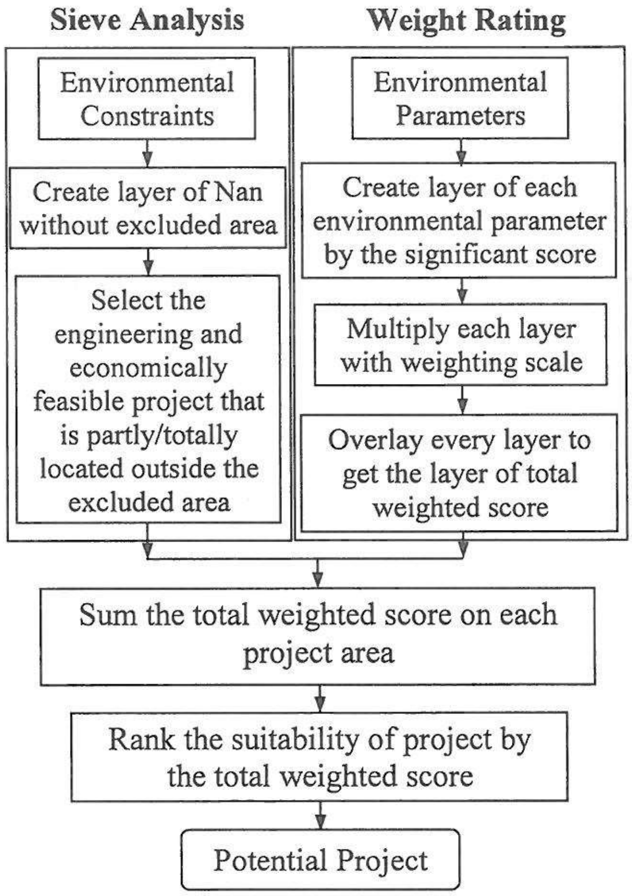

Fig.3 Framework of run-of-river type hydropower project site selection

(1) <u>Environmental Constraints</u>

The environmental constraints were used as a criterion to indicate the wanted/ unwanted project to be used in Sieve Analysis for the next step. The following constraints are set up due to the regulation and physical characteristics.

(2) <u>Environmental Parameters</u>

The environmental parameters were used to indicate the degree of suitability. Each environmental parameter was initially classified the suitability rank for score assigning based on the literature study before disperse the questionnaire to approve the rank.

The score was assigned from 1 to 5 by considering only the adverse impact to the environment which will be presented when the project is constructed.

Number 1 means Significant Adverse Impact
Number 2 means High Adverse Impact
Number 3 means Medium Adverse Impact
Number 4 means Low Adverse Impact
Number 5 means Slight Adverse Impact

After the first set of questionnaires was performed, the suitability ranks of environmental parameters were classified as follow. The suitability ranks for all environmental parameters are shown in Table1.

Table 1 The suitability rank of environmental parameters after the approval

Environmental Parameters	**Watershed Class**	**Wildlife Sanctuary**	**Land Use Type**	**Suspended Sediment**	**Population Density**	**Heritage**
Score	class	buffer (m)	type	tons/km^2	person/km^2	buffer (m)
1	1B	0-2000	Forest	above 120	above 40	below 500
2	2	2000-3000	Urban	100-120	30-40	500-1000
3	3	3000-4000	Agricultural	80-100	20-30	1000-1500
4	4	4000-5000	Industrial	60-80	10-20	1500-2000
5	5	Above 5000	Uninhabited land or Bush fallow	below 60	Below 10	above 2000

Six environmental criteria in term of constraints and parameters are explained below:

1) Watershed class, which was broken down into 5 classes, based on its physical characteristics, hydrological potential and its resources according to the regulation. [10] (Fig.4)

