APPLICATION OF FUZZY ANALYTICAL HIERARCHY PROCESS TO RANKING THE IMPORTANCE OF HYDROPOWER DAM SITES ALONG THE MEKONG RIVER, NORTHWESTERN REGION OF LAOS

Phetphoumin Paphaphanh

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การประยุกต์กระบวนการวิเคราะห์อย่างมีลำดับขั้นแบบคลุมเครือเพื่อการจัดลำดับความสำคัญของเขื่อนพลังน้ำตามแม่น้ำโขงในภูมิภาคตะวันตกเฉียงเหนือของประเทศลาว

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มหาวิทยาลัยเทคโนโลยีสุรนารี

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APPLICATION OF FUZZY ANALYTICAL HIERARCHY PROCESS TO RANKING THE IMPORTANCE OF HYDROPOWER DAM SITES ALONG THE MEKONG RIVER, NORTHWESTERN REGION OF LAO PDR

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

Thesis Examining Committee

____
(Assoc. Prof. Dr. Suwit Ongsomwang)
Chairperson

____
(Asst. Prof. Dr. Sunya Sarapirome)
Member (Thesis Advisor)

____
(Asst. Prof. Dr. Songkot Dasananda)
Member

____
(Assoc. Prof. Dr. Punya Charusiri)
Member

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and Innovation

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ลาวเป็นประเทศที่มีศักยภาพสูงและเป็นศูนย์กลางการค้าพลังงานหรือ "แบตเตอรี" ของเอเชียตะวันออกเฉียงใต้ไปยังประเทศเพื่อนบ้าน เช่น ไทย เวียดนาม และจีนตอนใต้ การก่อสร้างเขื่อนต้องใช้งบประมาณจำนวนมากก่อให้เกิดปัญหาสิ่งแวดล้อมและความขัดแย้งทางสังคม เป็นความท้าทายสำหรับผู้ตัดสินใจที่จะวิเคราะห์เชิงเปรียบเทียบว่าเขื่อนใดให้ผลประโยชน์และผลกระทบมากน้อยกว่ากัน การศึกษานี้จึงมีวัตถุประสงค์เพื่อจัดลำดับความสำคัญของโครงการเขื่อนจำนวน 5 เขื่อนตามแม่น้ำโขงในเขตภาคตะวันตกเฉียงเหนือของประเทศลาวด้วยคุณค่าเชิงปริมาณที่แม่นยำ พิจารณาจากปัจจัยค่าใช้จ่ายและผลประโยชน์ผ่านกระบวนการวิเคราะห์อย่างมีลำดับขั้นแบบคลุมเครือ น้ำหนักแต่ละเกณฑ์ของแต่ละเขื่อนได้รับการประเมินจากผู้เชี่ยวชาญจำนวน 13 คน ด้วยวิธีเปรียบเทียบเป็นคู่แบบคลุมเครือผ่านทางแบบสอบถาม น้ำหนักเปรียบเทียบระหว่างปัจจัยได้รับการประเมินเช่นกัน น้ำหนักเหล่านี้ได้ถูกประเมินความสอดคล้อง เฉลี่ยด้วยวิธีแบบเรขาคณิต และรวมเข้าด้วยกัน คะแนนที่ได้ยังเป็นแบบคลุมเครือซึ่งถูกทำให้เป็นค่าตัวเลขตัวเดียวด้วยวิธีดีฟัซซี ที่ระบุอันดับความสำคัญ ผลที่ได้ คือ เขื่อนหลวงพระบางมีความสำคัญมากที่สุด รองลงมาคือเขื่อนปากลาย เขื่อนชัยบุรี เขื่อนปากแบง และเขื่อนซะนะคาม ตามลำดับ ต่อมาจึงวิเคราะห์ความอ่อนไหวเพิ่มเติมเพื่อสังเกตว่าเกณฑ์ใดส่งผลต่อการจัดลำดับมากที่สุดด้วยวิธีการดึงเกณฑ์ออกจากกระบวนการวิเคราะห์ทีละเกณฑ์ ในระดับค่าใช้จ่ายและผลประโยชน์ ผลการจัดอันดับของเขื่อน และค่าความสำคัญเชิงเปรียบเทียบแสดงค่าเปลี่ยนแปลงอย่างเห็นได้ชัดเมื่อดึงเกณฑ์ผลประโยชน์ออก เขื่อนชัยบุรีได้รับการจัดให้มีความสำคัญมากที่สุด รองลงมาคือ เขื่อนปากแบง เขื่อนปากลาย เขื่อนซะนะคามและเขื่อนหลวงพระบาง ตามลำดับ ในระดับลักษณะประจำ ผลการจัดอันดับของเขื่อน และค่าความสำคัญเชิงเปรียบเทียบเปลี่ยนแปลงอย่างชัดเจนเมื่อดึงเกณฑ์กำลังการผลิตซึ่งเป็นหนึ่งในเกณฑ์ผลประโยชน์ออก ขณะที่ผลยังคงเป็นเช่นเดิมไม่เปลี่ยนแปลงเมื่อลักษณะประจำอื่นถูกดึงออก

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THESIS ADVISOR : ASST. PROF. SUNYA SARAPIROME, Ph.D. 192 PP.

FAHP/MEKONG RIVER/DAM AND RESERVOIR ASSESSMENT/MADM

Lao PDR has very high potential to become the battery of Southeast Asia and the hub of power trade to neighbouring countries such as Thailand, Vietnam, and south China. Dam construction normally requires not only large amount of budget and also can cause environmental problems and social conflicts. It becomes big challenge for decision makers to analyse which alternative can comparatively provide more benefit and impact. From this point of view, the objective of this study is to rank the relative importance of 5 proposed dam and reservoir sites along the Mekong River in northwestern region of Laos in terms of accurately quantitative values based on their costs and benefits using MADM-FAHP. Thirteen experts evaluate preferences on each criterion of each dam using fuzzy pairwise comparison through synthetic questionnaire survey. All criteria are compared to each other as well. Expert opinions responded are evaluated for consistency and aggregated by geometric mean method. The aggregated fuzzy scores are later summation as fuzzy weighted summation of individual alternatives. The results are defuzzified to indicate relative importance of five proposed dams. The result reveals that Luangprabang dam has the highest relative importance, following by Paklay dam, Xayabury dam, Pakbeng dam, and

Xanakham dam, respectively. The sensitivity analysis is additionally applied to observe which criterion is mostly related or influence to the rank of alternatives by dropping out one criterion at a time from the analytical process. In cost and benefit level, alternative ranking is changed and the relative importance expresses higher difference when benefit criteria is dropped from the process. Xayabury dam site is ranked to be the most importance following by Pakbeng, Paklay, Xanakham, and Luangprabang, respectively. In attribute level, the ranking of alternative dam sites is different from ranking of all attribute consideration and their relative importance shows more variation only when power generation attribute, an attribute of benefit criteria, is dropped while of the rests are the same.

School of Remote Sensing Student's Signature ____________________

Academic Year 2013 Advisor's Signature ____________________

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LIST OF ABBREVIATIONS

AR	=	Accessibility Requirement
AHP	=	Analytical Hierarchy Process
amsl	=	above mean sea level
CI	=	Consistency Index
CR	=	Consistency Ratio
CIEC	=	China National Electronics Import Export Corporation
CIGB	=	Commission Internationale des Grands Barrages
CMA	=	Construction Material Availability
cu.m/sec	=	cubic meter per second
DEM	=	Digital Elevation Model
DGM	=	Department of Geology and Mine
DGMV	=	Department of Geology and Mines of Vietnam
FAHP	=	Fuzzy Analytical Hierarchy Process
FG	=	Foundation Geology
FSL	=	Full Supply Level
GIS	=	Geography Information System
GWh/yr	=	Gig watt hour per year
HPP	=	Hydropower project
ICEM	=	International Center for Environmental and Management
ICOLD	=	International Commission On Large Dams

LIST OF ABBREVIATIONS (Continued)

IDW	=	Inverse distance weighting method
IHA	=	Inundated Historic and Archeological sites
IPM	=	Inundated Potential Mineral deposit
JICA	=	Japan International Cooperation Agency
Lao PDR	=	Lao People's Democratic Republic
LII	=	Land Instability Index
LMB	=	Lower Mekong Basin
LULC	=	Land use and Land cover
MADM	=	Multi-Attribute Decision Making
MCDA	=	Multi-criteria Decision Analysis
MCDM	=	Multi-Criteria Decision Making
mil.cu.m	=	Million cubic meters
MRC	=	Mekong River Commission
MW	=	Megawatt
N	=	North
NE	=	North East
NGD	=	National Geography Department, Lao PDR
N-S	=	North to South
PG	=	Power Generation
PGA	=	Peak Ground Acceleration
PNPCA	=	Prior Consultation and Agreement

LIST OF ABBREVIATIONS (Continued)

RI	=	Random Index
SAW	=	Simple Additive Weight
SE	=	Seismic Effect
SEA	=	Strategic Environmental Assessment
SEAN	=	South East Asia Energy
SI	=	Settlement Impact
Sl	=	Slope percentage
SRTM	=	Shuttle Radar Topography Mission
TA	=	Tourist Attraction
TL	=	Transmission Line
TM	=	Thematic Mapper
WCD	=	World Commission on Dams
WSW	=	West Southwest

CHAPTER I

INTRODUCTION

1.1 Problem background and the significance of the study

The Mekong River is a large and long river starting from China, flowing to the sea through six countries including China, Myanmar, Lao People's Democratic Republic (Lao PDR), Thailand, Cambodia, and Vietnam. The main stream in People's Republic of China was dammed by the first four projects in a planned cascade of up to eight hydropower projects. Since 2006, the interest in hydropower has escalated in the Lower Mekong Basin (LMB) accompanied by increasing private sector investment in power infrastructure. The investors and developers mostly from China, Malaysia, Thailand, and Vietnam have submitted proposals for 12 hydropower projects along LMB mainstream drawing on concepts from past decades (Mekong Secretariat, 1994). These proposals are among the largest and most significant developments ever considered by LMB countries for the basin.

According to Strategic Environmental Assessment (SEA) baseline and impact assessment 96% of power demand to 2025 stems from Thailand and Vietnam and these two countries are targeted to purchase close to 90% of the power generated by the mainstream projects (ICEM, 2010).

With the increasing in demand of energy utility from Thailand and Vietnam, as well as the upsurge of investment from Thailand, China, Russia, Vietnam and Malaysia, hydropower industry is extremely booming, especially in Lao PDR. With the significant natural resource in hand like Mekong River, Lao has the high expectation of leading this small country toward the big change in term of economic development, by tending to be “the battery of Southeast Asia”. As a matter of fact, Lao PDR has the largest hydropower potential of the four LMB countries, because of Lao’s geographic location and mountainous nature yielding hydropower potential, Lao PDR also views itself as a hub of power trade with markets linkage between Thailand and Vietnam (King, Bird, and Haas, 2007). As all factors mentioned above, department of energy promotion and development’s “Electric Power Plants in Laos" as of March 2013 was introduced 98 existing and planned Lao hydropower projects (greater than 10 MW) with includes 12 development hydropower projects before year 2000, 16 operations, 14 under construction, 24 in planning stage, and 32 in the feasibility stage. In addition, 12 large hydropower projects have been proposed and approved along the main stream of Mekong River (Table 1.1), 8 in Lao PDR, 2 of which are on the Lao-Thailand reaches of the mainstream and 2 in Cambodia (ICEM, 2010) as shown in (Figure 1.1).

Table 1.1 Proposed mainstream hydroelectric run-off river projects in the Lower Mekong Basin (ICEM, 2009).

No	Project	Country	Installed Capacity (MW)
1	Pakbeng	Laos	1,230
2	Luangprabang	Laos	1,410
3	Xayabury	Laos	1,260
4	Paklay	Laos	1,320
5	Xanakham	Laos	700
6	Pak Chom	Laos - Thailand	1,079
7	Ban Koum	Laos - Thailand	1,872
8	Lat Sua	Laos	686
9	Don Sahong	Laos	240
10	Thakho Diversion	Laos	50
11	Stung Treng	Cambodia	980
12	Sambor	Cambodia	2,600

The Mekong River starting in China appears to have very high hydropower potential. Specifically, its lower part in the northwestern Laos flows through Bokeo, Oudomxai, Luangprabang, Xayabury, and Vientiane provinces to the Lao-Thai border with total length about 700 kilometers (Figure 1.1). This area is mountainous, valley, and jungles with mean elevation 900 m above mean sea level (amsl). The area shows high potential for hydropower development with minimum environmental, social, and economic impacts. Due to the characteristics of the area, the Mekong River Commission (MRC) conducted the feasibility study and resulted in the purpose of 5 potential dam sites at Pakbeng, Luangprabang, Xayabury, Paklay, and Xanakham (Table 1.2).

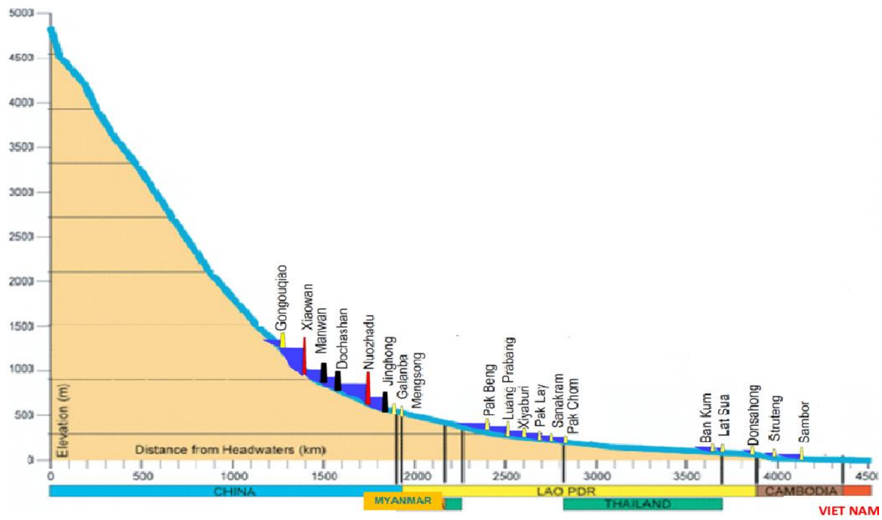

Figure 1.1 Proposed Mekong mainstream hydropower projects in the LMB and Yunnan Province, China (ICEM, 2010).

Generally, each dam has its own characteristics, which results in the difference of benefits and impacts. The benefits include hydropower and water resource productivity, flood and drought control system, etc., while the impacts can be environmental, social, and economic. Ranking of dams and reservoirs based on their benefits and impacts should be carried out before the priority of dam construction is determined. Good priority may provide time to observe the unexpected consequences both in benefits and impacts and the next measure of the program can be reviewed and revised properly. Not only required for the priority of dam construction but the accurate ranking is also very important for the consequent activities after the construction. The method required for ranking is considered very crucial because the fruitful result can be expected if it covers all essential criteria and stakeholders including experts in the analytical process. To achieve this purpose the Geographic Information System (GIS) and Multi-criteria decision analysis (MCDA) are considered to be efficient tools for spatial data analysis and decision making.

Table 1.2 Location, developers, and power productivity of dam sites in the study area (ICEM, 2009).

Project	Developer	Coordination		Power
		Latitude	Longitude	(MW)
Pakbeng	Datang from China	19°50'37.64"	101°1'7.22"	1230
Luangpabang	Petrovietnam Power Corporation	20°03'58.8"	102°11'30.7"	1410
Xaignabouri	SEAN and Ch. Karnchang of Thailand	20°03'58.8"	102°11'30.7"	1260
Paklay	CIEC and Sinohydro of China	18°24'5.34"	101°35'1.01"	1320
Xanakham	Datang from China	17°50'00"	101°33'00"	700

Decision analysis is a set of systematic procedure for analyzing complex decision problems. The alternatives are usually evaluated by a number of people (managers, decision maker, and stakeholders, interest group), who are often characterized by unique preferences with respect to the relative importance of criteria and based on which the alternative are evaluated. Accordingly, Multi-attribute Decision Making (MADM) as a class of Multi-Criteria Decision Making (MCDM) or

MCDA is the approach dealing with the ranking and selection of one or more sites from the alternatives. Some important characteristics of MADM are having restricted set of alternatives and explicitly defined set of alternatives, requiring a priori information on the decision maker's preferences and being outcome oriented (Chakhar and Martel, 2003). In solving a MADM, one needs to know the importance or weights of the not equally important attributes and also the evaluations of the alternatives with respect to the attributes. There have been different methods on MADM and the most known are simple additive weight (SAW), ideal point method, and Analytical Hierarchy Process (AHP).

In addition, AHP method is a procedure to ordering alternatives (Saaty, 1980), AHP method is the concept of preference thinking hierarchy but in fact there are some uncertain variables to confuse decision maker judgment. The traditional AHP requires crisps judgments. However, due to the complexity and uncertainty involved in real world decision problem, a decision maker may sometime feel more confident to provide fuzzy judgment than crisp comparison. Fuzzy decision making is powerful paradigm for dealing with human expert knowledge (Sousa and Kaymak, 2002) and has been used to solve or support spatial reasoning problems in a number of different contexts, such as locating convenience stores and other site selection (Kuo, Chi, and Kao, 1999; Chi and Kuo, 2001; Kuo, Chi, and Kao, 2002; Witlox, 2003; Partovi, 2006) screening potential landfill sites (Charnpratheep, Zhou, and Garner, 1997), supplier selection (Kahraman, Cebeci, and Ulukan, 2003; Önüt, Kara, and Işik, 2009; Ho, Xu, and Dey, 2010) and local park planning (Zucca, Sharifi, and Fabbri, 2008).

Instead of using AHP, the study aims at employing Multi-Attribute Decision Making-Fuzzy Analytical Hierarchy Process (MADA-FAHP) to rank the relative importance of the hydropower dams along the Mekong River in northwestern Laos based on their benefits and impacts. Ranking can be carried out by using AHP or Fuzzy Analytical Hierarchy Process (FAHP). Obviously, the FAHP can provide the result responding weights of ranking from experts more accurately.

1.2 Research objective

To rank the relative importance of dam and reservoir sites along the Mekong River in northwestern Laos in terms of accurately quantitative values based on their costs and benefits using MADM-FAHP.

1.3 Basic assumptions

(1) The decision making analysis will not involve any governmental policies and legal issues.

(2) Locations of 5 proposed dam sites are based on ICEM (2009) MRC SEA for hydropower on the Mekong mainstream inception report Vol. 2, main stream project profile summaries.

(3) The shape of reservoir area of each dam is very long and narrow because both sides of the Mekong River are very steep and the highest level of water storage of each reservoir is not much higher from the river water level. Therefore, impact from LULC and landslide in the watersheds of proposed dams is not seriously considered. Data of LULC is relied on the previous study while simplified method is applied to potential landslide study.

(4) Seismic effect is relied on the study result of Pailoplee, Sugiyama, and Charusiri (2009). The effect at a dam site is strongly related to the effect of the surrounding original points reported from the study.

(5) The distance of transmission lines is considered from dam sites to stations/substations of the proposed grid system.

(6) Potential borrow area for construction is basically relied on limited field investigation and very limited geologic information of dam sites.

1.4 Scope and limitations of the study

(1) The decision making process of the study is basically relied on experts opinions, not including the opinion of local people.

(2) Due to the limitation of data availability, GIS data with different scales are brought to analyze together. Positional data are mainly based on the scale of 1:200,000.

(3) The sediment load per year of each reservoir is not considered due to lacking of data from previous study and basic data for estimation.

1.5 Benefits of the study

(1) The preferences of dam and reservoir sites and criteria from FAHP based on expert opinions are clarified.

(2) The ranking of dam and reservoir sites from different defuzzification methods of FAHP, i.e., α cut, center of area, and fuzzy extent analysis are achieved.

(3) The achievement of ranking dam and reservoir sites resulted from the total consideration of defuzzification methods and comparison of each method are obtained.

CHAPTER II

LITERATURE REVIEW

The relevant literature and research review in this chapter include definitions of dam and reservoir, multi-criteria decision analysis (MCDA) composed of the application of Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (FAHP), previous studies of FAHP, and finally synthesis of the research approach.

2.1 Dam and reservoir

A dam is a hydraulic structure barrier constructed to hold back or control water flows and raise its level, forming a reservoir on its upstream side for impounding water used for irrigation, hydroelectric, flood control, navigation, water supply, and recreation (CIGB-ICOLD, 2007).

The reservoir is an area developed to be water body due to construction of a dam downstream. The reservoir site is evaluated in terms of topology, geology, rim stability against slides, water tightness and water holding capability, seismicity, bank storage, evaporation, sedimentation, land use and mineral resources, property ownership, relocation of the people who live in the area, utilities, and transportation facilities, historical-cultural and religious monuments etc (Iqtidar H. Siddiqui, 2009).

In simple terms, reservoir means a construction that holds a volume of water, and dam is the structure, which holds back the water (Brassington, 1995). This definition indicates the need to examine both the reservoir and dam site. Dam and reservoir are investigated mainly in the fields of engineering survey, geological and hydrological investigations. Engineering surveys are conducted for dam, reservoir and other associated works in form of topographical survey to obtain the contour plan. The horizontal control is usually provided by triangulation survey and the vertical control by precise leveling. Geological investigations of dam and reservoir site are the consideration of foundation suitability for a dam, water tightness of reservoir basin, and location of the quarry sites for the construction materials. Hydrological investigations are conducted for the purposes to study the runoff pattern and storage capacity, and to determine the maximum discharge at the site.

Novak, Moffat, Nalluri, and Narayaman (2007) extensively determined factors, such as catchment hydrology, available head and storage volume, functional and technical, geological and geotechnical investigations, foundation investigations, material for dam construction to confirm the site that can be developed on the desired scale and at acceptable cost. The World Commission on Dams (WCD) developed seven strategic priorities, designed to inform all decisions related to future dam developments. These priorities follow principles of public participation, social equity, environmental sustainability, economic efficiency and accountability (Scodanibbio and Manez, 2005).

Ledec and Quintero (2003) considered the environmental and social criteria for site selection of hydroelectric projects. Furthermore, the failure of a number of dams and the increase in environmental awareness require the inclusion of environmental and social factors in the processes besides economy (Baban and Wan-Yusof, 2003). In short, the approval for a large dam project proposal these days predominantly involves satisfying broad criteria of economic development, social equity, and environmental sustainability (Wasimi, 2010).

2.2 Principles of AHP and FAHP

Inability of AHP to deal with the imprecision and subjectiveness in the pairwise comparison process has been improved in fuzzy AHP. Instead of a crisp value, fuzzy AHP uses a range of value to incorporate the decision maker's uncertainty (Kuswandari, 2004). The Fuzzy AHP can be presented in term of Van Laarhoven and Pedrycz's approach, Buckley's fuzzy AHP, Chang's extent analysis method (Chang, 1996; Vahidnia, Alesheikh, Alimohammadi, and Bassiri, 2008), and fuzzy AHP with entropy value. Both basic principle of AHP and FAHP are reviewed herein.