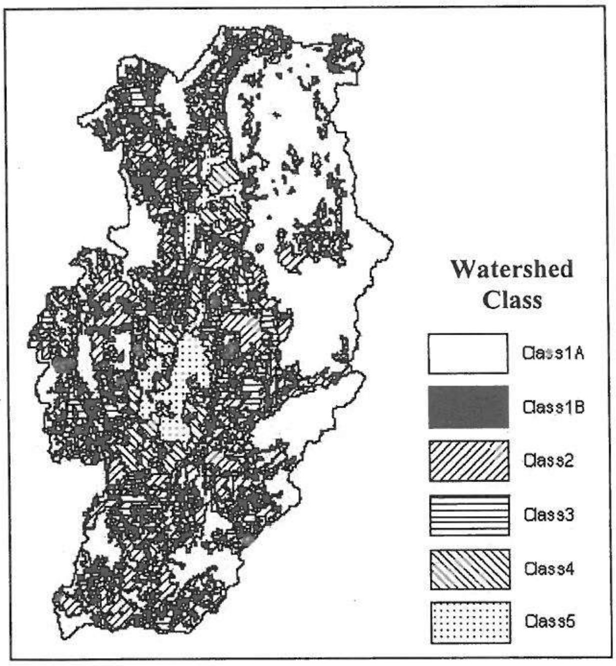

Fig. 4 Watershed classification

Class1 is preserved as productive watershed with sensitive characteristics: percentage of slope greater than 60% and high erodibility.

Class1A means the watershed class1, which still be the productive forest area. This class is the watershed consisting of plentiful forests. According to the cabinet resolution, changing forest by any means is restricted. Thus the watershed class1A was used as an environmental constraint.

Class1B means the watershed class 1, which contains a destroyed forest or a disturbed area which was changed for development or other ways of land use. There must be a special treaty on this disturbed area.

Class2 is in mountainous area covered by destroyed forest. The ridge of hill is round and narrow. The water channel is rather wide. The slope is in between 35-50 %. The ground has small to medium soil depth with high erodibility.

Class3 has low soil erodability. The slope of almost all areas is between 25-35%. Cultivation, mining and plantation are allowed under restrictive controls.

Class4 has the slope in between 6-25% with less erodibility of soil. The forest is mostly cleared for farming. All activities are permitted. Nevertheless, agriculture has to be well-planned by using land and water conservation principles.

Class5 has plain surface or small slope. The majority of the forest is cleared for agriculture. All activities are permitted without soil erosion measure.

The watershed class1B to class5 was chosen as the environmental parameters. According to the productivity of each class, the class1B was assigned number 1 score, the lower productive watershed classes were assigned the lower scores consequently, and the class5 was assigned the number 5 score.

2) Wildlife sanctuary is productive area preserving the habitat of wildlife and plants. The environmental status in these areas must be maintained as its original state. Then the extent of wildlife sanctuary is also used as an environmental constraint.

The buffer of wildlife sanctuary, which was created start from its extent, is used as the environmental parameter. The buffer zone was created based on the buffer zone management of Huai Kha Kaeng Wildlife Sanctuary.[11] The inner buffer indicates the sensitive area which is 2000m gets number 1 score. The outer zone, which is 3000m from the inner zone, was divided into three buffer zone getting the higher score when it goes further.(Fig.5) The highest score, number 5 score, is given to the area furthest from the conservative area extent by more than 5km.

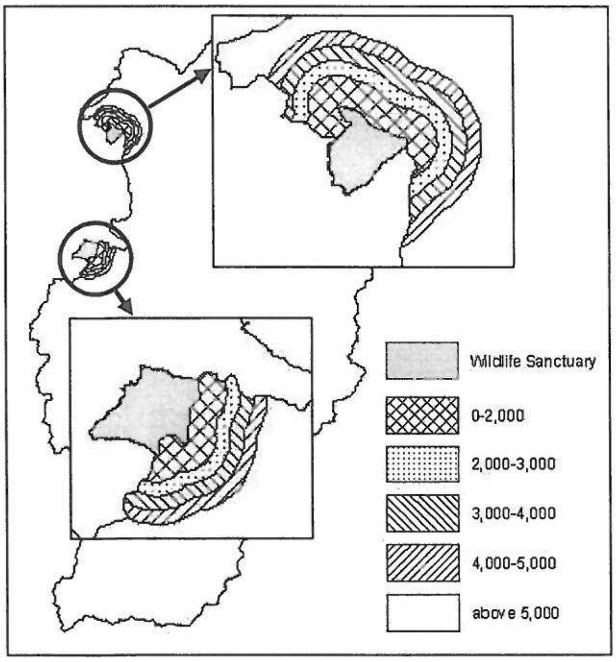

Fig. 5 Wildlife Sanctuary and its buffer

3) Heritage cannot be moved or destroyed due to its cultural worth. Therefore, the heritage extent is chosen to be an environmental constraint. As the geographic information is available for the heritage location only, the heritage extent was set as 1000-m radius from its location resulting from the questionnaire. The parameter was set up by using the buffer. Four buffer zone started from the heritage extent with the equally range of 500-m radius recommend from the first set of questionnaires. (Fig.6) The score is increased from number 1 score to number 4 score as the buffer gets longer. The number 5 score is given to the area furthest from the fourth buffer zone.

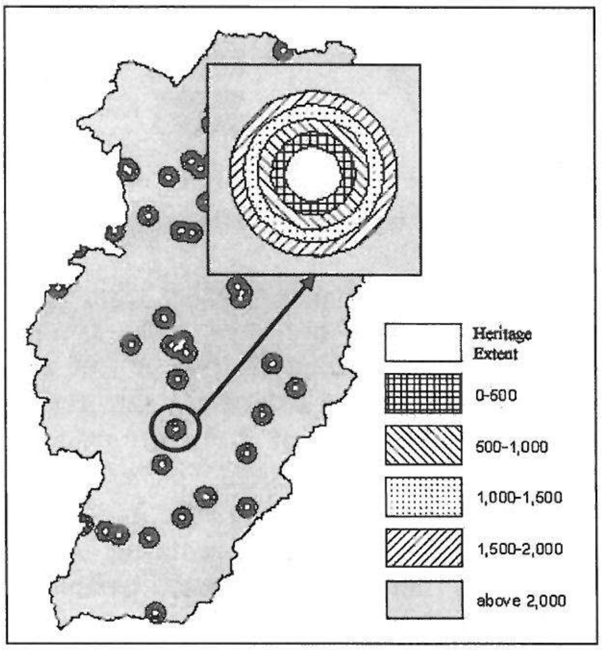

Fig.6 Buffer of Heritage

4) Land use type was chosen to be an environmental parameter by assigning the score according to the impact. The forest land, the number 1 score, is the first priority over other types because the natural environment needed to be protected more than others. To avoid the effect to people, Urban and built-up land area was the next type that had been allocated the number 2 score. The agricultural land was considered before the industrial land because the project area is usually located on the agricultural land more than industrial land. The

uninhabited land will be least affected was assigned number 5 score. (Fig.7)

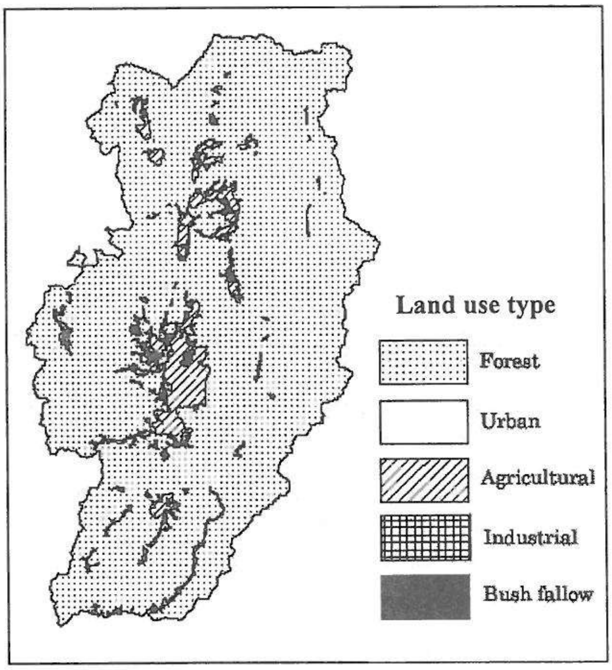

Fig.7 Land use Classification

5) Mean annual suspended sediment is the value which indicates the average suspended sediment load per one unit of area for one year. The more sediment in the original state can be the cause of the more sediment after the project construction. The amount of sediment may affect the aquatic ecosystem. The mean annual suspended sediment is then selected as an environmental parameter. According to the report of International Energy Association (IEA) the mean annual sedimentation rate above 97 Metric Ton/km^2 was reported to have high sediment rate.[8] The mean annual suspended sediment was then classified into five classes: over 120 tons/km^2, 100-120 tons/km^2, 80-100, tons/km^2, 60-80 tons/km^2, and lower than 60 tons/km^2. (Fig.8) The score was assigned from 1 to 5 respectively.

6) Population density is selected as another important environmental parameter in the view of social effect. The area having less population density means that less people are affected by the project. From the study of the Pacific Disaster Centre the population density higher than 40 persons/km^2 was used as the maximum range.[12] Then this study classified the population density into: over 40 persons/km^2, 30-40 persons/km^2, 20-30 persons/km^2, 10-20 persons/km^2, and lower than 10 persons/km^2. (Fig.9) The score was assigned from 1 to 5 respectively.