2.2.1 Analytical hierarchy process (AHP)

AHP is a multi-criteria decision method that uses hierarchical structures to represent a problem and then develops priorities for alternatives based on the judgment of the user (Saaty, 1980). AHP has been widely used as useful MCDM estimated in many areas such as selection, evaluation, planning and developing, decision making, forecasting and so on. The AHP procedure involves six essential steps (1) define the unstructured problem, (2) develop the AHP hierarchy, (3) operate pairwise comparison, (4) estimate the relative weights, (5) check the consistency, and (6) obtain the overall rating (Cheng, 1999; Chi and Kuo, 2001; Murtaza, 2003; Lee, Chen, and Chang, 2008).

2.2.1.1 Define the unstructured problem

In this step, the unstructured problem and their characters should be recognized and the objectives and outcomes stated clearly.

2.2.1.2 Develop the AHP hierarchy

The first step in the AHP procedure is to decompose the decision problem into a hierarchy that consists of the most important elements of the decision problem (Boroushaki and Malczewski, 2008). In this step the complex problem is decomposed into a hierarchical structure with decision elements (objective, attributes, i.e., criterion map layer and alternatives) as shown in Figure 2.1.

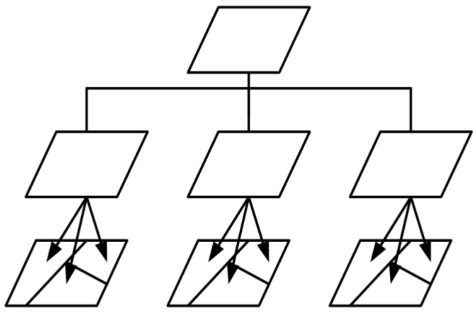

Figure 2.1 AHP hierarchy (Vahidnia et al., 2008).

2.2.1.3 Operate pairwise comparisons

Pairwise comparisons matrices have been operated to compare each element of the hierarchy structure as shown in Equation (2.1).

$$A=\begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & 1 & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{bmatrix}, \tag{2.1}$$

where A = comparison pairwise matrix,

w_1 = weight of element 1,

w_2 = weight of element 2, and

w_n = weight of element n.

In order to determine the relative preferences for two elements of the hierarchy in matrix A, an underlying semantically scale is employed with values from 1 to 9 to rate Scales for pairwise comparison (Saaty, 1980), shown in Table 2.1.

Table 2.1 Scale for pairwise comparison (Saaty, 1980).

Preferences expressed in numeric variable	Preferences expressed in linguistic variables
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

2.2.1.4 Estimate the relative weights

Some methods like eigenvalue method are used to calculate the relative weights of elements in each pairwise comparison matrix. The relative weights (W) of matrix A is obtained from-Equation (2.2).

$$(A-\lambda_{max}I)W=0; \tag{2.2}$$

where λ_{max} = the biggest eigenvalue of matrix A, I = unit matrix.

2.2.1.5 Check the consistency

In this step, the consistency ratio (CR) of matrices is estimated to ensure that the judgments of decision makers are consistent. For this end some pre parameter is needed. Consistency Index (CI) is calculated as shown in Equation (2.3).

$$CI=\frac{\lambda_{max}-n}{n-1}. \tag{2.3}$$

The consistency index of a randomly generated reciprocal matrix shall be called to the random index (RI), with reciprocals forced. An average RI for the matrices of order 1-15 is generated by using a sample size of 100 (Nobre, Trotta, and Gomes, 1999). The table of random indices of the matrices of order 1-15 can be seen in (Saaty, 1980) as a part of them are listed in Table 2.2. The last ratio that has to be calculated is CR (Consistency Ratio). Generally, if CR is less than 0.1, the judgments are consistent, so the derived weights are reasonable and can be used. The formulation of CR is shown in Equation (2.4).

$$CR = \frac{CI}{RI}. \tag{2.4}$$

Table 2.2 Random inconsistency indices RI (Saaty, 1980).

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

2.2.1.6 Obtain the overall rating

In last step, the relative weights of decision elements are aggregated to obtain an overall rating for the alternatives as displayed in Equation (2.5).

$$W_i^s = \sum_{j=n}^{j=m} W_{ij}^s W_j^a \text{, } i=1,2,\ldots n; \tag{2.5}$$

where W_i^s = total weight of S_i,

W_{ij}^s = weight of alternative (S_i) associated to attribute (map layer) j,

W_j^a = weight of attribute j, m = number of attribute, and

n = number of S.

2.2.2 Fuzzy analytical hierarchy process (FAHP)

In spite of popularity of AHP, this method often is criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the decision maker’s perception to exact numbers (Deng, 1999). Since fuzziness and vagueness are the common characteristics in many decision-making problems, a fuzzy AHP (FAHP) method should be able to tolerate vagueness or ambiguity (Mikhailov and Tsvetinov, 2004). In other word, the AHP approach may not fully reflect a style of human thinking. The decision makers usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values and so FAHP is capable of capturing a human's appraisal of ambiguity when complex multi-attribute decision making problems are considered (Erensal, Öncan, and Demircan, 2006). This ability comes to exist when the crisp judgments transformed into fuzzy judgments. Zadeh (1965) published his work Fuzzy Sets, which described the mathematics of fuzzy set theory.

A fuzzy number has represented an expert's uncertain judgments in from of triangle of which membership function is defined by three real numbers lower, middle, upper (l, m, u). This membership function is illustrated in Figure 2.2 and described mathematically (Cox, 1995) as shown in Equation (2.6)

$$\mu_A(x)=\begin{cases} \frac{x-l}{m-l}, & l\leq x\leq m, \\ \frac{u-x}{u-m}, & m\leq x\leq u, \\ 0, & \text{otherwise.} \end{cases} \tag{2.6}$$

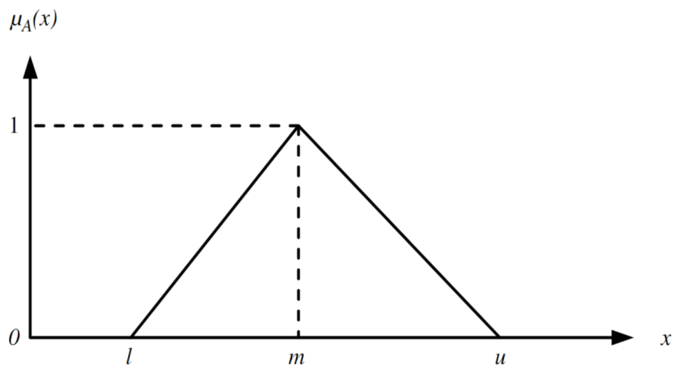

Figure 2.2 Fuzzy triangular number A= (l, m, u) (Vahidnia et al., 2008).

The process of FAHP starts with defining the unstructured problem and developing hierarchy as same as the AHP does.

2.2.2.1 Fuzzy pairwise comparison

When the expert judgments are expressed as triangular fuzzy numbers, the triangular fuzzy comparison matrix is obtained as shown in Equation (2.7).

$$\widetilde{A}=(\tilde{a}_{ij})_{nXn}=\begin{bmatrix} (1,1,1) & (l_{12},m_{12},u_{12}) & \cdots & (l_{1n},m_{1n},u_{1n}) \\ (l_{21},m_{21},u_{21}) & (1,1,1) & \cdots & (l_{2n},m_{2n},u_{2n}) \\ \cdots & \cdots & \vdots & \\ (l_{n1},m_{n1},u_{n1}) & (l_{n2},m_{n2},u_{n2}) & \cdots & (1,1,1) \end{bmatrix}; \tag{2.7}$$

where $\tilde{a}_{ij}=\left(l_{ij}, m_{ij}, u_{ij}\right)$ and $\tilde{a}_{ij}^{-1}=\left(\frac{1}{u_{ij}},\frac{1}{m_{ij}},\frac{1}{l_{ij}}\right)$, for i,j,=1,2…n and i≠j.

In order to perform a pairwise comparison among fuzzy parameters, linguistic variables have been defined for several levels of preference, shown in Table 2.3

Table 2.3 Triangular fuzzy number of linguistic variables (Vahidnia, Alesheikh, and Alimohammadi, 2009).

Preferences expressed in linguistic variables	Triangular fuzzy numbers	Reciprocal triangular fuzzy numbers
Equal importance	(1,1,1)	(1/1,1/1,1/1)
Moderate importance	(2,3,4)	(1/4,1/3,1/2)
Strong importance	(4,5,6)	(1/6,1/5,1/4)
Very strong importance	(6,7,8)	(1/8,1/7,1/6)
Extreme importance	(9,9,9)	(1/9,1/91/9)
Intermediate values	(7,8,9),(5,6,7), (3,4,5), (1,2,3)	(1/9,1/8,1/7),(1/7,1/6,1/5), (1/5,1/4,1/3), (1/3,1/2,1/1)

The fuzzy triangular numbers used to represent these preferences are depicted in Figure 2.3.

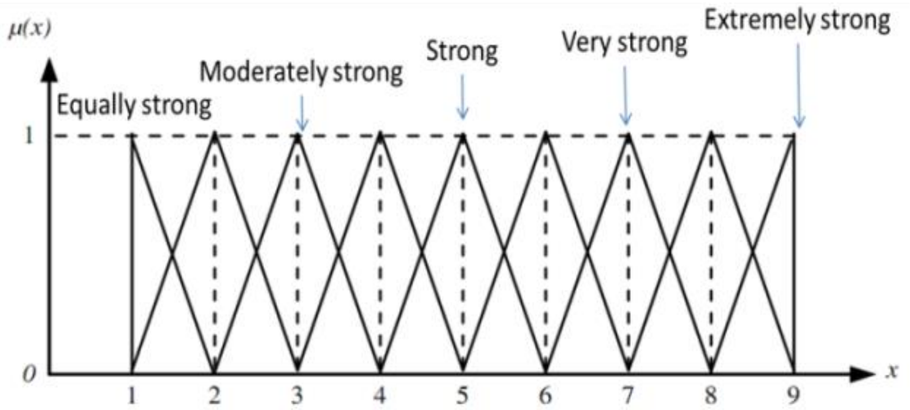

Figure 2.3 Triangular fuzzy numbers corresponding to linguistic variables representing levels of preference (Vahidnia et al., 2008).

2.2.2.2 Aggregation of expert preferences

There is a number of procedures which is specifically designed to tackle estimating weights based on a group of experts, including multiple comparison technique (Dunn-Rankin and King, 1969), geometric means (Davies, 1994). The geometric mean operations are commonly used within the application of fuzzy AHP and can be expressed as Equation (2.8).

$$l_{ij}=\left(\prod_{k=1}^{n} l_{ijk}\right)^{1/n}, m_{ij}=\left(\prod_{k=1}^{n} m_{ijk}\right)^{1/n}, u_{ij}=\left(\prod_{k=1}^{n} u_{ijk}\right)^{1/n}, \tag{2.8}$$

where (l_{ij}, m_{ij}, u_{ij}) is the fuzzy evaluation of experts k (k=1, 2, 3…n).

2.2.2.3 Fuzzy weighted summation

Fuzzy weighted summation is obtained from computing the normalized value of row sums (i.e. fuzzy synthetic extent) by fuzzy arithmetic operations as shown in Equations (2.9) and (2.10).

$$\tilde{S}_i=\sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{k=1}^{n}\sum_{j=1}^{n} \tilde{a}_{kj}\right]^{-1} ; \tag{2.9}$$

$$\tilde{S}_i=\left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}},\frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}},\frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right), \text{ for } i=1, 2 \dots n; \tag{2.10}$$

where ⊗ denotes the extended multiplication of two fuzzy numbers.

These fuzzy triangular numbers are known as the relative weights for each alternative under a given criterion, and are also used to represent the weight of each criterion with respect to the total objective. A weighted summation is then used to obtain the overall performance of each alternative.

2.2.2.4 Fuzzy rank method (Defuzzification)

Defuzzification is a kind of the transformation from triangular fuzzy member values to a crisp value. Practically, many defuzzification methods are available for transforming fuzzy member. In this study, three defuzzification methods are used i.e. 1) fuzzy extent analysis, 2) α cut, and 3) center-of-area. The ranking of relative importance of alternatives are then represented as crisp values.

(1) Fuzzy extent analysis

Fuzzy extent analysis, a kind of defuzzification proposed by Chang (1996), can be summarized as follows:

Frist, the degree of possibility for $\tilde{S}_i \geq \tilde{S}_j$ is computed from fuzzy weighted summation using Equation (2.11) and it can be displayed in Figure 2.4.

$$V\left(\tilde{S}_i \geq \tilde{S}_j\right)=\sup\left[\min(\tilde{S}_j(x),\tilde{S}_i(y))\right]_{y\geq x}. \tag{2.11}$$

This formula can be equivalently expressed as Equation (2.12)

$$V\left(\tilde{S}_i \geq \tilde{S}_j\right)=\begin{cases} 1 & m_i \geq m_j; \\ \dfrac{u_i-l_i}{(u_i-m_i)+\left(m_j-l_j\right)} & l_j \leq u_i\,; \quad i,j=1\dots n;\ j\neq i, \\ 0 & \text{otherwise.} \end{cases} \tag{2.12}$$

where $\tilde{S}_i=(l_i,m_i,u_i)$ and $\tilde{S}_j=\left(l_j,m_j,u_j\right)$.

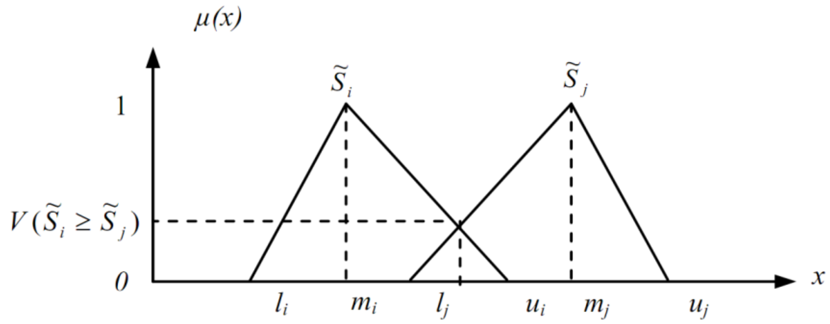

Figure 2.4 The degree of possibility of $V(\tilde{S}_i \geq \tilde{S}_j)$ (Vahidnia et al., 2008).

Second is to calculate the degree of possibility of $\tilde{S}_i$ and it should be greater than all the other (n-1) convex fuzzy numbers $\tilde{S}_j$ by Equation (2.13)

$$V(\tilde{S}_i \geq \tilde{S}_j | j=1, 2, ...n, j \neq i) = \min_{(j \in (1...n), j \neq i} V(\tilde{S}_i \geq \tilde{S}_j); \ i=1, 2, ...n. \tag{2.13}$$

Finally, estimate the priority vector $w = (w_1, \ldots w_n)^T$ of the fuzzy comparison matrix as Equation (2.14)

$$w_i = \frac{V(\tilde{S}_i \geq \tilde{S}_j | j=1,...,n, j \neq i)}{\sum_{k=1}^{n} V(\tilde{S}_k \geq \tilde{S}_j | j=1,...,n, j \neq k)}. \tag{2.14}$$

(2) α-cut method

In this method, fuzzy extent analysis is applied to calculate the fuzzy weights and performance matrix for criteria, as well as alternatives under each criterion. A fuzzy weighted sum performance matrix ($\tilde{P}$) can be derived for the alternatives by multiplying the fuzzy weight vector related to criteria with the decision matrix for alternatives under each criterion, and summing the obtained vectors, as shown in Equation (2.15).

$$\tilde{P} = \begin{pmatrix} (l_1, m_1, u_1) \\ (l_2, m_2, u_2) \\ \vdots \\ (l_n, m_n, u_n) \end{pmatrix}; \tag{2.15}$$

where n is number of alternative.

According to Wang (1997), in order to check and compare two fuzzy number A and B as shown in Figure 2.5. The α-cut-based method stated that, if let A and B be fuzzy numbers with α-cuts, $A_\alpha = [a_{\alpha-}, a_{\alpha+}]$ and $B_\alpha = [b_{\alpha-}, b_{\alpha+}]$. Fuzzy number of A is smaller than B denoted by A ≤ B, if $a_\alpha - < b_\alpha -$ and $a_{\alpha+} < b_{\alpha+}$ for all α in the range of [0, 1]. Hence, cannot be compared A and B, if $b_{\alpha-} \leq a_{\alpha-}$ for small α but $b_{\alpha-} \geq a_{\alpha-}$ for large α. In practice, A ≤ B if $a_{\alpha+} \leq b_{\alpha+}$ for all $\alpha \in [c, 1]$, where c is a constant that is usually larger than 0.5. This method clearly emphasizes the numbers with large membership values.

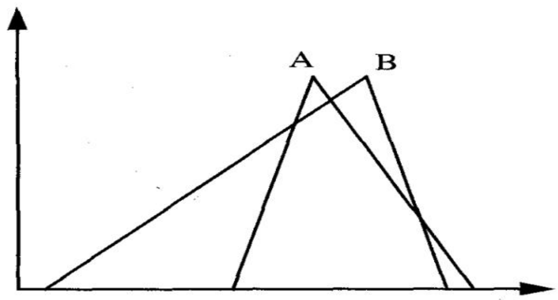

Figure 2.5 α-cut-based method (Wang, 1997).

In next step, α-cut analysis as shown in Figure 2.6 is applied to transform the total weighted performance matrices into interval performance matrices, which is showed with αLeft and αRight for each alternative as shown in Equations (2.16), (2.17), and (2.18).

$$\tilde{P}_\alpha = \begin{pmatrix} (\alpha Left_1, \alpha Right_1) \\ (\alpha Left_2, \alpha Right_2) \\ \vdots \\ (\alpha Left_n, \alpha Right_n) \end{pmatrix}; \tag{2.16}$$

$$\alpha Left = [\alpha * (m-l)] + l, \tag{2.17}$$

$$\alpha Right = u - [\alpha * (u-m)]. \tag{2.18}$$

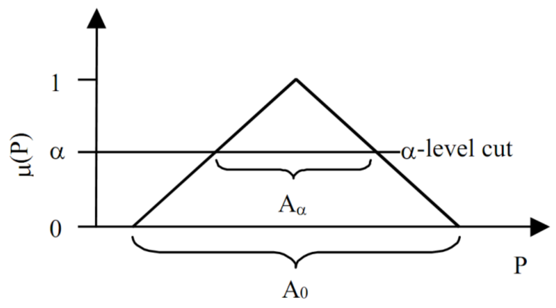

Figure 2.6 α-cut level (Abebe, Guinot, and Solomatine, 2000).

Last step is to convert interval matrices into crisp values. It is done by applying the Lambda function which represents the attitude of the decision maker that is maybe optimistic, moderate or pessimistic. Decision maker with optimistic attitude will take the maximum λ, the moderate person will take the medium λ and the pessimistic person will take the minimum λ in the range of [0,1]. The α-cut is to account for the uncertainty in the fuzzy range chosen in. In this case, the decision maker expressed personal confidence about this range. The confidence value is ranges between 0 and 1, from the least confidence to the most confidence as shown in Equations (2.19) and (2.20)

$$C_\lambda = \begin{pmatrix} C_{\lambda 1} \\ C_{\lambda 2} \\ \vdots \\ C_{\lambda n} \end{pmatrix}; \tag{2.19}$$

$$C_\lambda = \lambda \ \text{x} \ \alpha Right + (1 - \lambda) \ \text{x} \ \alpha Left, \tag{2.20}$$

where C_λ is crisp value, and

λ is a decision maker attitude.

These values should be normalized because of different scales.

(3) Centre of area defuzzification

Centre of area defuzzification method (Ross, 1995) is a method for transforming fuzzy triangular numbers into real numbers (Figure 2.7).

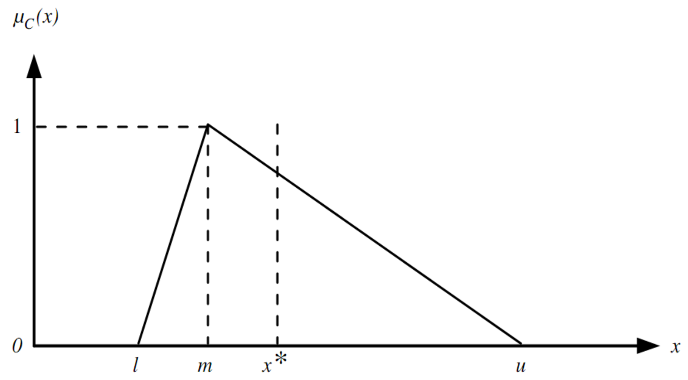

Figure 2.7 Center-of-area method for defuzzifying a triangular fuzzy number (Vahidnia et al., 2009).

This method can determine actual site priorities and overall scores. For a convex fuzzy number ~C, a real number x* corresponding to its. This procedure is the most prevalent and physically appealing of all defuzzification method (Sugeno, 1985; Lee, 1990). Center of area of ~ C is defined by Equation (2.21).

$$x^* = \frac{\int \mu_{\tilde{c}}(x)dx}{\int \mu_{\tilde{c}}dx}. \qquad (2.21)$$

2.3 Sensitivity analysis

The aim of sensitivity analysis is to determine how the recommended alternative (the output) is affected by changes in the input which are geographical data and the decision maker's preference. There are few methods for sensitivity analysis. One is making change in the single-criterion vales, the weights assigned to the evaluation criteria, and the probabilities (if any) to discover which of these quantities are important in determining the final recommendation (Malczewski, 1999). Other can be observation the change of output according to the influence of every index. This can be conducted by observing the change of recommendation when remove a criterion, one at the time, from the decision process (Zhang and Wang, 2009).

2.4 Previous studies

Multi-criteria decision making research has developed rapidly and effectively for analyzing complex decision problem like making decision for dam site construction with big amount of budgets. The problem is involved a set of alternatives that can be evaluated and compared in terms of the conflict, cost, and benefit, with some incommensurate criteria. MCDM represents decision outcome for a set of alternatives and a set of evaluation criteria.

Mekong Secretariat (1994) conducted an inventory of suitable project which will avoid, to the maximum impact, relocation of communities and disturbance of valuable agriculture and other resources. Twelve hydro projects along the Mekong River of LMB between Chiang Khong to Phnom Penh were selected as candidate alternatives. Consideration on the basis of impact and benefit analysis including design and cost analyses of each alternative site was operated. The method was evaluated based on the numbers of impact and benefit contained numbers of population affected, land affected, and economic indicator (internal power generation). The alternative had been evaluated as individual isolate project for comparison their merits in selecting promising option. It was found that 9 project sites appear to offer attractive economic opportunities for electric power generation. Among those candidates, priority was suggested based on the apparent and probable social and environmental effect. However, ICEM (2009) continually evolved the design and characteristic of the 12 mainstream hydropower projects based on update and new information.