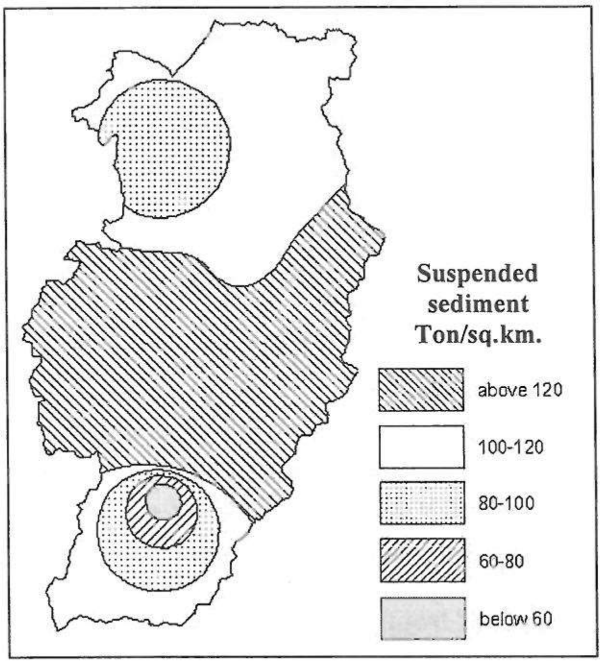

Fig.8 Mean Annual Suspended Sediment Classification

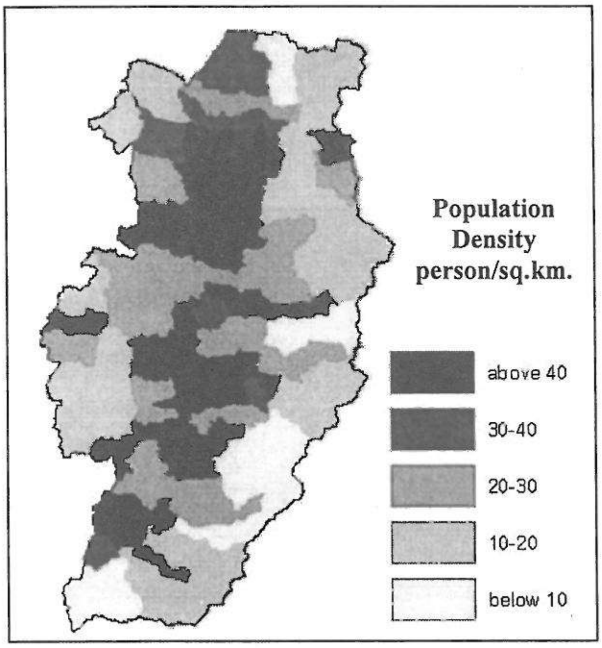

Fig.9 Population Density Classification

3.3 Sieve Analysis

Sieve Analysis or Sieve Mapping is used to study the variables, or the factors affecting development, mainly physical characteristics such as streams and conservative areas. This spatial analysis can be done by specifying the boundary of the obstructed area or vetoed area on the map. After that, each map layer will be brought to an overlay. The area outside that boundary will be the possible area for development.[13]

The layers of watershed class 1A, wildlife sanctuary, and heritage extent are overlaid to get the boundary of province without those constraints. Fig. 10 shows the overlay diagram.

The watershed class 1A was inverse selected to get the area without watershed class 1A. The layer of wildlife sanctuary was union with the province layer and then inverse selected to get the area without wildlife sanctuary. After the result from those two inverse selections was added together it becomes the area without watershed class1A, and wildlife sanctuary.

The 1,000m-radius buffer was created at the heritage location to define the extent. Then the province layer was added with the created extent and the inverse selection was performed to get the area without the heritage extent.

Finally the area without watershed class1A, and wildlife sanctuary was added with the area without heritage extent to get final result which is the area without watershed class1A, wildlife sanctuary, and heritage extent. It is the layer of Nan province without excluded area.

The resulting area was overlaid with the engineering and economically feasible projects to get the engineering and economically feasible projects that fall into the area outside the excluded area. These projects were used to overlay with the layer of total weighted score determined in Section 3.5 to get total weighted score of each project.

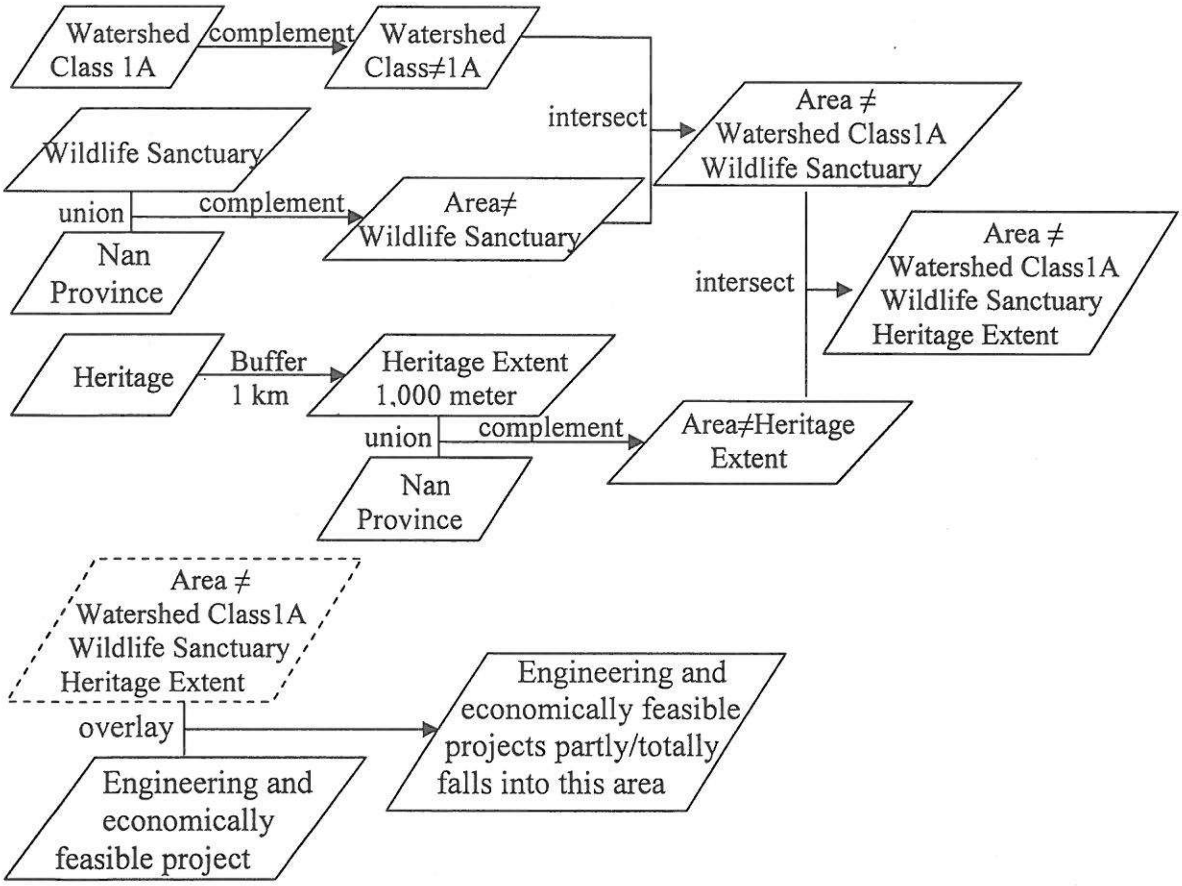

Fig.10 Overlay layer for sieve analysis

3.4 Expert Approach

The expert approach is applied from the Delphi technique, which is an intuitive technique utilizing the knowledge of experts in a particular area of concern.[14] The Delphi technique requires a panel of experts in the problem area to reply a set of questions. Each responding expert is contacted and given a set of questions offered on open-end design to elicit a broad range of responses. The responses from the first round are used to determine the degree of consensus. The second round the respondents are provided with a pattern of the first responses and asked to reconsider the earlier responses. In cases where a person's response is outside group interquartile range, justification for the extreme response is clearly stated. Then the process continues in several rounds until some 'desirable' degree of consensus among respondents is acquired. However, most of the group's responses are realized by the end of the second round.

Anyhow, the Delphi Methodology is not exactly applied to this study because the questionnaires were separated into two sets and distributed only once. The degree of consensus among respondents was not determined.