Additionally, Saaty (1980) proposed the systematic analytical hierarchy process (AHP) to solve the MADM problem, as AHP is a flexible and yet structured methodology for analyzing and solving complex decision problems by structuring them into a hierarchy. At that time, AHP has been widely used as useful multi-criteria decision making (MCDM) estimated in many areas of research such as site selection (Guiqin, Li, Guoxue, and Lijun, 2009; Şehnaz, Erhan, Bilgehan, and Remzi, 2010; Vidal, Sahin, Martelli, Berhoune, and Bonan, 2010), land suitability evaluation (Bunruamkaew and Murayam, 2011; Javadian, Shamskooshki, and Momeni, 2011; Ouyang, Lu, Wu, Zhu, and Wang, 2011; Anane, Bouziri, Limam, and Jellali, 2012) and development and planning (Lai, Han-lun, Qi, Jing-yi, and Yi-jiao, 2011).

Hence, Chang (1996) first introduced fuzzy AHP approach with function of triangular fuzzy number for pairwise comparison, while fuzzy extent analysis method was used to synthesis extent value of the pairwise comparison. However, the traditional model of Chang (1996) may contained outputs such information as "zero is used as divisor", or "data is out of range", then Zhu, Jing, and Chang (1999) improved the basic theory of the triangular fuzzy number and the formulation of comparing the triangular fuzzy number's size. Chan and Kumar (2007) applied the fuzzy extent analysis hierarchy process for global supplier development considering both qualitative and quantitative factors of risk factor, to identify and discuss some of the important and critical decision criteria including risk factors for the development of an efficient system for global supplier selection. Fuzzy extended analytic hierarchy process based methodology was discussed to tackle the different decision criteria like cost, quality, service performance and supplier's profile including the risk factors involved in the selection of global supplier in the current business scenario. Fuzzy extended analytic hierarchy process was an efficient tool to handle the fuzziness of the data involved in deciding the preferences of different decision variables. The proposed model can provide not only a framework for the organization to select the global supplier but also has the capability to deploy the organization's strategy to its supplier.

Büyüközkan (2009) determined the mobile commerce (m-commerce) user requirements using an analytic approach. The approach consisted of three main steps of identifying m-commerce user requirement, structuring m-commerce user requirement, and identifying the importance of weights for m-commerce user requirements. For the comprehensively identifying m-commerce user requirement, a two-step approach was followed. First, a list of preliminary success factors was identified based on an extensive review of m-commerce, mobile business and mobile applications literature. Second, the identified requirements were subject to the examination and modification of information technology experts. By this two-step approach, 13 factors were finally retained and grouped into three categories. However, for structuring m-commerce user requirement, three categories with 13 factors were formed in hierarchy model. The hierarchy model consisted of three levels of objective (level 1), main requirement (level 2), and sub-requirement (level 3). Level 2 contained functionality, profitability and credibility. Further, the level 3 on basis of functionality consisted of (simplicity, usability, flexibility, interface, speed, and accessibility), profitability (added value, options of payment, price, and individualization), and credibility (reliability, safety, and correction of the system). The FAHP methodology was applied to criteria weight determination. It was also well recognized that human assessment on the relative importance of individual customer requirements was always subjective and imprecise. Hence, fuzzy extent analysis method was used to calculation composite priority weights of m-commerce user requirements. Additionally, the fuzzy extent method applied in this paper was proved to be simple, less time taking and having less computational expense as compared to other existing decision-making systems. The results showed that for Turkish m-commerce users, the most important requirements were price, added value, reliability, safety and simplicity.

Wang, Luo, and Hua (2008) examined and discussed in example number of applications of the extent analysis method on fuzzy AHP proposed by Chang (1996). The priority vectors determined by the extent analysis method do not represent the relative importance of decision criteria or alternatives and that the misapplication of the extent analysis method to fuzzy AHP problems may lead to a wrong decision when some useful decision information such as decision criteria and fuzzy comparison matrices was not considered. The result indicated that the extent analysis method may assign a zero weight to a decision criterion or alternative, leading to the criterion or alternative not to be considered in decision analysis; the weights determined by the extent analysis method do not represent the relative importance of decision criteria or alternatives and cannot be used as their priorities; the extent analysis method may make a wrong decision and select the worst decision alternative as the best one when it was misused for solving a fuzzy AHP problem. The extent analysis method cannot make full use of all the fuzzy comparison matrices information and may cause some useful fuzzy comparison matrices information to be wasted when it assigns an irrational zero weight to some useful decision criteria or sub-criteria. Therefore, the extent analysis method is not a method for deriving priorities from a fuzzy comparison matrix. It was just a method of showing how the degree of priority of one decision criterion or alternative is bigger than those in fuzzy comparison matrix.

Vahidnia et al. (2008) treated the steps AHP and its manner in term of its weaknesses and strengths. Then, the fuzzy modified analytical hierarchy process (FAHP) was proposed in order that the concepts like of fuzziness, uncertainty and vagueness were able to broadly posed in expert’s decision making. The fuzzy extent analysis method and α-cut based method on fuzzy AHP were described to obtain a crisp priority vector from a triangular fuzzy comparison matrix. The advantage of α-cut-based method was that the conclusion was less controversial and also the uncertainty and the different attitude of decision maker can be taken into account in this method but the fuzzy extent analysis was more easy in computation.

Vahidnia et al. (2009) developed a multi-criteria decision analysis process that combines Geographical Information System (GIS) analysis with the Fuzzy Analytical Hierarchy Process (FAHP) to determine the optimum site for a new hospital in the Tehran urban area. The GIS was used to calculate and classify governing criteria, while FAHP evaluated the decision factors and their impacts on alternative sites. Three methods were used to estimate the total weights and priorities of the candidate sites: fuzzy extent analysis, center-of-area defuzzification, and the a-cut method. The three methods yield identical priorities for the five alternatives considered. Fuzzy extent analysis provided less discriminating power, but was simpler to implement and compute than the other two methods. The α-cut method was more complicated, but it could integrate the uncertainty and overall attitude of the decision-maker. Center of area was scientific determination for actual site priorities and overall scores.

2.5 Synthesis of the research approach

From literatures mentioned above, their advantage and disadvantage are synthesized as follows, which could lead to contribute to this study.

(1) From the previous works, the criteria consideration to rank the relative importance of an alternative was based on only individual proposed site. No pairwise comparison among alternatives, based on each criterion, was operated. Thus, this study is planned to cover such a comparison.

(2) Normally, to rank the relative importance of the proposed dam sites and reservoirs, the single theme of environmental effect or affected communities or affected ecology, etc was considered. This study tries to cover more themes as many as possible.

(3) Factors to be considered are normally in form of quantitative number such as a number of people affected from the project and benefit as expressed in mega Watt like electricity generation. This study plans to include quantification of some descriptive factors such as foundation geology, availability of construction materials, etc.

(4) AHP has been widely used as a useful tool in MCDM and has been applied to many fields of study. Nevertheless, it has never been found to be employed for ranking the importance of proposed dam sites and reservoirs which are one of the complicated decision problems. However, the comparison in AHP has limitation of 9 point scale. This makes it more difficult when AHP deals with the imprecision and subjectivity in the pairwise comparison process.

(5) FAPH has been improved to fulfill the decision maker imprecise and subjectivity in pairwise comparison by transforming crisp judgments into fuzzy

judgments. In other word, FAHP is suitable to be applied in a case of having uncertainty and less data and information to provide for the decision making. Therefore, this study which shares the same point of judgment decides to employ FAHP for ranking the importance of the proposed dam sites and reservoirs. The application of these most detailed representative weights of ranks obtained from the FAHP to a certain purpose is expected to return the more accurate result, for example, when requires to allocate very big amount of budget to support every dam activities based on their benefits and costs. These activities might include hydropower supply, enhancing implementation of tourist network development, environmentally monitoring study, foundation maintenance, etc.

(6) There are many methods for defuzzification or transforming fuzzy judgment to be crisp ranking e.g. fuzzy extent analysis, center-of-area, α cut, geometric mean approximation, etc. Each technique has its own advantage. Therefore, this study includes each technique in order that the results can be compared and discussed. This can be used as useful and explainable basic information for decision makers.

(7) The output can be affected differently by the influence of individual criterion. To provide more information to decision makers, sensitivity analysis, operating on dropping one criterion at the time, is added in the study.

CHAPTER III

CHARACTERISTICS OF THE STUDY AREA AND PROPOSED DAM PROJECTS

3.1 Regional information

Lao PDR or herein called Laos is considered as landlocked country, which an area extent is about 236,800 sq.km, and located in the center of the Southeast Asia peninsula. It lies mostly between latitudes 13°54' and 22°30' N, and longitudes 100°05' and 106°38' E. Laos shares boundary with 5 countries, namely the People's Republic of China in the North, the Kingdom of Cambodia in the South, the Socialist Republic of Vietnam in the East, the Kingdom of Thailand in the West, and the Union of Myanmar in the North West.

Physiography of Laos has been divided into three regions (Duckworth, Salter, and Khounboline, 1999) i.e. Northern Highlands, Annamite Range or Saiphou Louang range, and Mekong Plain, as illustrated in Figure 3.1. The Northern Highlands is characterized by complex mountains of which altitudes vary between 500-2,500 m. The Saiphou Louang Range is between 500-2,000 m, with less rugged terrain than the Northern Highlands and soil type is generally similar to those in the North. The Mekong Plain lies in the south of the Northern Highlands and West of the Annamite Range. It is an area of primarily flat to gently undulating topography, mostly below 200 m.

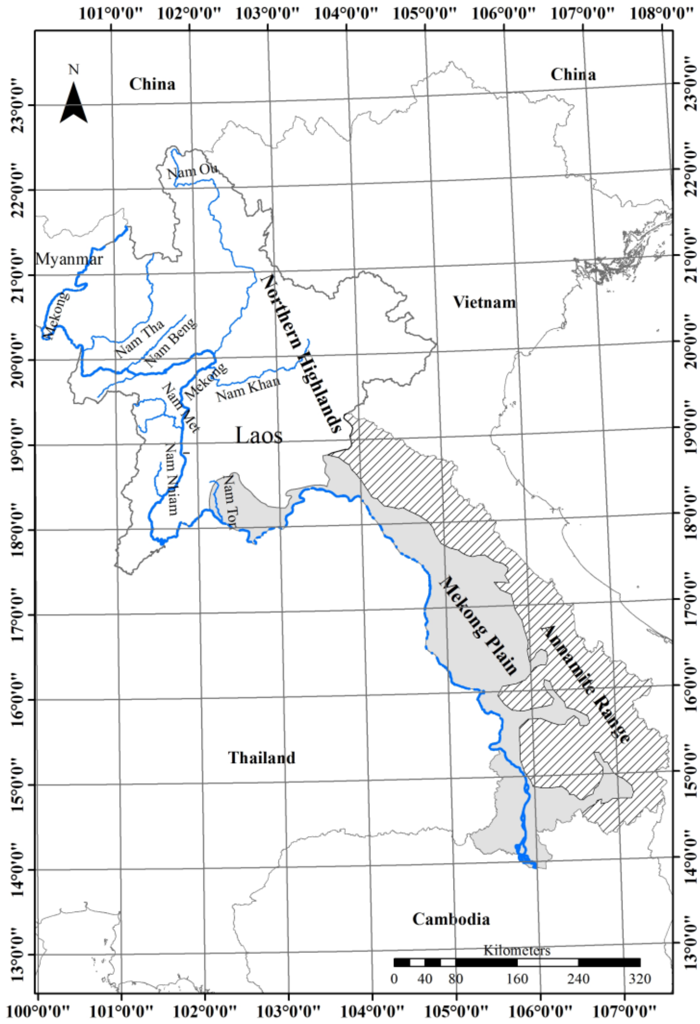

Figure 3.1 Physiographic units of Lao PDR (Duckworth et al., 1999).

The study area is located at the southwestern part of the Northern Highlands where Mekong River flows through Laos at Houyxay district, Bokeo province before acts as the Laos-Thailand border in the south of the area. The area consists of the various intermontane basins. More or less, each basin has become the location of a famous town due to its physical characteristic, socio-economic condition, and tourist attraction e.g. Oudomxaiy, Luangprabang, Xienghone, Ngeun, Hongsa, Nan, Xaiyabury, Phiang, Kasy, Mad, Vungvieng, Fuang, Xanakham, Parklai, Boten, Kenthao intermontane as shown in Figure 3.2.

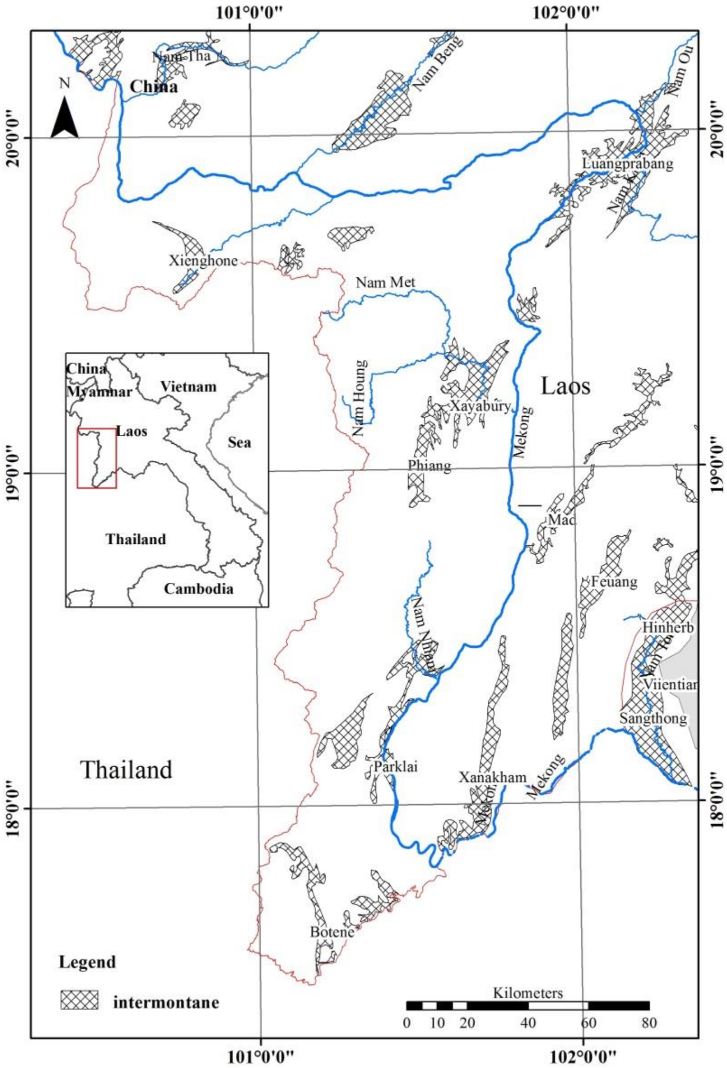

Figure 3.2 Intermontane basins in the North of Laos.

3.1.1 Climate

Laos is located within a tropical area where the weather is generally hot and humid. The general climate of Laos is characterized by two distinct seasons, dry season from November to March and the rainy season from April to October.

Most climates of Lao are strongly influenced by the annual monsoon cycle (Figure 3.3), with the west-southwest (WSW) monsoon from May to October and NE Monsoon from November to February. The WSW monsoon originates from the Indian Ocean lasts from mid-May until the end of October brings around 90 percent of annual rainfall and the depression and typhoon occur during June, July, August, and September, due to these months are usually the month of intense rainfall. As the season progress, the cyclonic storms originate from the west Pacific Ocean and the South China Sea. The storm moves from their origins towards the west and northwest direction. After crossing the peninsula coast into Vietnam, Lao, and Thailand, their intensities usually decrease and maintain in the types of depression storms.

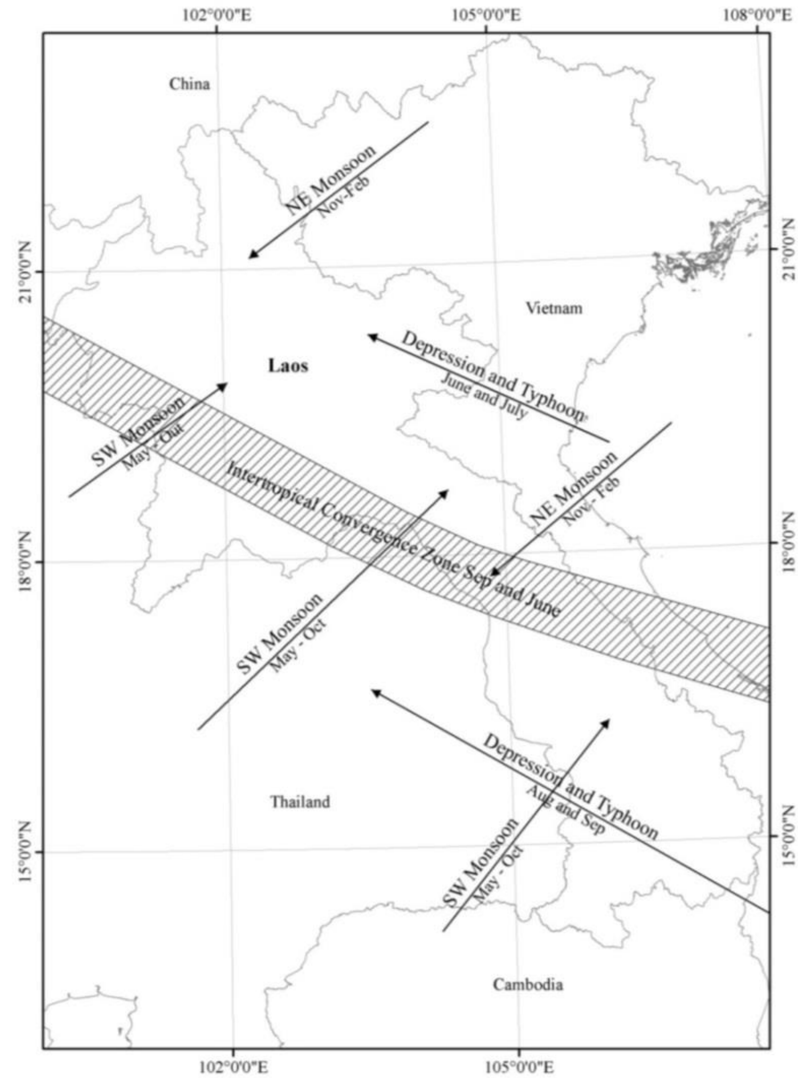

Figure 3.3 Monsoon and depression condition in Laos (Ch.karnchang Public Company Limited, 2010).

The mean annual rainfall ranges between 1,400 and 2,500 mm over most of the country, although the Bolaven Plateau receives on average over 3,500 mm, and areas around Savannakhet and parts of the north generally receive less than 1,500 mm. The mean annual temperature is between 25-26˚C, the coolest month in December to January (20-21˚C), and the hottest in April to May (28-30˚C). In some areas, temperatures are possibly 40 to 42˚C.

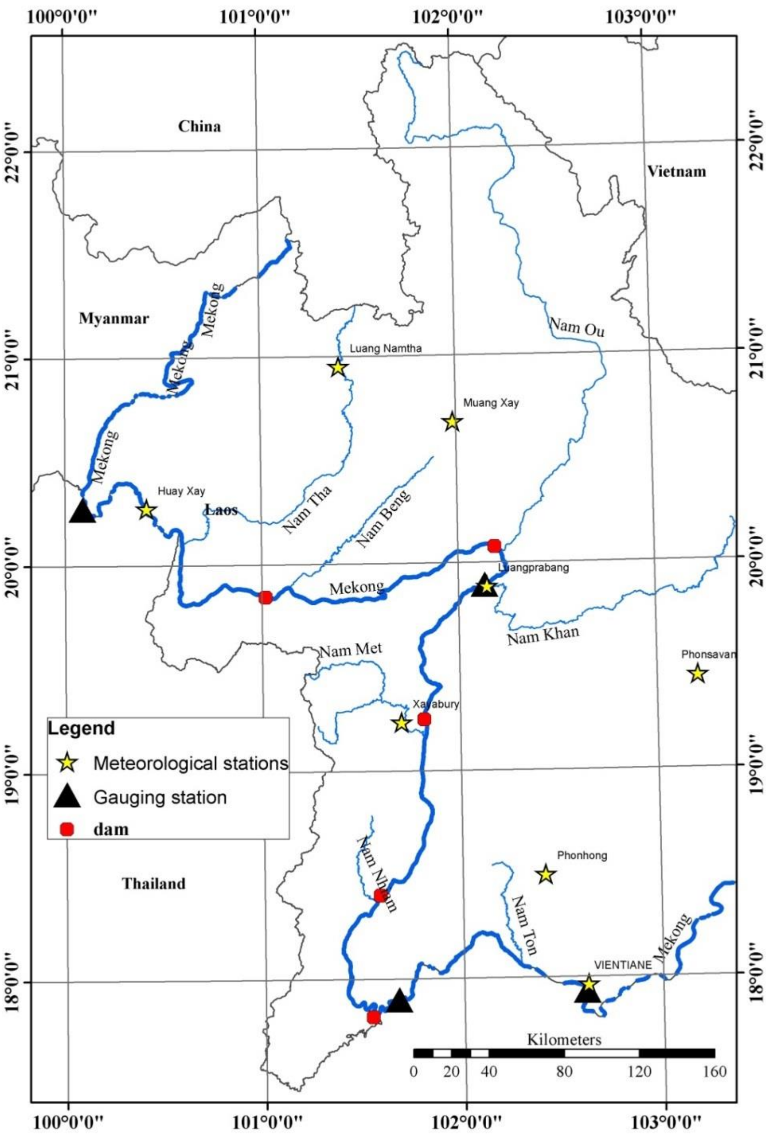

Figure 3.4 Location of river gauging stations and meteorological stations in the study area.

The climate of the study area is almost the same as the whole Laos country. Table 3.1 shows the mean monthly rainfall from 8 available meteorological stations located at Huayxay, Luangnamtha, Muangxay, Luangprabang, Phonsavan, Xyabury, Phonhong, and Vientiane (Figure 3.4).

Table 3.1 Mean monthly rainfall (mm).