There are two sets of questions. The first set was used to ask the experts' opinion on suitability rank that is previously arranged by literature study. The second set was used to explore the experts' opinion on environmental criteria used to select the site for run-of-river type hydropower project in order to find which criteria is correct or not and to find out the importance of each parameter. The weighting scale, which will be as weight of important for environmental parameters, was determined from questionnaires as shown in Table 2. It can be seen that the experts gave the highest important to the watershed class and the population density is the lowest one.

3.5 Weight Rating

Weighted linear combination is used to summarize the total score of all attributes and alternatives in the same unit such as a suitability score for an area for a particular purpose. Formally, the decision rule evaluates each alternative A_i, by the following formula:

$$A_i = \sum_j w_i x_{ij} \qquad (1)$$

where the x_{ij} is the i^{th} alternative score with respect to the j^{th} attribute and w_i is the relative importance of the attribute.

When the overall alternative scores are calculated, the most preferred alternative is selected by identifying the maximum value of A_i $(i = 1,2,...,m)$[15]

The environmental parameters were weighted by multiplying the weight determined from the questionnaire to the suitability score. The weighted scores of the environmental parameters were summed for each project passing sieve analysis. Then the total weighted scores as the degree of suitability for establishing run-of-river type hydropower project were ranked from the highest to the lowest.

Table 2 Weighting scale of environmental parameters

Parameter	Weighting Scale
Watershed Class	0.23
Wildlife Sanctuary	0.20
Land Use	0.17
Heritage	0.14
Suspended Sediment Yield	0.14
Population Density	0.12
	1.00

4. Results

First, the site selection of run-of-river type hydropower projects in Nan province is conducted by the method proposed by C. Kupakrapinyo (2003) [9], [16], in which engineering and economic criteria are considered.

The proposed method is briefly described as follows:

Based on topographic map and runoff data, the hydropower projects with different installed capacity are selected by using engineering criteria, such as calculation of design discharge (Q_d) from the catchment area, calculation of installed capacity (P) from the design discharge (Q_d) and the head, defined by difference in water levels at weir and powerhouse site. The economic analysis of all engineering feasible projects is performed, such as estimation of construction cost, calculation of benefit-cost ratio (B/C) and internal rate of return (IRR). The economical criteria used here is the same as the previous study [9], [16], such as B/C greater than 1 and IRR greater than 8% means the projects are economically feasible. By the above-mentioned method, 50 engineering and economically feasible projects in Nan province are selected.

Secondly, the sieve analysis in Section 3.3 is performed to select the projects that fall outside the excluded area. As listed in Table 3, the results of sieve analysis are 16 projects selected from 50 engineering and economically feasible projects.

Finally, the total weighted scores of each of 16 projects are calculated by the weight rating method explained in Section 3.5. Table 3 shows the results of the total weighted scores ranked from the highest to the lowest, i.e. the most to the least environmentally feasible projects. For the titles of projects in Table 3, the names of streams are used. However, in one stream, there may be more than one project depending on locations of weir and powerhouse. The number in parenthesis after the project titles means the project number on the same stream for example, Nam Khwang (1/4): on Nam Khwang stream there are four feasible projects, and (1/4) indicates the project number 1 among these four projects.

Fig. 11 shows the location of 16 potential projects on different 6 streams: Nam Sad, Nam Kon, Nam Pua, Nam Khwang, Nam Mae Sa, and Nam Phang. By combining the method proposed by C. Kupakrapinyo (2003) [9], [16] and the present method, the site selection of run-of-river type small hydropower projects based on engineering, economic, and environmental criteria can be successfully performed as shown in the case study of Nan province.

Table 3 Potential run-of-river type hydropower projects summary (environmental criteria)