Month	Huayxay (1996-2009)	Luangnamtha (1994-2009)	Muangxay (1991-2009)	Luangprabang (1971-2009)	Phonsavan (1982-2009)	Xyabury (1971-2009)	Phohong (1971-2009)	Vientiane (1971-2009)
Jan	13.4	16.1	11.6	13.9	8.4	9.1	7.1	5.7
Feb	28.2	29.4	21.7	23.4	15.8	14.1	19.4	20.2
Mar	46.7	58.2	49.3	43.5	58.9	43.5	44.4	40.9
Apr	123.8	113.8	98.9	105.3	146.5	116.1	104.1	90.8
May	242.1	217.6	177.4	159.3	189.8	169.4	344.0	238.2
Jun	229.8	201.2	201.3	178.3	188.9	158.4	347.6	281.3
Jul	373.6	300.5	279.4	260.9	276.1	202.8	449.4	288.6
Aug	404.0	297.8	318.2	278.8	302.3	238.9	459.5	316.2
Sep	248.6	169.4	170.7	161.9	155.3	227.0	347.0	274.4
Cot	114.9	110.4	65.6	111.0	69.6	97.2	114.3	92.5
Nov	42.7	46.5	30.2	33.9	22.3	26.3	19.0	12.8
Dec	12.7	28.8	20.6	15.6	7.9	9.1	3.5	3.8
Mean annual	1,880.5	1,586.8	1,444.9	1,382.1	1,441.8	1,297.3	2,259.2	1,665.4

3.1.2 Hydrology

The hydrology of the study area consists mainly of the Mekong River and tributaries. Seven main tributaries include Nam Tha, Nam Ngeun, Nam Beng, Nam Ou, Nam Khan, Nam Met and Nam Houng, and Nam Khiam. They additionally provide runoff to the Mekong River and could affect to a dam design and evaluation. Four gauges stations at Chiang Saen, Luangprabang, Chaingkhan, and Vientiane are selected for observation mean monthly runoff. This information is tabulated in Table

3.2 and can be plotted as Figure 3.5 to illustrate the relationship between runoffs in each month.

Table 3.2 Mekong River means monthly runoff (m³/s) at selected stations.

Month	Chiang Saen 1962-2005	Luangprabang 1960 - 2005	Chiang Khan 1967 - 2005	Vientiane 1960 - 2005
Jan	1,145	1,670	1764	1784
Feb	928	1,262	1302	1394
Mar	824	1,050	1074	1201
Apr	901	1,085	1084	1225
May	1,332	1,585	1704	1777
Jun	2,471	3,106	3411	3472
Jul	4,787	6,487	7072	7110
Aug	6,366	9,912	10579	11184
Sep	5,421	8,861	9854	10937
Cot	3,788	5,670	6323	6801
Nov	2,483	3,771	3951	4216
Dec	1,666	2,368	2505	2554

Source: MRC (2005)

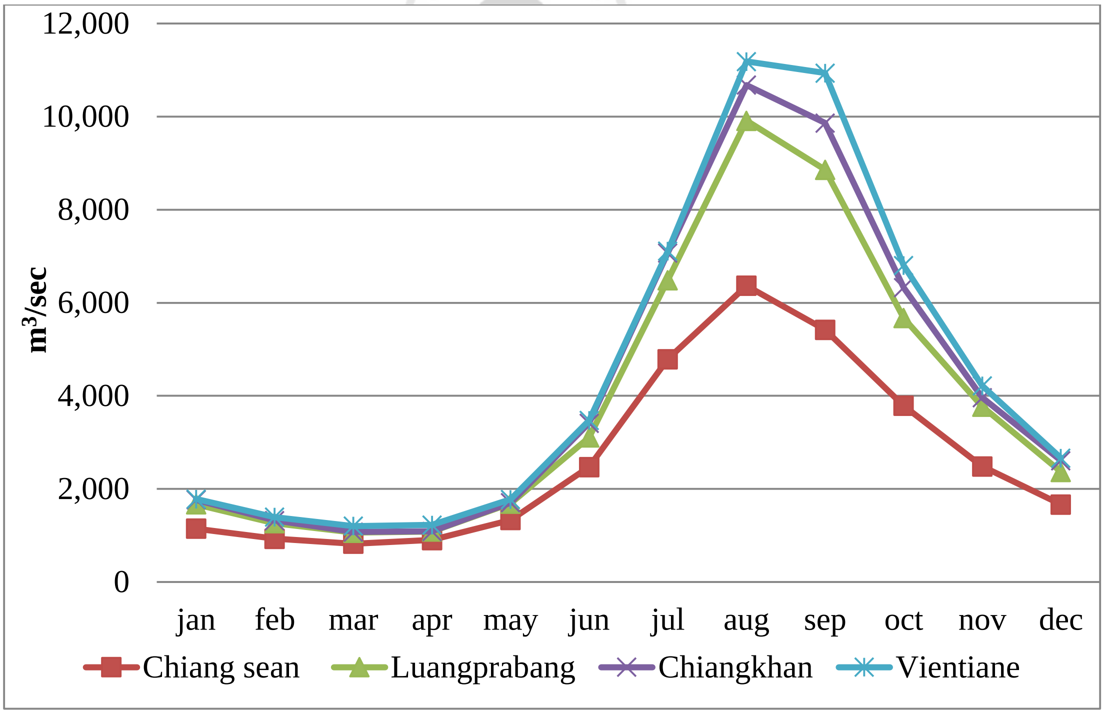

Figure 3.5 Mean monthly runoff in m^3/sec at selected stations along Mekong River.

Figure 3.5 illustrates the mean monthly discharge (m^3/sec) of four selected gauges on the Mekong River. The discharge for the whole year presents the normal downstream increase at stations respectively. During rainy season, the runoff rapidly increased at all stations from June to the peak in August before dropping to the base level in January. This indicates that between Chiang Saen and Vientiane there are several large tributaries provide discharge to the Mekong River and cause its increasing downstream.

3.1.3 Topography and landform

The terrain condition and surface configuration of any area results from the operation of particular geomorphic process on particular types of bedrock, surficial materials and geologic structure (Wright, 1984). Slope and landform together with lithology can play an important role in controlling the energy of sediment transportation, which in turn, has a direct effect on a grain size of materials in various deposition environments. Source rocks often control the mineralogical composition of surficial materials and these characteristic often affect their engineering behavior.

The study area consists of NE to N orientated high and complex mountain ranges with alternating some narrow intermontane basins. The elevation varies between 170 to 2,400 m as shown in Figure 3.6. Associated to the Mekong River and tributaries, the valleys and intermontane basins were formed.

Most of the landform of this area consists of complex mountains, ridges and hills, piedmont fringes and valley flats. The large mountain is typically characterized by high relief and steep slope, lying along both sides of the Mekong River and its tributaries, with altitude ranges from 500-2,400 m. Valley flats appear more and bigger at the south with elevation ranges between 170-600 m.

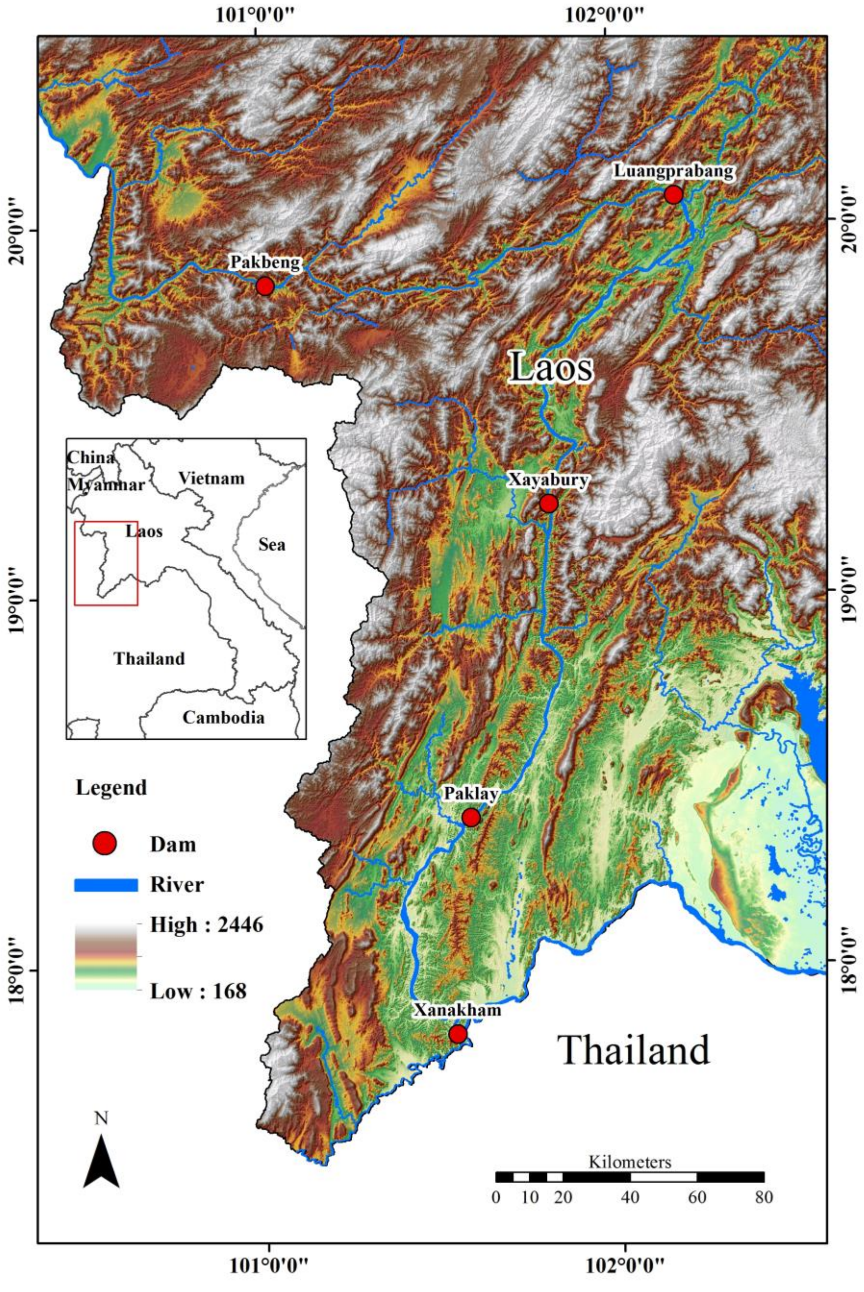

Figure 3.6 Topography of the study area and locations of proposed dam projects.

3.1.4 Geology

Basic geology of the study area is available in a map scale at 1:1,000,000 (JICA and DGM, 2008a). More detailed map was partly mapped at two different scales, 1:200,000 at the northern part (DGMV and DGM, 2007) and 1:100,000 at the southern part (JICA and DGM, 2008b) as shown in Figure 3.7.

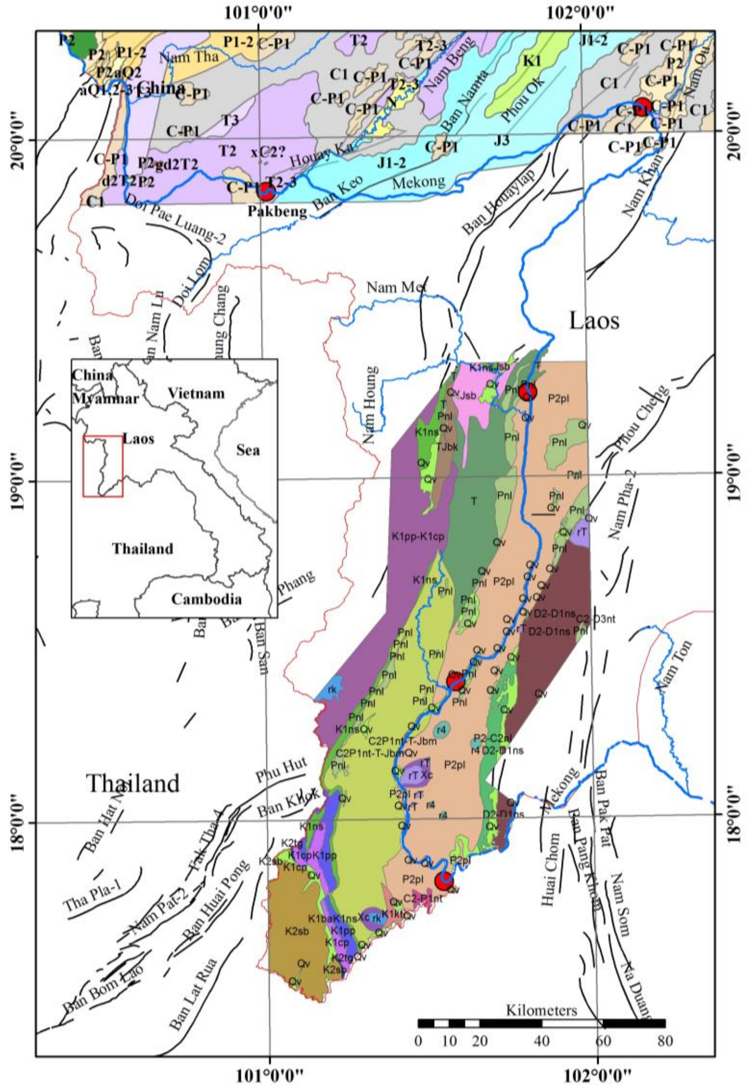

Figure 3.7 Available basic geological data.

Geology at these scales along both sides of the Mekhong River from Xayabury to Luangprabang is missing. Therefore, visual interpretation is used to extract geologic information at the scale of 1:200,000 based on previous maps, Landsat TM satellite imagery, hillshade image. The hillshade image can be obtained from grid DEM of the Shuttle Radar Topography Mission (SRTM) with resolution of 90x90 m. Stratigraphic units of the original geologic maps at all scales mentioned above are used for geologic interpretation and not completely compiled. However, general rock types of the units can be extracted to use for Land Instability Index determination. The geologically interpreted result is shown in Figure 3.8. (See description of map unit in Appendix A).

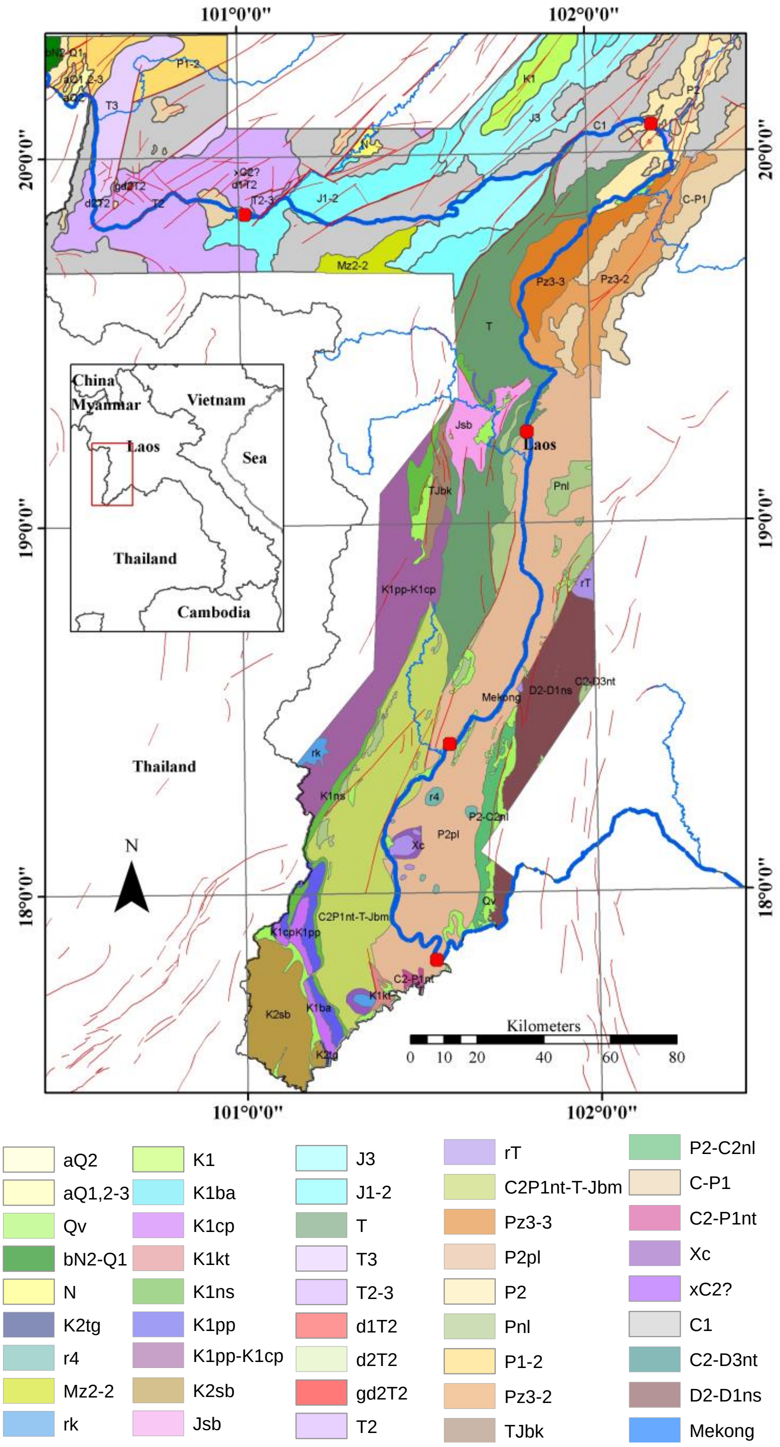

Figure 3.8 Interpreted and modified geology of the area related to proposed dam projects in the study area.

Geology of the area is characterized by the presence of rocks and sediments in Paleozoic to Cenozoic eras and from Devonion to Quaternary periods.

As described by JICA and DGM (2008a), Paleozoic and Mesozoic rocks consist of continental fluvial and shallow to deep marine sediments dominate throughout the area. These rocks have been intruded by numerous granitoid plutons comprising granodiorites, monzonites and quartz porphyries during the Devonian to Triassic. The detail of symbols of rock units is described in appendix A.

The Cenozoic sediments contains Quaternary and Neogene repetitive group of surface deposits. Alluvium sand and gravels along the Mekong River and tributaries including higher land always appear in intermontane basins while finer grains like sand, silt and clay are present in the narrow valley flats.

3.2 Proposed dam projects information

Five hydropower projects along the Mekong River within Northwestern Laos are proposed. According to ICEM (2010), general specifications of these proposed dams and reservoirs can be described as follows:

3.2.1 Pakbeng dam

Pakbeng Dam is the northernmost of the LMB located upstream of the town of Pakbeng between boundaries of Pakbeng district, Oudomxai province, and Ngeun district, Xayabury province. It has an installed capacity of 1,230 MW from a proposed dam with 943 m long, 76 m high and rated head of 30 m. It has a reservoir area of 86.51 km^2 and live storage of 442 million cubic meters (million.cu.m). As originally designed with a Full Supply Level (FSL) at 345 m amsl, it would have inundated land back into Thailand, but under the Lao Government Optimizations Study for the cascade of the proposed project, the FSL was lowered to 340 m amsl to avoid this impact. Eighty percentage of the reservoir area will be confined to the main channel. The latest estimate of people to be resettled is approximately 6,700 persons. More detail is described in Table 3.3 below.

Table 3.3 Overview of Pakbeng dam and reservoir (ICEM, 2009).

Overview of project	Description
Name of dam	Pakbeng HPP
Proposed location	2,188 upstream delta Latitude 19°50'37.64" Longitude 101°1'7.22"
Height	76 m
Length	943 m
Type of Dam construction	Concrete gravity
Rated head	30 m
Plant discharge	7,250 cu.m/sec
Number of units	10x123 MW
Install capacity	1,230 MW
Firm and secondary energy generated annually	Mean 5,517 GWh/yr, firm 4,074
Mean annual discharge	3,160 cu.m /sec (312.05 m amsl)
Min observed flow	635 cu.m/sec (306.20 m amsl)
Max observed flow	23,500 cu.m/sec (333.7 m amsl)
Gated spillway	15 gates elevation 322
Spillway dimensions	15m wide x 23 m height
Max spillway design discharge and return period used	27,300 (P=0.2%)
Proposed	
Proposed market for electricity, nation	10%
Proposed market for electricity, export to Thailand	90%
Multipurpose uses considered (if any)	Navigation
Reservoir	
Full Supply level of reservoir	340 m amsl
Low Supply level of reservoir	339 m amsl
Area inundated at FSL	86.51 sq. km
Active volume of the reservoir	442 million.cu.m
Dead storage volume of reservoir	NA
Length of reservoir	130-144.5 km
Construction	
Material source variable	2 quarries at left and right banks
Accessibility requirement	1.74 km to connect the road from Ban Pakbeng Internal access roads: 7.4 km concrete roads and 6.5 km of gravel roads.

Table 3.3 (Continued).

Construction	Description
Transmission line	to Thailand about 80 km
Dimensions of navigation locks	1 lock capacity 500 tonnes 73 m long x 12 m wide x 3.2 m deep Lift 37.48 m
Type and dimensions of fish passes	included but no details
Impacts	
Number of communities to be resettled	28 villages
Number of households to be resettled	774 households
People	6,700 persons
Total reservoir	86.51 sq.km
Total area of agricultural land inundated	13.25 sq.km
Mixed bamboo and secondary forest	4 sq.km
Tourism and cultural sites lying in the inundation zone	None

3.2.2 Luangprabang dam

Luangprabang are the second dam in the cascade, located above Luangprabang town, about 3 km above the confluence with the Nam Ou, and the Pak Ou caves. The power will be destined for Vietnam. It has an installed capacity of 1500 MW, length 318 m and 57.5 m high with a rated head of 33.6 m which designed as concrete gravity dam installed of 10 Kaplan unit. The main proposed market for electricity, 90% will be exported to Vietnam and used as multipurpose to be navigated. It has a reservoir area of 72.39 km^2, with 320 m amsl FSL and 318 m amsl Low supply level (LSL). Reservoir length is about 170 km at FSL, 40% of the length is contained within the channel and live storage of 136.1 Mm^3. The latest estimate of people to be resettled was approximately 12,966 persons, impact to 36 communities, and 2,516 households. The more detail is described in Table 3.4.

Table 3.4 Overview of Luangprabang dam and reservoir (ICEM, 2009).

Overview of project	**Description**
Name of dam	Luangprabang
Proposed location	2,188 upstream delta Latitude 20°03'58.8" Longitude 102°11'30.7"
Height	57.5 m
Length	318 m
Type of Dam construction	Concrete gravity
Rated head	32 m
Plant discharge	5,091 cu.m/sec
Number of units	10 Kaplan
Install capacity	1,500 MW
Firm and secondary energy generated annually	Isolated 7,102.7 GWh/yr, cascade 8,258 GWh/yr
Mean annual discharge	3,061 cu.m/sec
Min observed flow	NA
Max observed flow	45,900 cu.m/sec
Gated spillway	10 gates
Spillway dimensions	18 m wide x 22 m height
Max spillway design discharge and return period used	44,838 - 1:10,000 yrs
Proposed	
Proposed market for electricity, nation	10%
Proposed market for electricity, export to Vietnam	90%
Multipurpose uses considered (if any)	Navigation
Reservoir	
Full Supply level of reservoir	320 m amsl
Low Supply level of reservoir	318 m amsl
Area inundated at FSL	72.39 sq. km
Active volume of the reservoir	136.1 million.cu.m
Dead storage volume of reservoir	1,453.7 million.cu.m
Length of reservoir	170 km at FSL, 140 km at amsl
Construction	
Material source variable	2 quarries at left and right banks
Accessibility requirement	1 bridge across Nam Ou, temporary bridge across mainstream, 4 km access road along left bank, 11 km from Pak Ou to route 13
Transmission line	to Vietnam about 400 km
Dimensions of navigation locks	Multiple step, 1,210,000 tons of shipping /yr 2 locks at 12 x 120 x 3 m depth
Type and dimensions of fish passes	Provided on the right bank but no details

Table 3.4 (Continued).

Impacts	Description
Number of communities to be resettled	26 villages
Number of households to be resettled	2,516 households
People	12,966 persons
Total reservoir	72.39 sq.km
Existing water surface	28.64 sq.km
Total area of agricultural land inundated	1.94 sq.km
Mixed bamboo and secondary forest	41.81 sq.km
Tourism and cultural sites lying in the inundation zone	Pak Ou caves are 3 km downstream of the dam site

3.2.3 Xayabury dam

Xayabury, the third dam in the cascade which is located about 150 km downstream of Luangprabang town. The power will be destined for Thailand. It has an installed capacity of 1,260 MW with a dam 810 m long and 32 m high and a rated head of 24 m. It is proposed to operate continuously. It has a reservoir area of 49 km^2 (96% confined within the main channel) and live storage of 225 Mm^3. The proposals and studies for Xayabury are the most advanced, and become the first in line for consideration under the MRC’s Procedures for Notification, Prior Consultation and Agreement (PNPCA). The latest estimate of people to be resettled is approximately 2,130 persons. More detail of the dam is in Table 3.5.

Table 3.5 Overview of Xayabury dam and reservoir (ICEM, 2009).

Overview of project	Description
Name of dam	Xayabury hydroelectric power project
Proposed location	2,188 upstream delta Latitude 20°03'58.8" Longitude 102°11'30.7"
Height	32 m
Length	810 m
Type of Dam construction	Composite of powerhouse, spillway, fish passing facilities and navigation locks with no dam body
Rated head	29.5 m
Plant discharge	5,000 cu.m/sec

Table 3.5 (Continued).

Overview of project	**Description**
Number of units	8 Kaplan
Install capacity	1,280 MW
Firm and secondary energy generated annually	Primary energy 4,180.9 GWh/yr Secondary energy 871 GWh/yr Excess energy 2,264.7 GWh/yr Total energy 7,316.6 GWh/yr
Mean annual discharge	2,000 cu.m/sec
Min observed flow	NA
Max observed flow	NA
Gated spillway	12 gates
Spillway dimensions	18 m wide x 20 m height
Max spillway design discharge and return period used	47,500 cu.m/sec - 1:10,000 yrs
Proposed	
Proposed market for electricity, nation	10%
Proposed market for electricity, export to Thailand	90%
Multipurpose uses considered (if any)	Navigation
Reservoir	
Full Supply level of reservoir	275 m amsl
Low Supply level of reservoir	268 m amsl
Area inundated at FSL	49 sq. km
Active volume of the reservoir	211.97 million.cu.m
Dead storage volume of reservoir	514.05 million.cu.m
Length of reservoir	90 km
Construction	
Material source variable	NA
Accessibility requirement	25 km
Transmission line	220 km
Dimensions of navigation locks	Two steps of navigation locks 12 m x 195 m x 5m.
Type and dimensions of fish passes	2 sets of fish ladder with opening of 3x10 m^2, between the spillway and power house and left abutment near power house
Impacts	
Number of communities to be resettled	10 villages
Number of households to be resettled	391 households
People	2,130 persons
Total reservoir	72.39 sq.km
Existing water surface	28.64 sq.km
Total area of agricultural land inundated	0.18 sq.km
Mixed bamboo and secondary forest	1.62 sq.km
Tourism and cultural sites lying in the inundation zone	None

3.2.4 Paklay dam

Paklay, the fourth dam in the cascade is located just above the district town of Paklay in Lao PDR. Two options for its location are proposed and the upper option has been recommended during the Laos Government Optimization Study because it would significantly reduce the number of people to be relocated from about 18,000 to 6,129. The power will be destined for Thailand. It has an installed capacity of 1,320 MW. The dam is 630 m long and 35 m high with a rated head of 26 m. It has a reservoir area of 70 sq. km (33% confined within the main channel) and live storage of 144 million.cu.m. More detail of the dam is in Table 3.6.

Table 3.6 Overview of Paklay dam and reservoir (ICEM, 2009).

Overview of project	**Description**
Name of dam	Paklay
Location of preferred	Latitude 18°24'5.34" Longitude 101°35'1.01"
Height	35 m
Length	630 m
Type of Dam construction	Set of 5 earth fill rock closure dykes across two channels
Rated head	38.5 m at 211.5 m amsl
Plant discharge	4,500 cu.m/sec
Number of units	10 Kaplan
Install capacity	1,320 MW
Firm and secondary energy generated annually	Mean 6,460 GWh/yr Firm 4,636 GWh/yr
Mean annual discharge	3,850 cu.m/sec
Min observed flow	NA
Max observed flow	NA
Gated spillway	12 radial gates
Spillway dimensions	NA
Max spillway design discharge and return period used	38,400 cu.m/sec - 1:10,000 yrs
Proposed	
Proposed market for electricity, nation	0%
Proposed market for electricity, export to Thailand	100%
Multipurpose uses considered (if any)	Hydropower only

Table 3.6 (Continued).

Reservoir	Description
Full Supply level of reservoir	240 m amsl
Low Supply level of reservoir	237 m amsl
Area inundated at FSL	70 sq.km
Active volume of the reservoir	144 million.cu.m
Dead storage volume of reservoir	NA
Length of reservoir	110 km
Construction	
Material source variable	NA
Accessibility requirement	62 km
Transmission line	66 km
Dimensions of navigation locks	1000 tones, One single line double-lift lock chamber
Type and dimensions of fish passes	Planned but no dimensions yet
Impacts	
Number of communities to be resettled	16 villages
Number of households to be resettled	643 households
People	6,129 persons
Total reservoir	70 sq.km
Existing water surface	39.99 sq.km
Total area of agricultural land inundated	8.21 sq.km
Forest	21.80 sq.km
Tourism and cultural sites lying in the inundation zone	None

3.2.5 Xanakham dam

Xanakham, the final dam of the cascade, is situated just upstream of the Thai-Lao border, between Loei and Vientiane provinces. The developer is Datang International Power Generation from China and the power is destined for Thailand. It has an installed capacity of 700 MW. The dam is 1,144 m long and 38 m high with a rated head of 25 m. It has a reservoir area of 81 km^2 (83% confined within the main channel) and live storage of 106 Mm^3. The latest estimate of people to be resettled is approximately 4,000 persons. More detail of the dam is in Table 3.7.

Table 3.7 Overview of Xanakham dam and reservoir (ICEM, 2009).

Overview of project	**Description**
Name of dam	Xanakham
Location of preferred	1,737 km upstream of delta Latitude 17°50'00" Longitude 101°33'00"
Height	38 m
Length	1,143.6 m
Type of Dam construction	Concrete gravity
Rated head	25 m
Plant discharge	5,918 cu.m/sec
Number of units	10 Kaplan x 70 MW
Install capacity	700 MW
Firm and secondary energy generated annually	Mean 3,210 GWh/yr Firm 4,438 GWh/yr
Mean annual discharge	4,160 cu.m/sec
Min observed flow	NA
Max observed flow	33,900
Gated spillway	NA
Spillway dimensions	NA
Max spillway design discharge and return period used	NA
Proposed	
Proposed market for electricity, nation	10%
Proposed market for electricity, export to Thailand	90%
Multipurpose uses considered (if any)	Navigation
Reservoir	
Full Supply level of reservoir	220 m amsl
Low Supply level of reservoir	215 m amsl
Area inundated at FSL	94 sq.km
Active volume of the reservoir	186.7 million.cu.m
Dead storage volume of reservoir	NA
Length of reservoir	80 km
Construction	
Material source variable	NA
Accessibility requirement	44 km
Transmission line	To Thailand – route not determined yet
Dimensions of navigation locks	2 step ship lock capacity1,000 tones
Type and dimensions of fish passes	Included but no details
Impacts	
Number of communities to be resettled	10 villages
Number of households to be resettled	800 households
People	4,000 persons
Total reservoir	94 sq.km

Table 3.7 (Continued).

Impacts	Description
Existing water surface	20 sq.km
Total area of agricultural land inundated	60 sq.km
Forest	14 sq.km
Tourism and cultural sites lying in the inundation zone	Non

CHAPTER IV

RESEARCH PROCEDURE

This chapter explains about the research procedure of the study, which mainly covers processes of criteria selection and collection, FAHP analysis, and fuzzy rank methods. The conceptual framework of this research is displayed in Figure 4.1, including (1) criteria selection and data collection (2) decision matrix design (3) questionnaire design and survey, (4) expert preference analysis (5) consistency checking, (6) aggregation of expert preferences, (7) fuzzy weighted sum estimation, (8) defuzzification, (9) ranking of relative importance of dam and reservoir, and (10) sensitivity analysis.

4.1 Criteria selection and data collection

Five alternatives of the dam and reservoir sites including Pakbeng, Luangprabang, Xayabury, Paklay, and Xanakham, have been proposed for ranking the importance of their priority of development. Criteria selection is therefore based on their characteristics related to environmental impact conditions, cost of construction and maintenance, and benefit provided from dams. These projects are not really multi-purposes. They are mostly concentrated on hydropower generation. There is no potential and intensive agricultural activity located in the surroundings of alternative locations. These reservoirs are also characterized by long and narrow shape containing limited amount of water. Therefore, irrigation is not one of the purposes of the development projects. However, the criteria selection is finally, more or less, controlled by data availability of this specific area. The criteria selected including physical, cultural, and social properties spatially related to dams and reservoirs together with their benefits are listed in Table 4.1. The attributes or criteria of each dam from the table are described in the followings.

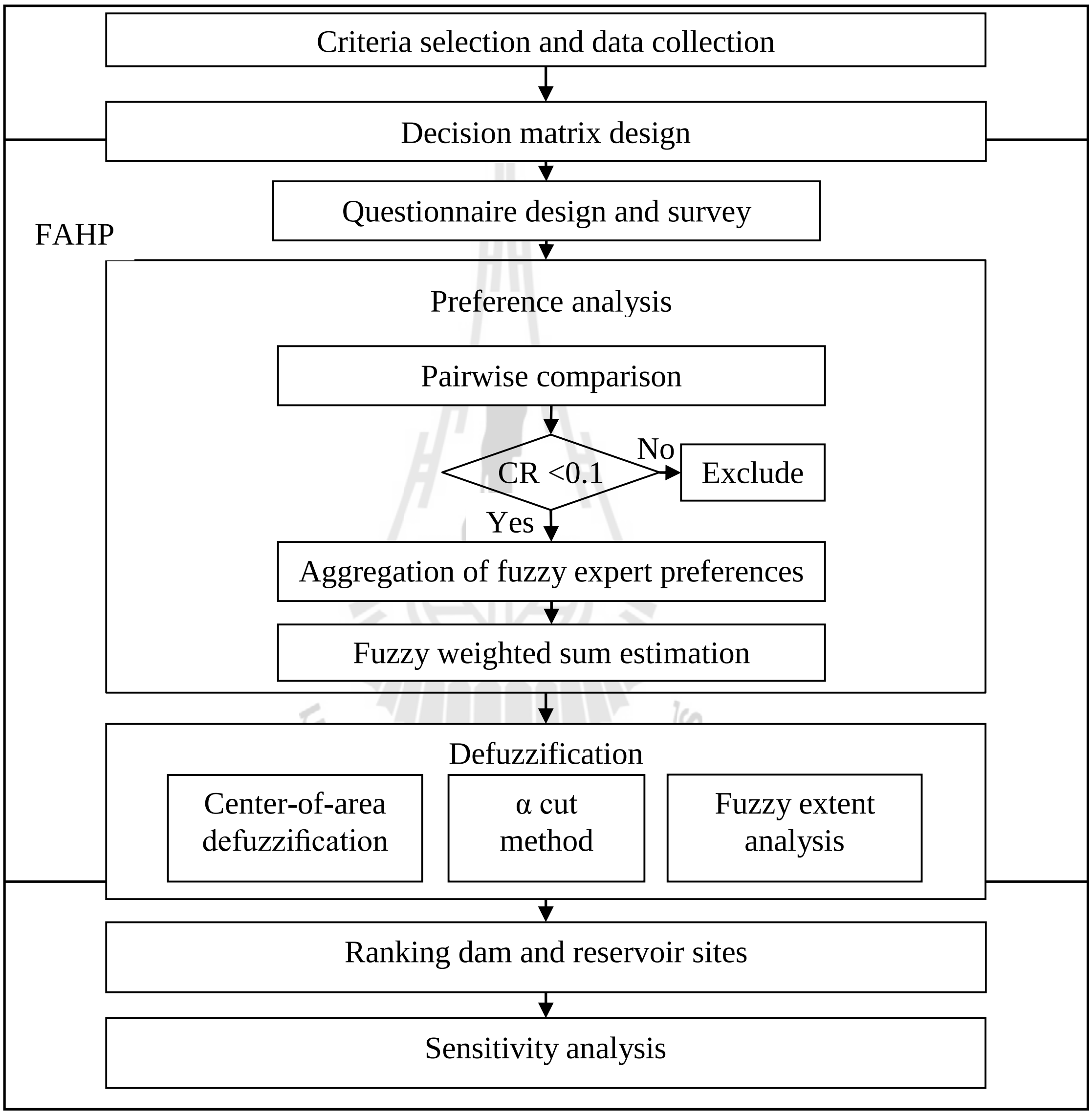

Figure 4.1 Conceptual framework of the research methodology.

4.1.1 Seismic effect

The seismic effect mainly influencing to the dam safety is considered in term of Probable Horizontal Peak Ground Acceleration (PGA). 10% PGA with two different periods of 50 and 100 years in Thailand and adjacent areas was estimated using probabilistic seismic hazard analysis carried out by Pailoplee et al., (2010). This resulted in PGA representing seismic effect in 2521 grid points with spacing 0.25^{o}x0.25^{o} mesh in a rectangle form (Figure 4.2).

Table 4.1 The criteria selected for ranking dams and reservoirs.

Objectives	Sub objective	Attribute	Basic data/sources
Cost	Dam-related	Seismic effect	Probabilistic seismic hazard analyses (Pailoplee et al., (2010)).
		Foundation geology	Geologic map (DGMV and DGM, 2007;JICA and DGM,2008b).
		Construction material availability	Geologic map (DGMV and DGM, 2007;JICA and DGM,2008b).
		Accessibility requirement	Road network and their proposed road.
		Transmission line	Proposed line on dam.
	Reservoir related	Settlement impact	MRC SEA for hydropower on the Mekong mainstream inception report Vol. 2.
		Landslide instability index (LII)	Slope and geologic maps.
		Inundated land use/ land cover (LULC)	MRC SEA for hydropower on the Mekong mainstream inception report Vol. 2.
		Inundated mineral potentiality	Potential mineral map (JICA and DGM,2008b).
		Inundated historic and archeological sites	Archeology data from Ministry of information and culture.
Benefit		Power generation	MRC SEA for hydropower on the Mekong mainstream, inception report Vol. 2.
		Tourism attraction	Tourist information (Laos National Tourism Administration (2012)).

These PGA points within 30 km buffered zone around each dam site (Figure 4.3) are adopted for an interpolation to obtain the PGA at a dam site. The simplest method of inverse distance weighting (IDW) is applied on interpolation to represent effectively local PGA directly influent to a site.

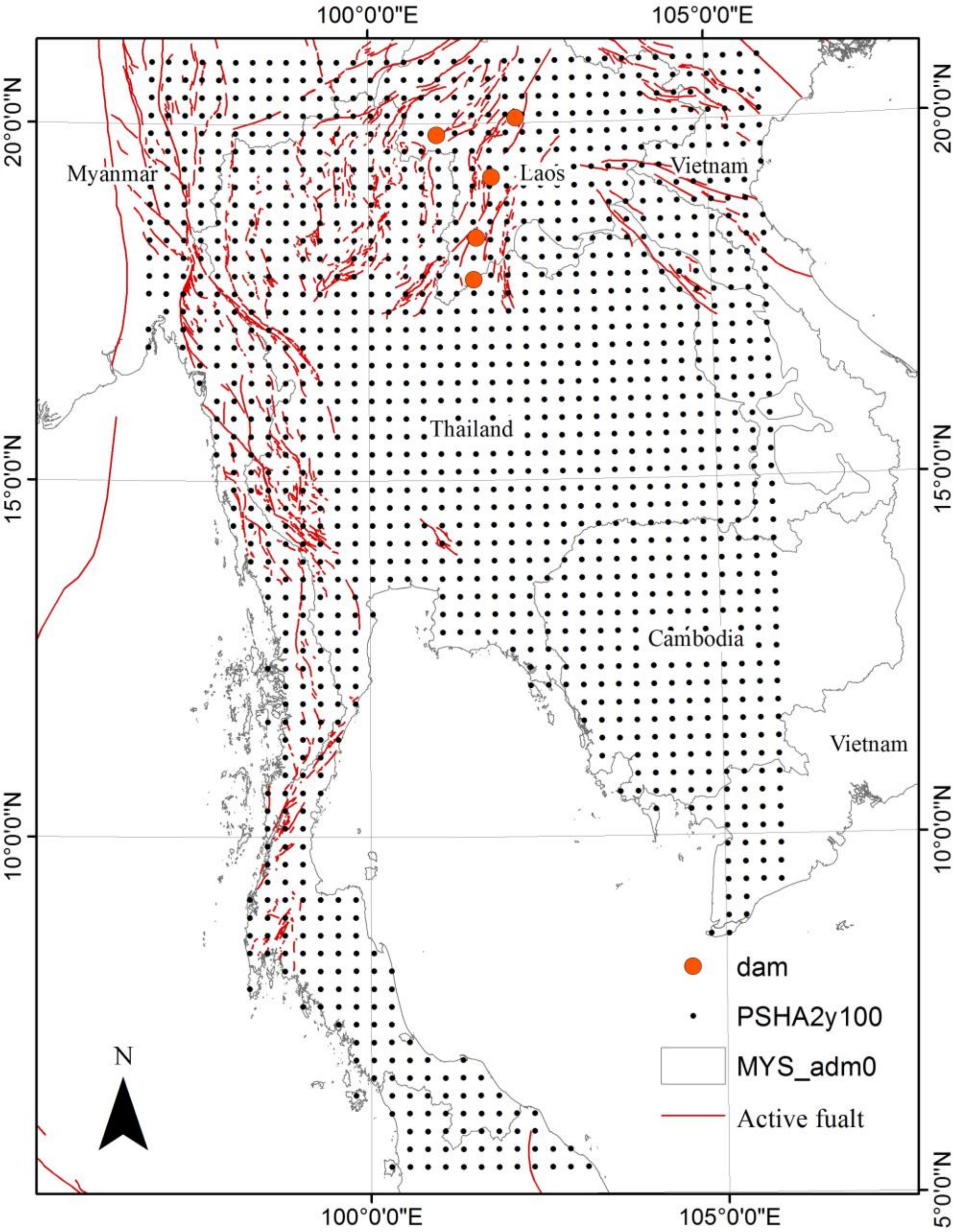

Figure 4.2 Probable peak ground acceleration (PGA) and active faults in Thailand and the adjacent area (Map generated from raw data provided by Pailoplee et al., 2009 and 2010).

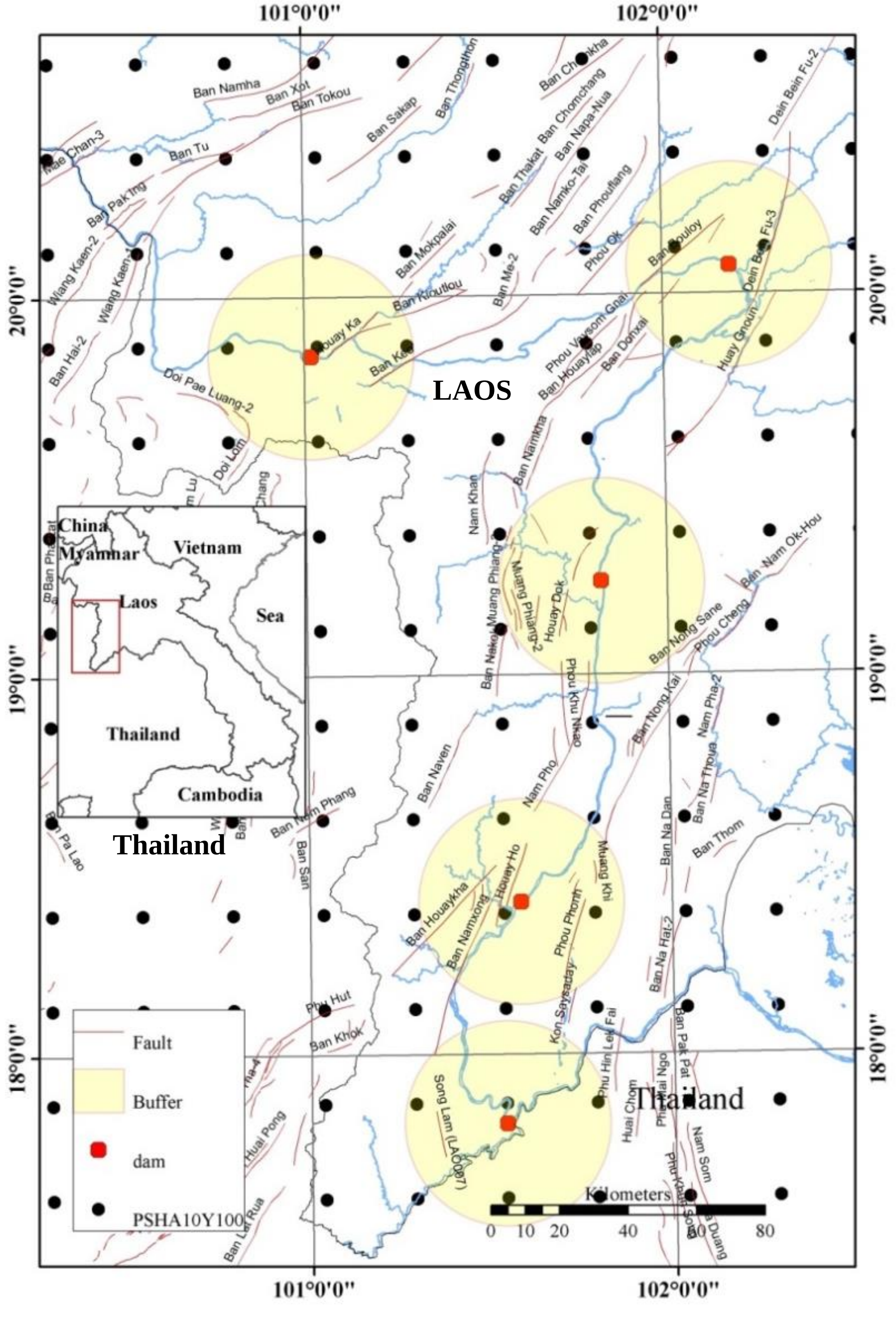

Figure 4.3 Map of northern Laos showing probable peak ground acceleration points, fault, and dam site buffering.