Project	Amphur	Head (m)	Catchment Area (km^2)	Design Discharge Q_d (m^3/s)	Installed Capacity P (kW)	Construction Cost (MB)	Benefit-Cost Ratio	Internal Rate of Return (%)	Total Weighted Score
Nam Khwang (3/4)	Pua	47.06	361.565	1.19	2000	120.63	1.23	10.52	1591.77
Nam Pua (2/3)	Pua	126.20	334.732	3.19	3000	154.87	1.44	12.65	1563.98
Nam Mae Sa (3/4)	Waingsa	178.96	321.460	4.53	2000	127.20	1.17	9.85	1454.42
Nam Sad (1/2)	Chalemprakait	104.30	412.266	2.64	1500	99.52	1.12	9.32	928.71
Nam Khwang (2/4)	Pua	47.06	414.07	1.19	1500	91.30	1.22	10.41	462.96
Nam Pua (3/3)	Pua	126.20	295.573	3.19	4000	212.66	1.39	12.23	371.72
Nam Phang	Maecharim	104.08	323.737	2.63	2250	131.60	1.27	10.93	353.43
Nam Mae Sa (2/4)	Waingsa	178.96	328.363	4.53	1750	112.45	1.15	9.72	187.33
Nam Khwang (4/4)	Pua	47.06	335.312	1.19	2250	146.35	1.14	9.56	163.68
Nam Kon (1/2)	Chaingklang	117.06	440.432	2.96	1500	107.13	1.04	8.43	141.12
Nam Sad (2/2)	Chalemprakait	104.30	400.421	2.64	1750	124.09	1.05	8.52	107.82
Nam Mae Sa (1/4)	Waingsa	178.96	335.267	4.53	1500	106.25	1.05	8.53	102.08
Nam Pua (1/3)	Pua	126.20	344.521	3.19	2750	154.29	1.32	11.49	98.14
Nam Mae Sa (4/4)	Waingsa	178.96	314.556	4.53	2250	147.14	1.13	9.50	95.70
Nam Khwang (1/4)	Pua	47.06	466.575	1.19	1000	73.07	1.01	8.17	14.45
Nam Kon (2/2)	Chaingklang	83.72	464.724	2.12	2750	144.35	1.41	12.41	2.94

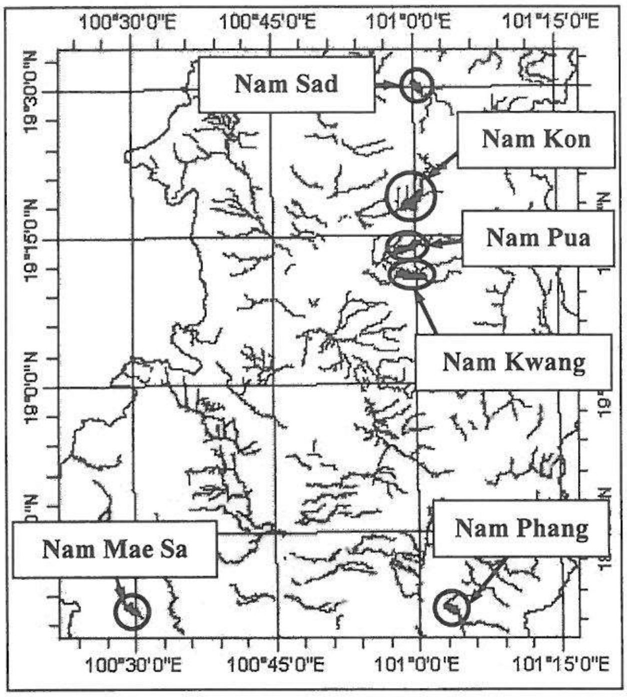

Fig.11 Location of the potential project

5. Concluding Remarks

The study had performed the site selection on run-of-river type hydropower project based on environmental criteria using GIS.

There are six environmental criteria used in this study: watershed class, wildlife sanctuary, land use, heritage, suspended sediment, and population. The environmental criteria were divided into two parts: constraints and parameters.

The environmental constraints consisting of watershed class (1A), wildlife sanctuary, and heritage were defined to reject the unwanted project by using Sieve Analysis.

For the environmental parameters consisting of watershed class (1B, 2, 3, 4, 5), wildlife sanctuary buffer, heritage buffer, land use type, suspended sediment, population density, the scores were assigned and multiplied with the weights determined from questionnaires based on Delphi Technique. The weighted scores of all parameters were summed to get the total weighted score of each project. The degree of suitability was ranked from the highest weighted score to the lowest weighted score.

As a case study, Nan province is considered. Out of 50 engineering and economically feasible projects, 16 projects are selected and ranked by considering the environmental criteria. It is found that the most suitable three projects with almost the same scores are located on three streams namely Nam Khwang, Nam Pua, and Nam Mae Sa.

In order to make this study to be more practical, it needs more complete and up-to-date data to be analysed. A further study should include the fish population in the environmental criteria. The scope of the study should be increased from a province to country. The engineering, economic, and environmental criteria integrated in the study should have the different weight indicating the importance of each criterion. In addition the integrated methodology should be improved.

6. Acknowledgements

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