The IDW interpolation can be expressed in Equation (4.1) as shown in Equation (4.1).

$$PGA_j = \frac{\sum_{i=1}^{n} \frac{PGA_i}{D_{ij}^2}}{\sum_{i=1}^{n} \frac{1}{D_{ij}^2}} \tag{4.1}$$

where, PGA_j is the Probable Horizontal Peak Ground Acceleration (PGA) at a dam site j^{th}, PGA_i is the Probable Horizontal Peak Ground Acceleration (PGA) at grid point i^{th}, and D_{ij} is the distance from piont i^{th} to point j^{th}.

4.1.2 Foundation geology

Foundation of a dam site mainly influences the cost of construction. The foundation, which is not sound, can require very large budget for ground preparation before dam construction. Foundation of the dam site is evaluated based on geologic conditions which include rock types and structure. This information can be extracted from available geologic maps and additional field investigation.

4.1.3 Construction material availability

Quarries and borrow pits are used to provide construction material for dam construction, including rock, sand and gravel, and soils for aggregates and lining. To save costs, the construction materials should be available nearby the dam site. This information can be obtained from field survey around the site.

4.1.4 Accessibility requirement

Connection from main road to dam site construction is the most significant for materials and equipment transportation. Available accessibility to dam sites was described by (ICEM 2009, 2010). Closest distances from the road network to the sites are determined based on existing road network (NGD, 2003) and position of the sites. The information helps planning and budgeting for constructing new road to sites.

4.1.5 Transmission lines

Electric power transmission is the bulk transfer of electrical energy from generating power plants to high voltage substations. Transmission lines, when interconnected, become the transmission networks, typically referred to as the power grid. The length of transmission lines from dam sites producing electricity to the border of Laos and target countries of customers are explicitly related to cost of construction. Additionally, high-voltage transmission line can affect to environment, social, agriculture, and forest and require cost for remediation. This information is obtained from ICEM (2009).

4.1.6 Settlement impact

Settlement impact is assessed using a number of potentially inundated existing villages, households, schools, and monastery including cemeteries. The information on possible numbers of villages, households, and people to be inundated and impacted when dams are constructed are reported by ICEM (2009).

4.1.7 Land instability index (LII)

LII directly affects a reservoir in terms of potential landslide and erosion in an area surrounding the reservoir. The products of landslide and erosion might cause a dam break and increasing sediment load to shorten dam life. In this study the potential of landslide and erosion in regional scale is determined in the form of LII of each reservoir. This can result from the compilation of slope and rock types. To achieve LII, the procedure can be performed in 3 steps.

First, the affected areas surrounding reservoirs border is extracted by the drainage divide which is visually and manually interpreted from combination of shaded relief image and DEM data as displayed in the Figure 4.4.

Second, slope percentage and geologic units within affected areas are analyzed. Slope percentage is extracted from DEM data using spatial analysis tools in ArcGIS software while rock types of geologic units are extracted from the available geologic maps. Rock types are then transformed to the numeric values on the basis of erodibility of rock types modified after Wooldridge (1986).

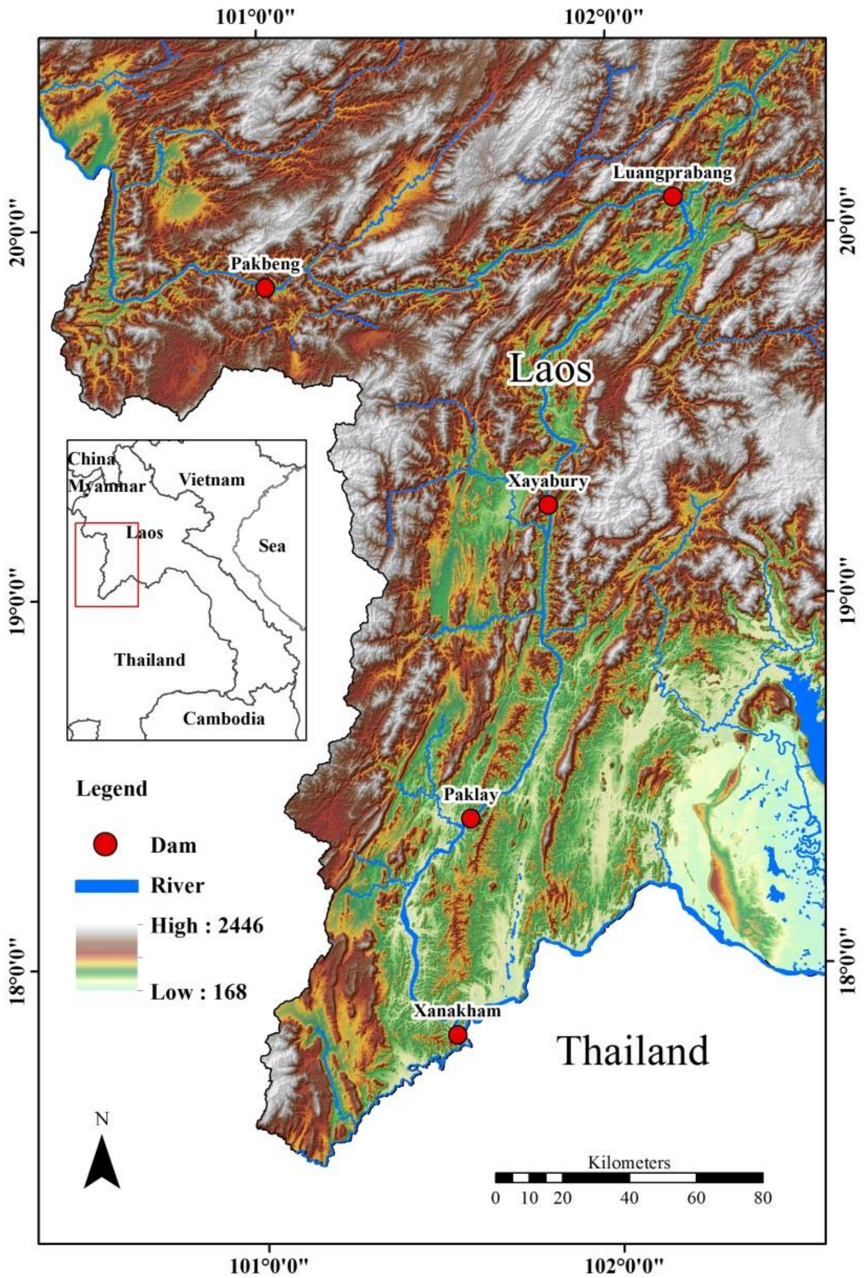

Figure 4.4 Combination of DEM data and Hillshade image.

Finally, the transformed geology scores (GeoSc) and slope percentage (Sl) inform of raster format are multiplied and divided by affected area of each reservoir Equation (4.2). The performance of the function is local operation. The result of each LII is then normalized.

$$\mathrm{LII} = \frac{\sum_{i=1}^{n} (\mathrm{Sl}_i.\mathrm{GeoSc}_i)}{\mathrm{A}} \tag{4.2}$$

where: n : a number of cell in the affected area,

LII : land instability index of an affected area,

Sl_i : slope percentage of each cell i in an affected area,

$GeoSc_i$: geology score of each cell i in an affected area,

A is a total affected area of a reservoir.

4.1.8 Inundated land use and land cover (LULC)

Inundated LULC is assessed using the areas of inundated agricultural land and forest. The more inundated properties indicate the more adverse impact. The inundated forest, agriculture, and irrigation area are reported in the inception report Vol II of MRC SEA for hydropower on the Mekong main stream (ICEM, 2009). All types of LULC for this study level are considered the same. Therefore, there is no weight applied for different types of LULC.

4.1.9 Inundated mineral potentiality

Mineral potential is economic growth related criterion and can be lost in the inundated reservoir area. Related to the impact of mineral potential, the expected inundated types and areas are considered. This information is obtained from overlay analysis between reservoir area and mineral potential mineral map which is only available at the scale of 1:1,000,000. This information is provided by the Department of Geology and Mines (JICA and DGM, 2008a).

4.1.10 Inundated historic and archaeological sites

Historic and archaeological sites expected to be inundated are a criterion influence on social impact. Their inundation in the reservoir can affect directly to traditional culture. This information is obtained from the Ministry of Information and Culture and report of MRC SEA for hydropower on the Mekong mainstream inception report Vol 2: main stream project profile summaries (ICEM, 2009). The more inundated historic and archeological sites indicated more adverse impact.

4.1.11 Power generation

The electricity generated from hydropower is considered very important in aspect of the benefit of a proposed dam. Most of dams in the study area are constructed for power generation proposed. 90% of the power will be exported to Thailand. Only the one generated by the Luangprabang dam will be exported to Vietnam. These information are obtained by propose of dam from the report of ICEM (2009). Power productivity of dams can be obviously different and strongly affected to the importance ranking.

4.1.12 Tourism attraction

In this study tourist attraction is one of the decision criteria for dam site evaluation. Once constructed, a dam is a by-product tourist attraction. To be more attractive, an alternative dam site should be near to the other tourist attraction sites. A bigger number of tourist attractions within 30 km surrounding a dam, which is a distance that can be travelled back and forth within a day, are considered to be more attractive. These considered tourist sites are achieved from Ministry of Information, Culture, and Tourism.

4.2 FAHP Analysis

FAHP is one of the decision rules of MADA. It requires many steps i.e. decision matrix design, questionnaire design and survey to obtain experts' preference, and fuzzy preference analysis. The preference analysis includes fuzzy pairwise comparison, consistency examination, aggregation of expert preferences, and fuzzy weighted sum estimation. Each process is described as follows:

4.2.1 Decision matrix design

Decision matrix is designed for decision making process to achieve the goal. It can be constructed in term of hierarchy structure of the goal, objective, sub-objective, attribute, and dam site alternative levels. Nevertheless, to achieve the goal, each level is considered in different factors or criteria. For objective level, cost and benefit criteria is considered. In the sub-objective level, dam-related criteria and reservoir-related criteria are considered on the basis of cost. In attribute level, the comparison of physical, environmental impact, and benefit criteria are considered while dam site alternative level consists of five proposed dams.

4.2.2 Questionnaire design and survey

Questionnaires are written instruments that present responds with a series of question or statement to which they are to react either by writing out their answers or selecting from existing answers (Brown, 2001). Hence, questionnaires are best used for collecting factual data and appropriate questionnaire design is essential to ensure that we obtain valid responses to our questions. In addition, Dörnyei (2003) divided main parts of a questionnaire into five components including the title, instruction, questionnaire items, additional information, and final "thank you". However, this questionnaire is designed to obtain the preference from experts' opinion based on the provided information and integration of their experience. Modified after Dörnyei (2003), four parts are designed. Part 1 is for briefly information of an expert. The instruction of the questionnaire is conducted in the part 2. This part contains the research title, objective of the study, hierarchy structure of decision making, information providing for weight comparison including the scale of weight. Examples of criteria comparison with respect to alternatives are given as well. Part 3 provides all levels of criteria information of alternatives and forms for comparison responds. The respond forms of comparison between criteria of each level based on experts' experience are also provided in this part. Part 4 allows experts to express their additional comments/opinion. These questionnaires are distributed to target experts which include geologists and civil engineers. The questionnaire survey results are further used for preference analysis of dam site alternatives based on criteria.

4.2.3 Preference analysis

The preference analysis is performed based on dam site alternatives and associated criteria. Criteria are organized in forms of hierarchical levels and are considered one at a time to rank the relative importance of dam site alternatives. Other word, the alternative sites are compared to each other as pairs based on criteria information in the same group of each criterion level. The importance of criteria within the same level and the same group are compared to each other as a pair as well.

The preferences are obtained from a group of experts who are volunteer geologists and engineers through distributed questionnaire. Experts express their opinions through pairwise comparison of alternatives on basis of criteria levels. The evaluation at the alternative level is based on criteria information provided. The expert's experiences are also expressed in the evaluation at objective, sub-objective, and attribute levels. The consistency is then estimated from each expert's preferences to ensure a certain quality of a decision maker's judgment. The simplified calculation of the consistency ratio (CR) used for evaluation follows Equation (2.4). The pairwise comparisons of any expert with the CR exceeding the tolerance of 0.1 are excluded for further processes. The preferences of the consistent ones are then organized in form of fuzzy triangular member (l, m, u).

All expert opinions are then aggregated before the operation of a fuzzy weighted summation. Their preferences obtained from questionnaire are aggregated by means of geometric mean estimation (Davies, 1994) as introduced Equation (2.8). The aggregated results are further used to calculate the fuzzy synthetic extent or fuzzy weights of each level and alternatives site by the use of Equations (2.9) and (2.10). To obtain the total fuzzy weighted summation of each site, fuzzy weight summation of all levels in hierarchy structure of decision making are then estimated. The fuzzy synthetic extents of objective level are multiplied to each criterion of the lower levels, operating level by level from sub-objective to alternative levels respectively. The multiplication result of each alternative obtianed from each attribute is then summed to be the total fuzzy weights of each alternative.

4.3 Defuzzification

The total fuzzy weights summations of alternatives in form of fuzzy triangular member are used for defuzzification to achieve the relative importance crisp values of alternative sites. The resulted are attained from three different methods of fuzzy extent analysis, α cut method, and center-of-area.

4.3.1 Fuzzy extent analysis

First, the degree of possibility for $\tilde{S}_i \geq \tilde{S}_j$ is computed from fuzzy weighted summation by the use of Equations (2.11) and (2.12).

Second, the degree of possibility of $\tilde{S}_i$ is calculated by the use of Equation (2.13) and it should be greater than all the other (n-1) convex fuzzy numbers $\tilde{S}_j$.

Finally, estimation of the priority vector w = $(w_1,\ldots w_n)^T$ of the fuzzy comparison matrix as expressed in Equation (2.14) is performed.

4.3.2 α-cut method

The fuzzy weighted summation is transformed into the fuzzy weight matrix ($\tilde{p}$) as Equation (2.15). The fuzzy weight matrix is transformed into interval performance matrices by α-cut values as Equations (2.16), (2.17), and (2.18). The α-cut values can be varied from 0 to 1. In this study, α-cut value is considered the risk confidence to transforms matrix ($\tilde{p}$) into set of uncertainty interval matrices $\tilde{P}_\propto$. The λ function is applied to transform set of $\tilde{P}_\propto$ into crisp values as Equations (2.19) and (2.20). Decision maker with optimistic attitude will take the maximum λ from the ranges [0-1]. For this study, λ=0.8 is applied due to the optimistic attitude. In condition, the α-cut value of 0.8 is used duo to confidents in experts' preference opinion.

4.3.3 Center-of-area defuzzification

Center-of-area method seems to be more scientific in transforming fuzzy relative importance to crisp value. This method uses the area of fuzzy triangular and separates it into two equal areas using Equation (2.21). The value that cuts area of fuzzy triangular to be two equal parts is the crisp value.

4.4 Sensitivity analysis

As the results of three methods defuzzification on the basis of the total weight summation, the sensitivity analysis is applied to observe the relative importance of which criteria is most related to the rank of alternatives. Three assumption of sensitivity analysis are carried out to reveal the influence of different criteria on dam site alternatives. First, cost criterion in objective level is considered. Second, benefit criteria in objective level is considered. Finally, a criterion is ignore one at the time in the attribute level, the results of analysis cloud show the best solution of the criterion affect to the rank of relative importance of the sites.

CHAPTER V

RESULTS AND DISCUSSION

Main results according to components of research methodology are reported to fulfill main objective. The components include criteria selection and evaluation, decision matrix designs, questionnaire design and survey, preference analysis, defuzzification, and alternative ranking. Sensitivity analysis is also applied to observe the changes of relative importance of dam site alternatives when a criterion is ignored one at a time.

5.1 Criteria selection and data collection

Results of criteria selection and data collection provide information to support decision making in pairwise comparison process in order rank the relative importance of dam and reservoir sites. This information is described as following:

5.1.1 Peak ground acceleration at dam site alternatives

This information is the result of seismic effect study of Pailoplee et al. (2010). Figure 5.1 depicts the level of PGA that exceeds 10% probabilities of 50-year return period in form of spatial distribution. The points with PGA attribute, displayed seismic effect of two return periods of 50 years and 100 years, are interpolated. By this method, the PGA at dam site alternatives according to 50-year and 100-year return periods are obtained and listed in Table 5.1.

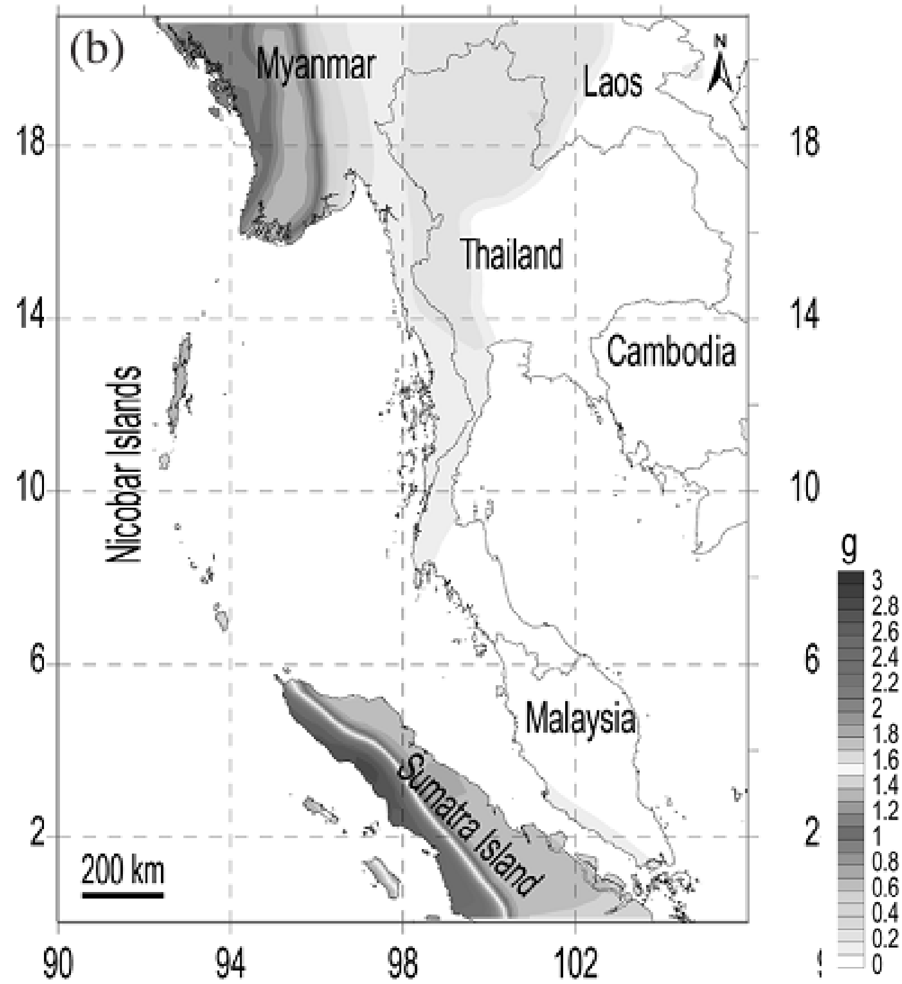

Figure 5.1 Probabilistic seismic hazard map of Thailand and adjacent area, showing the distribution of Peak Ground Acceleration (PGA) that exceeds 10% probabilities for a 50-year time period (Pailoplee et al., 2010).

Table 5.1 PGA with return period of 50 and 100 years at each dam site.

	S1	S2	S3	S4	S5
PGA10y100	0.512091	0.506115	0.505641	0.50675	0.503249
PGA10y50	0.4083	0.4035	0.40256	0.4035	0.3995

As a result, the values of PGA seem to be too high for dam construction at each site. This might be because the study emphasized more in regional information than local. Therefore, the result is considered to imply the relative effect more than the absolute one.

5.1.2 Foundation geology

Foundation geology is extracted from available geologic maps and additional field investigation. The information at each dam site is described in following:

Pakbeng (S1) dam: the channel bed geology is characterized by folded interlaminated argillaceous limestone, with intercalated very thin- to medium-bedded limestone to dolomitic limestone, moderate dipping, partly covered by gravel deposits in depression area. Clastic rocks, interbedding of sandstone, siltstone, and shale mapped as T2-3, appear at the left and right abutment (Figure 5.2).

Luangprabang (S2) dam: Channel bed geology is characterized by jointed volcanic rocks, andesitic agglomerate and tuff, flow structure with dip direction/angle: 50˚/45˚. Left and right abutments are thick-bedded to massive limestone of C-P1 unit as mapped by JICA and DGM (2008b) and shown in Figure 5.3.

Xayabury (S3) dam is the first site of 5 proposed dams which is now under construction. The geology at the base of dam site is characterized by phyllite, quartzite interbedded with thin-bedded limestone, wavy folded and faulted. Both abutments are limestone of unit Pnl (Figure 5.4).

Paklay (S4) dam is located in Phalat Formation (P2pl) which is composed of sandstone, siltstone, and slaty to phyllitic shale, brown to brownish-gray, micaceous, with plant fossils. Both abutments fall into P2pl formation. Right abutment could be interbedded clastic rocks while left abutment is more likely to be sandstone (Figure 5.5).

Xanakham (S5) dam is located in Phalat Formation at the upstream of Laos-Thailand border (Figure 5.6). Interpreted from the DEM data, the left abutment could be interbedded clastic rocks while the right abutment is more likely to be sandstone.

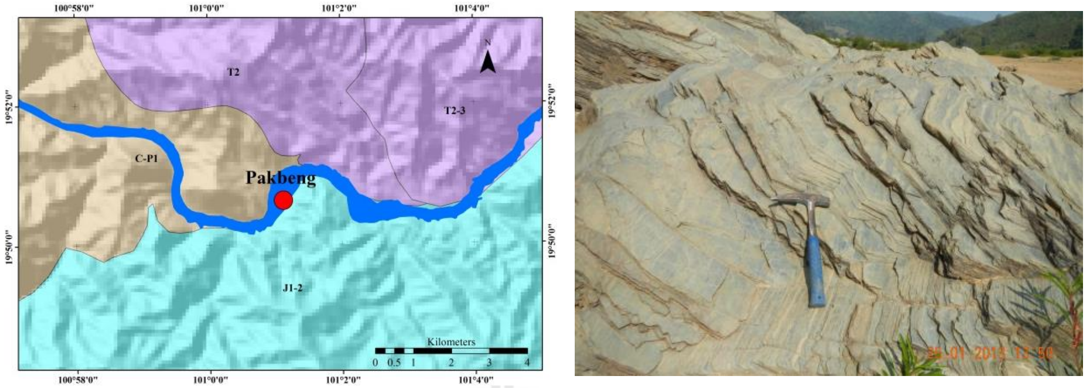

Figure 5.2 Geologic map (DGMV and DGM, 2007) and field photo at Pak Beng dam

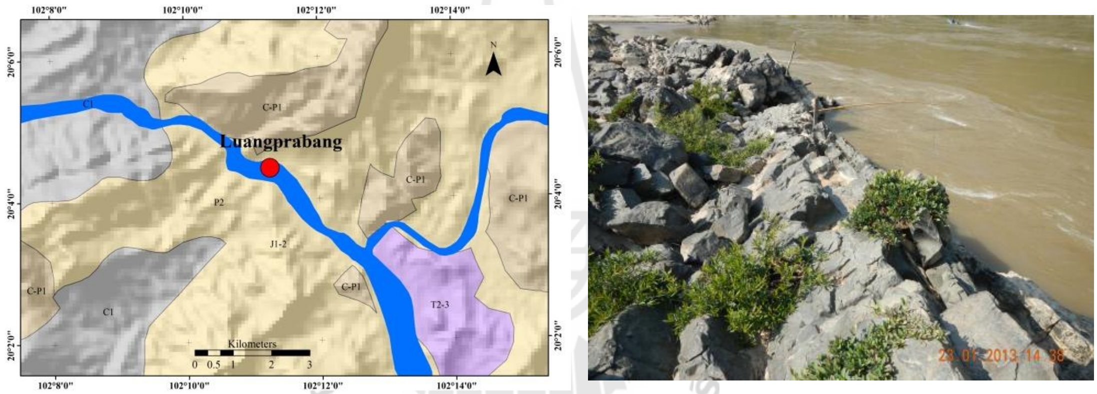

Figure 5.3 Geologic map (DGMV and DGM, 2007) and field photo at Luangprabang dam site.

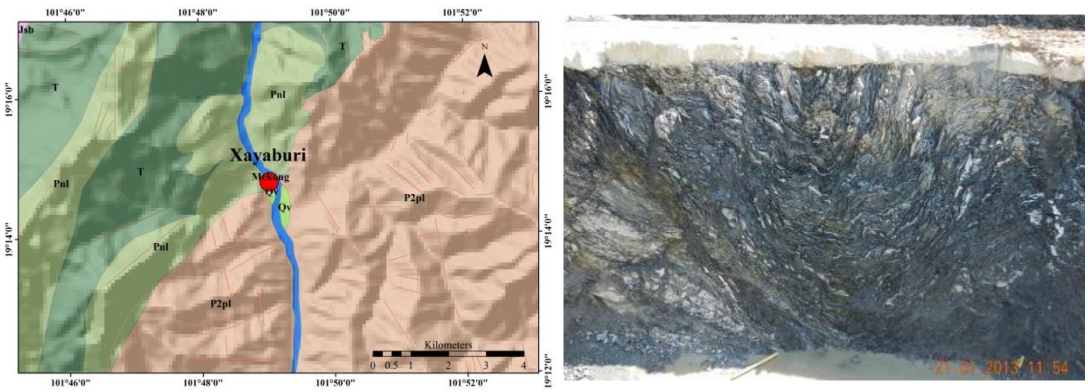

Figure 5.4 Geologic map (JICA and DGM, 2008b) and field photo at Xayabury dam site.

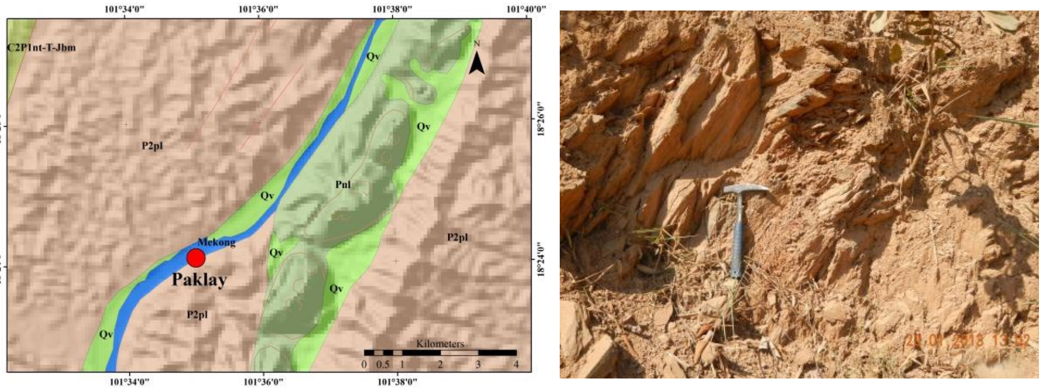

Figure 5.5 Geologic map (JICA and DGM, 2008b) and field photo at Pak lay dam.

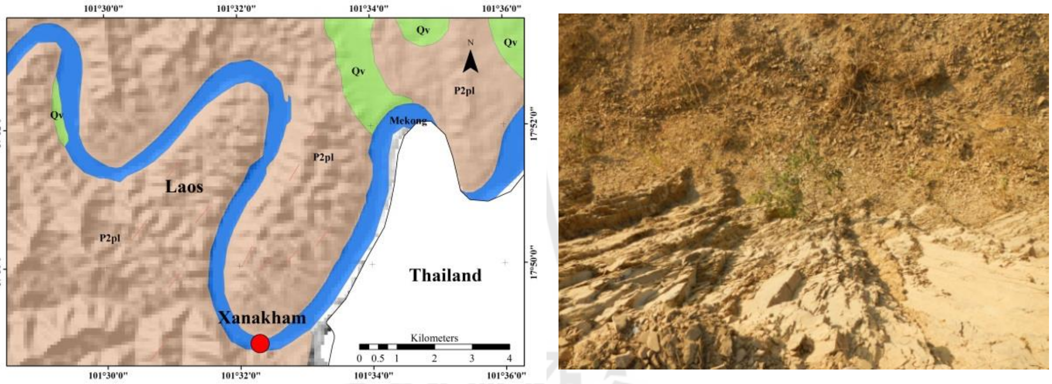

Figure 5.6 Geologic map (JICA and DGM, 2008b) at Xanakham dam site.

5.1.3 Construction material availability

According to geologic map and field survey, the potential of construction material availability of each dam is described below:

S1 (Pakbeng): limestone cliffs on top of hills next to dam site in the west and northwest direction could be potential quarries for construction material as shown in Figure 5.7.

Figure 5.7 Photo of cliff limestone on top of hills in the west of dam site (left) as appear in the Google imagery (right).

S2 (Luangprabang): there is limestone hill being potential quarry site next to the north of dam site as shown in Figure 5.8.

Figure 5.8 Photo of limestone hill next to the north of dam site.

S3 (Xayabury): the current limestone quarries are located about 1 km and 1.5 km to the southwest and the north of dam site as shown in Figure 5.9.

Figure 5.9 Available limestone quarries and the crushing mill located next to the southwest of dam site.

S4 (Paklay): limestone hill that can be potential quarry of construction material appear about 2 km away in the east of the dam site as shown in Figure 5.10.

Figure 5.10 Limestone hill in the east of dam site (photo taken from Mekong River in direction about 60°).

S5 (Xanakham): from geologic map it seems to have no limestone available in the vicinity. However, to the south of dam site resistant sandstone could be available (Figure 5.11).

Figure 5.11 Photos showing location of Xanakham dam site ((a) look upstream, (b) look WSW along Mekong River).

5.1.4 Accessibility requirement

The lengths of accessible roads proposed to be constructed from existing main road network to dam sites are listed in Table 5.2.

Table 5.2 The accessible road from existing main road network to dam site.

	S1	S2	S3	S4	S5
Accessible roads (km)	16	15 and 1 bridge	25	62	44

5.1.5 Transmission lines

The transmission lines proposed to construct from proposed dam sites to the country border are displayed as Figure 5.12. and listed as Table 5.3

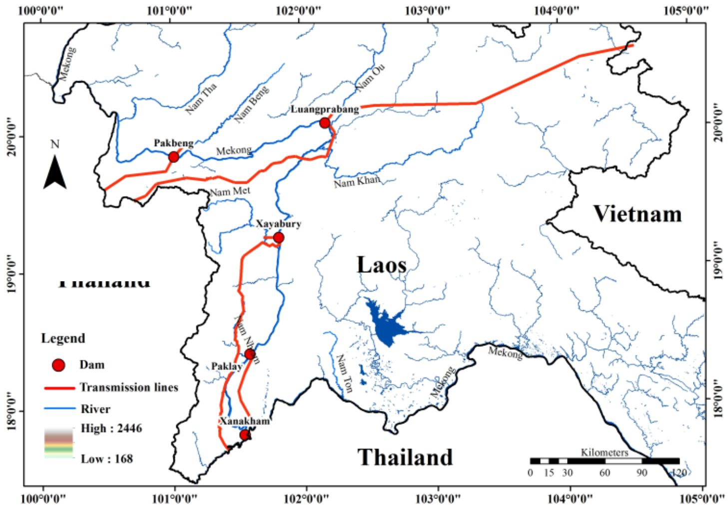

Figure 5.12 Proposed transmission lines from dam sites to destinations.

Table 5.3 Lengths of transmission lines to serviced countries.

	S1	S2	S3	S4	S5
Transmission lines (km)	80	400	220	66	2

5.1.6 Settlement impact

The settlement impact study of ICEM (2010) includes number of villages and households to be inundated after construction and number of people affected. They are tabulated in Table 5.4.

The more inundated properties indicate the more adverse impact.

Table 5.4 Number of inundated villages and households and impacted people after dam construction.

	S1	S2	S3	S4	S5
Villages	28	36	10	16	10
Households	774	2,516	391	643	800
People	6,700	12,966	2,130	6,129	4,000

Source: ICEM 2010.

5.1.7 Land instability index (LII)

The extents of affected areas surrounding reservoirs in term of land instability which includes erosion and landslide are visually and manually interpreted and shown in Figure 5.13.

The slope percentage extraction of each affected area is illustrated in Figure 5.14. The geology score derived from erodibility of rock types (modified after Wooldridge, 1986) is shown in Table 5.5. The derived geology scores specifically assigned for certain rock types are transferred to geologic units in affected areas as shown in Figure 5.15.

Table 5.5 Geology score derived from erodibility of rock types (modified after Wooldridge, 1986) available in affected areas.

Rock type	Geology score	Normalize geology score
Sand and gravel	1.74	1.00
Granite	1.11	0.64
Sandstone	1.6	0.92
Siltstone	1.6	0.92
Claystone	1.6	0.92
Conglomerate	0.69	0.40
Mafic volcanics	1.53	0.88
Hornfels	1.04	0.60
Shale	1.6	0.92
Limestone	0.5	0.29
Andesite and andesitic tuff	1.6	0.92
Mudstone	1.6	0.92

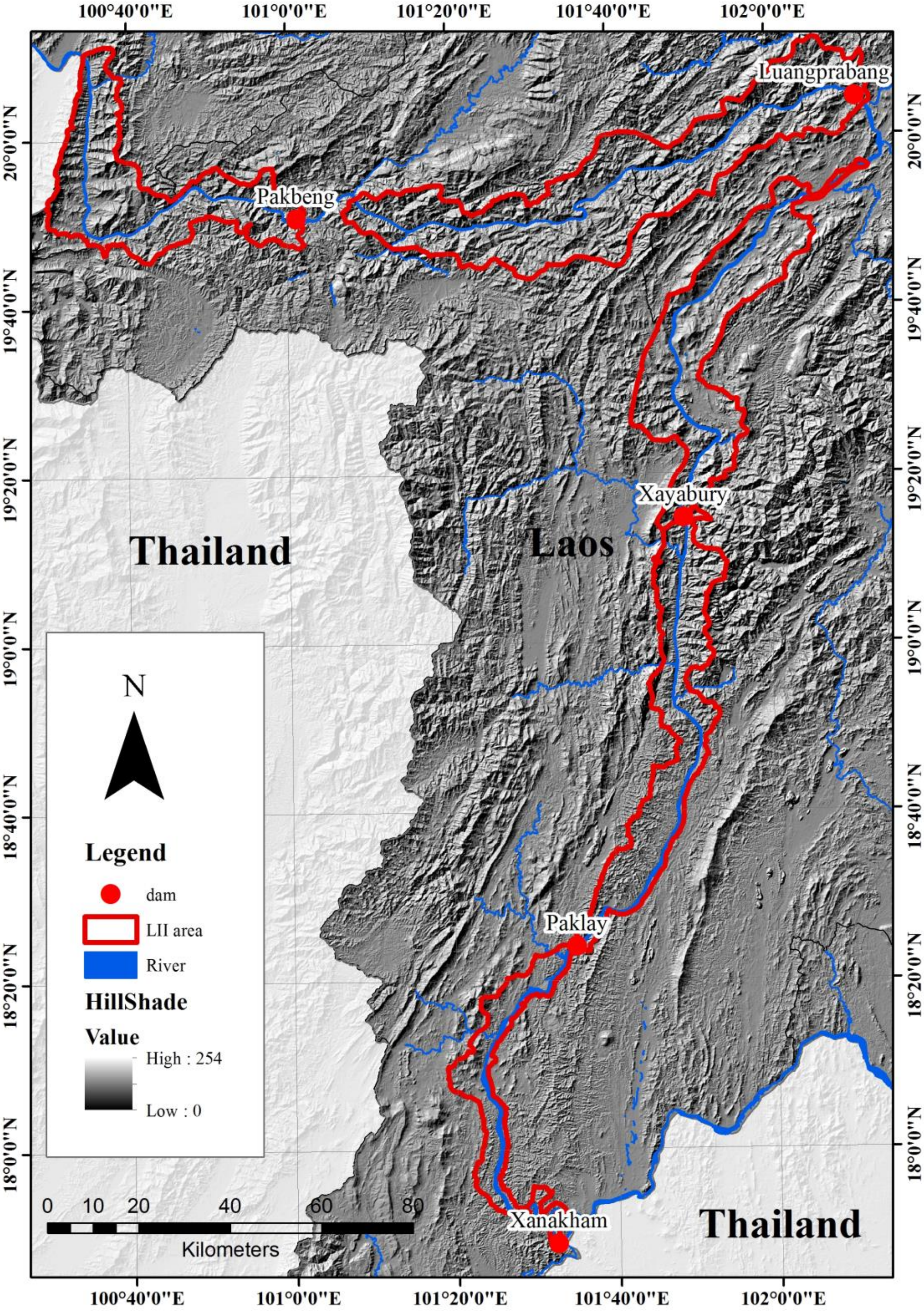

Figure 5.13 Shaded relief image with land instability affected areas surrounding reservoirs of alternatives.

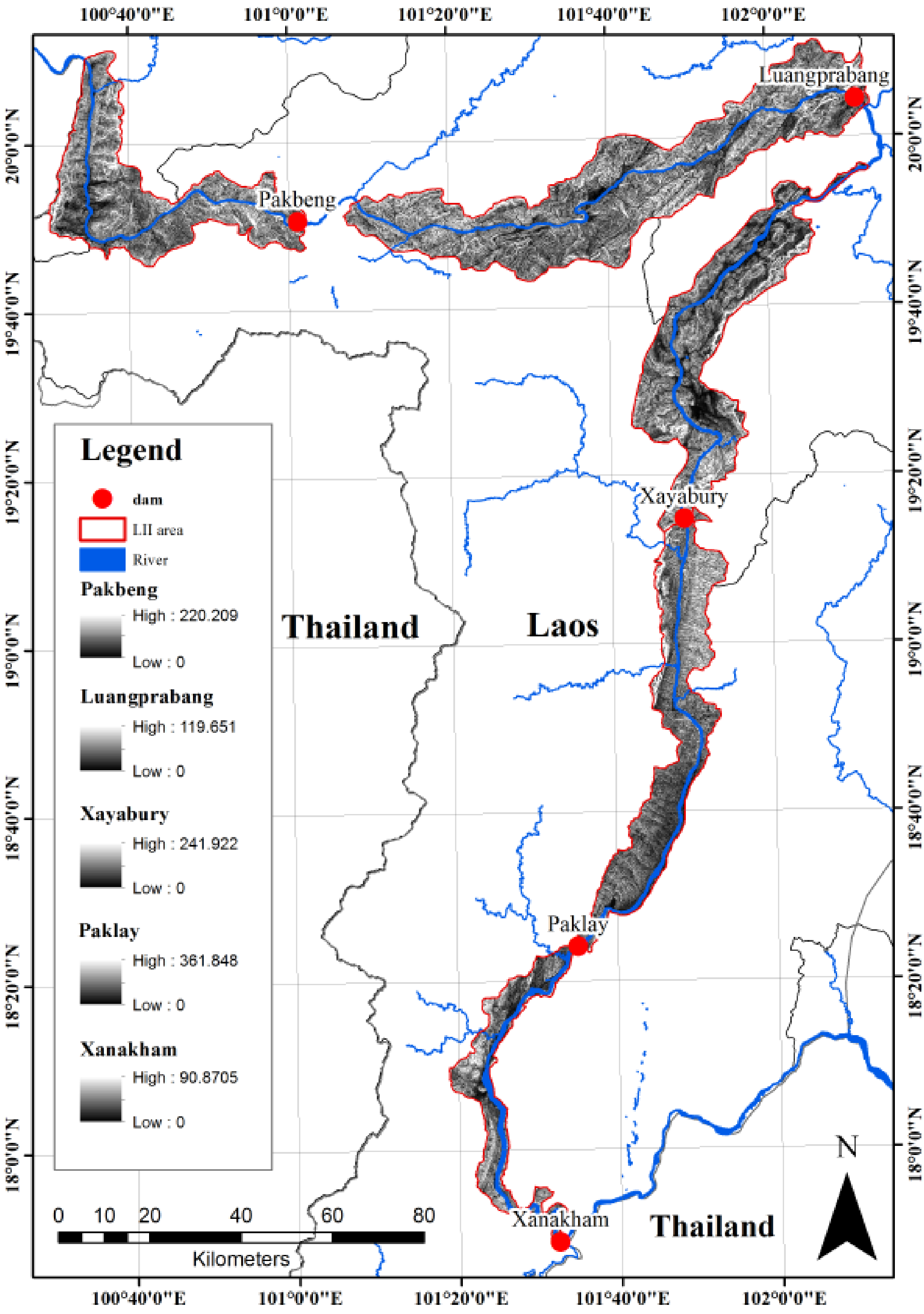

Figure 5.14 Slope percentage affected areas of each reservoir.

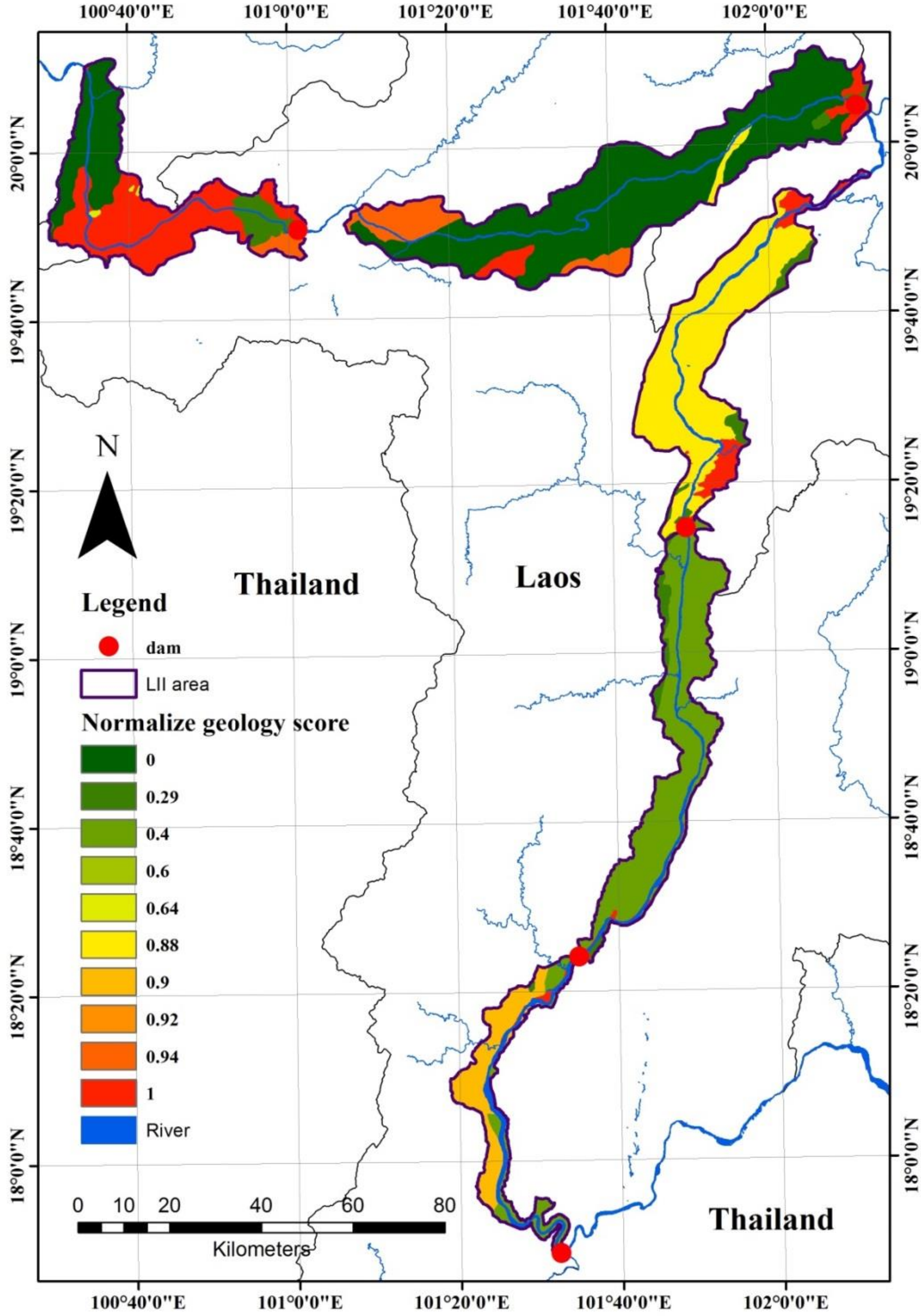

Figure 5.15 Geology scores (GeoSc) of different rock types in affected areas.

The result of normalized LII (as discussed in 4.2.7) is shown in Table 5.6. The area with LII nearly to 0 is more stability and vice versa it is more instability when close to 1.

Table 5.6 Normalized LII of each reservoir.

	S1	S2	S3	S4	S5
LII	0.57	0.85	0.56	0.42	1.00

5.1.8 Inundated land use and land cover (LULC)

The expectedly inundated areas of forest and agricultural land were reported by ICEM (2009) as shown in Table 5.7.

Table 5.7 Inundated LULC after dam construction.

	S1	S2	S3	S4	S5
Reservoir (sq. km)	86.51	72.39	49	70	94
Agricultural land inundated (sq. km)	13.25	1.94	0.18	8.21	60
forest (sq. km)	4	41.81	1.62	21.80	14

5.1.9 Inundated mineral potentiality

Using GIS overlay technique, the inundated mineral potential areas of reservoirs can be achieved and listed in Table 5.8.

Table 5.8 Expectedly inundated mineral potential area of each reservoir.

Potential area (km^2)	S1	S2	S3	S4	S5
Alluvial gold (Au)	39.50	0.6	0	0	0
Alluvial gold (Au) and chromite	1.60	5	0	0	0
Base metal sulfide	0	23.5	34.8	16	0
Alluvial gold (Au) and Cu-Zn in quartz vein	0	23.1	26.7	0	0
Gold in quartz vein and alluvial deposits	0	0	0	0	74.5
Totally inundated mineral potentiality Areas (km^2)	41.1	52.2	61.5	16	74.5

5.1.10 Inundated historic and archeological sites

The number of inundated historic and archeological sites of each reservoir reported by ICEM (2009) is listed in Table 5.9.

Table 5.9 Number of inundated historic and archeological sites of each reservoir.

	S1	S2	S3	S4	S5
Temple	3	3	4	1	3
Cemeteries	0	0	1	0	0
archeology site	NA*	NA	NA	NA	NA

NA = not available

5.1.11 Power generation

Each dam site has different installing capacity reported by ICEM (2009). Each of them is shown in Table 5.10.

Table 5.10 Installing capacity of power generation of each dam.

	S1	S2	S3	S4	S5
Power generation	1,230 MW	1,410 MW	1,260 MW	1,320 MW	700 MW

5.1.12 Tourism attraction

A number of tourist attraction sites within 30 km surrounding each dam is listed in Table 5.11. The distance considered should be suitable to be back and forth in a day.

Table 5.11 A number of tourism attraction sites within 30 km surrounding each dam.

Tourists attraction	S1	S2	S3	S4	S5
Natural site	3	5	6	7	2
History and Cultural site	4	40	4	3	5
Totally tourist site	7	45	10	10	7

5.2 FAHP analysis

FAHP results consist of the decision matrix, questionnaire and responses of expert opinions through the survey, fuzzy weights of alternatives and criteria. The fuzzy weights from all experts are aggregated by geometric mean method following by fuzzy weighted sum estimation. The crisp weights of alternative are further obtianed by defuzzification.

5.2.1 Decision matrix

The decision matrix resulted from the design is illustrated in Figure 5.16. To achieve goal, the comparison of alternatives on the basis of criteria in levels are synthesized in series of hierarchy structure respectively. The relations and comparisons between criteria of alternatives in levels of cost and benefit, dam- and reservoir-related, and attribute are analyzed based on fuzzy opinions of experts.

5.2.2 Questionnaire and survey

The questionnaire is designed as shown in Appendix B. It was distributed through 13 experts including volunteers of 6 civil engineers and 7 geologists. They provided opinions in pairwise comparison of alternatives based on their different criteria characteristics and between criterion to criterion as well. The design proposed the questionnaire easy for preference response and being transferred to fuzzy form in order to represent ambiguous or uncertain expert decision. The questionnaire responses from all experts and their fuzzy aggregation analysis are shown in Appendixes C and D, respectively. This information of decision makers' preference is further used for preference analysis.

5.2.3 Preference analysis

According to Appendix D, the responses from 13 experts are examined for their consistency in pairwise comparison matrix using CR. Only 9 of 13 sets of responses are valid (CR < 0.1). The valid ones are organized in term of fuzzy triangular member (l, m, u). Then, the fuzzy members of comparison weights from 9 experts are aggregated by geometric mean method and further used to calculate fuzzy synthetic extent or fuzzy weights of criteria in all levels.

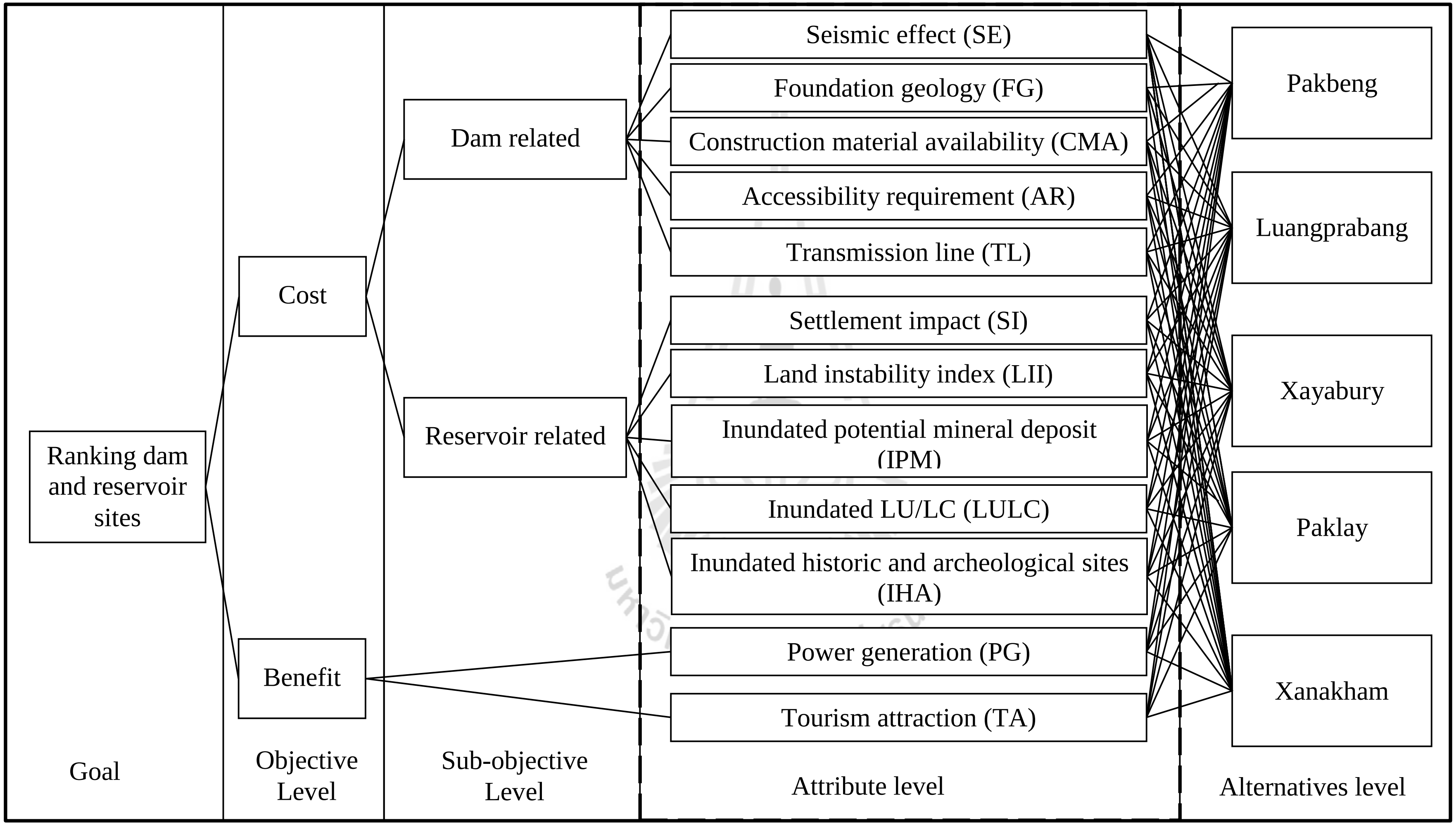

Figure 5.16 Hierarchy structure of decision matrix for ranking of dams and reservoirs.

The multiplication is firstly operated for fuzzy synthetic extents of criteria from cost-benefit level to attribute level, resulted in fuzzy synthetic extents of all attribute. Fuzzy synthetic extents of alternatives on the basis of each attribute are obtianed from the aggregation of valid opinions. Then the multiplication of fuzzy synthetic extents of attributes and alternatives is operated. These results are finally summed to obtain fuzzy synthetic extents of all alternatives based on all criteria.

The results from experts' opinions aggregation and fuzzy synthetic extents analysis of cost-benefit and dam-reservoir related levels are tabulated in Table 5.12 and 5.13, respectively. The results reveal that benefit criteria show obviously higher weight or more significance than cost criteria. Cost dam-related criteria are considered having about doubly higher weight than cost reservoir-related criteria. Then, the fuzzy synthetic extents of cost criteria and dam-reservoir related criteria are multiplied to each other and resulted in fuzzy weights of cost-dam-reservoir related criteria as tabulated in Table 5.14.

Table 5.12 Fuzzy preference aggregations and calculated fuzzy synthetic extent in pairwise comparison matrix of cost-benefit level.

Objective level	Cost	Benefit	Fuzzy synthetic extent
Cost	(1,1,1)	(0.520,0.639,0.787)	(0.323,0.390,0.471)
Benefit	(1.271,1.565,1.923)	(1,1,1)	(0.482,0.610,0.771)

Table 5.13 Fuzzy preference aggregations and calculated fuzzy synthetic extent in pairwise comparison matrix of dam-reservoir related level.

Sub-objective level	Dam-related	Reservoir-related	Fuzzy synthetic extent
Dam-related	(1,1,1)	(1.489,1.986,2.629)	(0.470,0.665,0.938)
Reservoir-related	(0.380,0.504,0.672)	(1,1,1)	(0.260,0.335,0.432)

Table 5.14 Multiplication of fuzzy synthetic extents of cost criteria and dam-reservoir related criteria.

Criteria	Fuzzy Synthetic extent
Cost-dam-related	(0.152,0.259,0.442)
Cost-reservoir-related	(0.084,0.131,0.204)

The results of aggregation and fuzzy synthetic extents of pairwise comparison of dam- and reservoir-related criteria are analyzed and shown in Tables 5.15 and 5.16. Also, attributes of power generation and tourist attraction of benefit criteria are aggregated and then analyzed for their fuzzy synthetic extents as shown in Table 5.17.

Table 5.15 Fuzzy preference aggregations and calculated fuzzy synthetic extent in pairwise comparison matrix of criteria on the basis of *dam-related attributes*.

Attribute level λ_{max} = 5.1754, CI= 0.0438, CR= 0.0392						
	SE	FG	CMA	AR	TL	Fuzzy synthetic extent
SE	(1,1,1)	(0.90,1.14,1.84)	(1.17,1.53,1.93)	(0.73,0.97,1.20)	(0.58,0.70,0.82)	(0.13,0.21,0.32)
FG	(0.54,0.88,1.12)	(1,1,1)	(0.88,1.21,1.58)	(0.84,1.07,1.34)	(0.88,1.08,1.28)	(0.13,0.20,0.30)
CMA	(0.52,0.65,0.86)	(0.63,0.82,1.14)	(1,1,1)	(1.20,1.56,1.91)	(1.22,1.51,3.08)	(0.14,0.21,0.38)
AR	(0.83,1.03,1.36)	(0.75,0.94,1.19)	(0.52,0.64,0.83)	(1,1,1)	(1.23,1.62,2.02)	(0.13,0.20,0.30)
TL	(1.22,1.42,1.71)	(0.78,0.93,1.14)	(0.32,0.66,0.82)	(0.50,0.62,0.81)	(1,1,1)	(0.12,0.18,0.26)

Table 5.16 Fuzzy preference aggregations and calculated fuzzy synthetic extent in pairwise comparison matrix of criteria on the basis of *reservoir-related attributes*.

Criteria λ_{max} = 5.0163, CI= 0.0041, CR= 0.0036						
	SI	LII	IMP	LULC	IHA	Fuzzy synthetic extent
SI	(1,1,1)	(0.90,1.16,1.40)	(1.08,1.38,1.73)	(1.06,1.42,1.84)	(1.37,1.67,2)	(0.17,0.26,0.37)
LII	(0.72,0.86,1.11)	(1,1,1)	(1,1.31,1.72)	(0.98,1.17,1.43)	(0.95,1.20,1.50)	(0.15,0.21,0.31)
IMP	(0.58,0.73,0.93)	(0.58,0.77,1)	(1,1,1)	(0.62,0.80,1.03)	(0.72,0.87,0.94)	(0.11,0.16,0.23)
LULC	(0.54,0.70,0.94)	(0.58,0.77,1)	(0.97,1.25,1.62)	(1,1,1)	(1.28,1.71,2.06)	(0.14,0.21,0.31)
IHA	(0.50,0.60,0.73)	(0.67,0.83,1.05)	(1.06,1.15,1.38)	(0.48,0.58,0.78)	(1,1,1)	(0.12,0.16,0.23)

Table 5.17 Fuzzy preference aggregations and calculated fuzzy synthetic extent in pairwise comparison matrix of criteria on the basis of benefit attributes.

Attribute level on the basis of benefit criteria	PG	TA	Fuzzy Synthetic extent
PG	(1,1,1)	(2.794,3.591,4.435)	(0.56,0.78,1.08)
TA	(0.225,0.278,0.358)	(1,1,1)	(0.18,0.22,0.27)

The global or final fuzzy synthetic extent of individual attribute resulted from involvement of all criteria levels are obtained by the multiplication of their fuzzy synthetic extents from the cost-benefit level down to attribute level. The fuzzy synthetic extents of cost-dam-related and cost-reservoir-related from Table 5.14 and benefit criteria from Table 5.12 are multiplied with the ones from Tables 5.15, 5.16, and 5.17, respectively. Finally, the global fuzzy synthetic extent of each attribute is tabulated in Table 5.18. PG is ranked to be the most importance followed by TA. The rests can be separated into 3 groups from higher to lower rank as: CMA, SE, AR, FG, and TL; SI, LII, and LULC; and IHA and IPM. These global fuzzy synthetic extents of attribute are further used for alternative dam sites comparison.

Table 5.18 Global fuzzy synthetic extents and rank of each criterion on the basis of attribute level.

Attribute level on the basis of dam-related criteria according to cost criteria and	Global fuzzy synthetic extent	Rank of attributes
Seismic effect (SE)	(0.020,0.053,0.141)	4
Foundation geology (FG)	(0.019,0.052,0.131)	6
Construction material availability (CMA)	(0.021,0.055,0.166)	3
Accessibility requirement (AR)	(0.020,0.052,0.133)	5
Transmission line (TL)	(0.018,0.046,0.114)	7
Attribute level on the basis of reservoir-related criteria according to cost criteria		
Settlement impact (SI)	(0.015,0.033,0.075)	8
Land instability index (LII)	(0.013,0.028,0.064)	9
Inundated potential mineral deposit (IPM)	(0.009,0.021,0.046)	12
Inundated LU/LC (LULC)	(0.012,0.027,0.062)	10

Table 5.18 (Continued).

Attribute level on the basis of dam-related criteria according to cost criteria and	Global fuzzy synthetic extent	Rank of attributes
Inundated historic and archeological sites (IHA)	(0.010,0.021,0.047)	11
Attribute level on the basis of benefit		
Power generation (PG)	(0.269,0.477,0.835)	1
Tourist attraction (TA)	(0.087,0.133,0.209)	2

From the valid experts' opinion, pairwise comparison among alternatives on the basis of each attribute are aggregated and analyzed to obtain their fuzzy synthetic extents as shown in Table 5.18. Table 5.19 shows aggregated fuzzy synthetic extents of alternatives on the basis of each attribute. Considering benefit and impact of individual attribute on alternatives, ranks of alternatives are provided. The higher rank indicates more benefit or less impact. For example, S2 is ranked to be the first in PG because, from project reports, S2 project will supply the most electric power. Considering FG, S2 is also ranked to be the first because it is located on the soundest volcanic rock with less discontinuity planes.

Then the fuzzy synthetic extents of alternatives on the basis of each attribute (Table 5.19) are multiplied by the global fuzzy synthetic extent of each attribute from Table 5.18 and summed fuzzy synthetic extents of all attributes for each certain alternative. This resulted in fuzzy weighted summation of each alternative under the consideration of all criteria levels and is shown in Table 5.20.

Table 5.19 Fuzzy preference aggregations and calculated fuzzy synthetic extent in pairwise comparison matrix of alternatives level on the basis of each attribute.

Seismic effect (SE) λ_{max} = 5.0623, CI= 0.0156, RI=1.12, CR= 0.0139						Fuzzy synthetic extent	Rank of alternative
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(1.94,2.60,3.42)	(0.41,0.52,0.67)	(0.69,0.90,1.14)	(0.48,0.65,0.92)	(0.05,0.08,0.13)	5
S2	(0.29,0.38,0.52)	(1,1,1)	(0.26,0.32,0.37)	(0.29,0.38,0.49)	(0.29,0.36,0.46)	(0.09,0.16,0.28)	4
S3	(1.49,1.91,2.44)	(2.71,3.11,3.82)	(1,1,1)	(1.25,1.72,2.40)	(0.90,1.42,2.01)	(0.14,0.25,0.43)	2
S4	(0.87,1.11,1.44)	(2.03,2.64,3.44)	(0.42,0.58,0.80)	(1,1,1)	(0.37,0.56,0.94)	(0.12,0.18,0.31)	3
S5	(1.08,1.53,2.10)	(2.17,2.75,3.48)	(0.50,0.70,1.11)	(1.07,1.78,2.71)	(1,1,1)	(0.18,0.34,0.58)	1
Foundation Geology (FG) λ_{max} = 5.0378, CI= 0.0094, CR= 0.0084							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(0.57,0.77,1.08)	(0.89,1.29,1.72)	(1.42,1.79,2.17)	(1,1.27,1.55)	(0.15,0.24,0.36)	2
S2	(0.93,1.30,1.77)	(1,1,1)	(0.86,1.16,1.54)	(1.17,1.63,2.18)	(0.83,1.07,1.38)	(0.15,0.24,0.37)	1
S3	(0.58,0.78,1.13)	(0.65,0.86,1.16)	(1,1,1)	(1.06,1.45,1.89)	(1.03,1.25,1.46)	(0.13,0.21,0.31)	3
S4	(0.46,0.56,0.71)	(0.46,0.61,0.86)	(0.53,0.69,0.94)	(1,1,1)	(0.75,0.96,1.15)	(0.10,0.15,0.22)	5
S5	(0.65,0.79,1)	(0.73,0.94,1.21)	(0.69,0.80,0.97)	(0.87,1.05,1.34)	(1,1,1)	(0.12,0.18,0.26)	4
Construction material availability (CMA) λmax = 5.0614, CI= 0.0154, CR= 0.0137							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(0.69,0.85,0.99)	(0.91,1.21,1.49)	(1.25,1.79,2.45)	(2.17,2.54,2.97)	(0.15,0.23,0.35)	3
S2	(1.01,1.18,1.45)	(1,1,1)	(1.05,1.46,1.82)	(1.99,2.86,3.67)	(2.58,3.03,3.60)	(0.20,0.30,0.45)	1
S3	(0.67,0.82,1.10)	(0.55,0.69,0.95)	(1,1,1)	(1.56,2.25,2.94)	(2.36,3.08,3.92)	(0.16,0.25,0.39)	2
S4	(0.41,0.56,0.80)	(0.27,0.35,0.50)	(0.34,0.44,0.64)	(1,1,1)	(1.66,2.30,2.91)	(0.09,0.15,0.23)	4
S5	(0.34,0.39,0.46)	(0.28,0.33,0.39)	(0.26,0.32,0.42)	(0.34,0.43,0.60)	(1,1,1)	(0.06,0.08,0.11)	5

Table 5.19 (Continued).

Accessibility requirement (AR) λ_{max} = 5.1163, CI= 0.0291, CR= 0.0260						Fuzzy synthetic extent	Rank of alternative
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(1.39,1.82,2.16)	(1.79,2.48,3.47)	(2.84,3.40,4.15)	(2.21,2.88,3.76)	(0.22,0.35,0.56)	1
S2	(0.46,0.55,0.72)	(1,1,1)	(0.82,1.19,1.74)	(1.84,2.29,2.91)	(1.46,1.86,2.47)	(0.13,0.21,0.34)	3
S3	(0.29,0.40,0.56)	(0.57,0.84,1.22)	(1,1,1)	(2.05,2.81,3.86)	(1.61,2.29,3.15)	(0.13,0.22,0.38)	2
S4	(0.24,0.29,0.35)	(0.34,0.44,0.54)	(0.26,0.36,0.49)	(1,1,1)	(0.29,0.42,0.66)	(0.05,0.08,0.12)	5
S5	(0.27,0.35,0.45)	(0.40,0.54,0.69)	(0.32,0.44,0.62)	(1.52,2.41,3.41)	(1,1,1)	(0.08,0.14,0.24)	4
Transmission line (TL) λ_{max} = 5.3538, CI= 0.0884, CR= 0.0790							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(4.60,5.63,6.65)	(2.57,3.66,4.71)	(0.50,0.71,1.05)	(0.18,0.23,0.30)	(0.14,0.21,0.32)	3
S2	(0.15,0.18,0.22)	(1,1,1)	(0.20,0.25,0.33)	(0.14,0.17,0.20)	(0.13,0.14,0.15)	(0.03,0.03,0.04)	5
S3	(0.21,0.27,0.39)	(3,4.05,5.09)	(1,1,1)	(0.18,0.23,0.30)	(0.17,0.21,0.27)	(0.07,0.11,0.17)	4
S4	(0.95,1.41,1.99)	(4.89,5.93,6.96)	(3.29,4.41,5.48)	(1,1,1)	(0.22,0.28,0.39)	(0.16,0.25,0.37)	2
S5	(3.38,4.43,5.46)	(6.62,7.34,7.79)	(3.70,4.86,5.90)	(2.54,3.58,4.61)	(1,1,1)	(0.27,0.40,0.58)	1
Settlement impact (SI) λ_{max} = 5.0337, CI= 0.008425, RI=1.12, CR= 0.0075							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(1.94,2.60,3.42)	(0.41,0.52,0.67)	(0.69,0.90,1.14)	(0.48,0.65,0.92)	(0.11,0.18,0.29)	4
S2	(0.29,0.38,0.52)	(1,1,1)	(0.26,0.32,0.37)	(0.29,0.38,0.49)	(0.29,0.36,0.46)	(0.05,0.08,0.12)	5
S3	(1.49,1.91,2.44)	(2.71,3.11,3.82)	(1,1,1)	(1.25,1.72,2.40)	(0.90,1.42,2.01)	(0.19,0.30,0.48)	1
S4	(0.87,1.11,1.44)	(2.03,2.64,3.44)	(0.42,0.58,0.80)	(1,1,1)	(0.37,0.56,0.94)	(0.12,0.19,0.31)	3
S5	(1.08,1.53,2.10)	(2.17,2.75,3.48)	(0.50,0.70,1.11)	(1.07,1.78,2.71)	(1,1,1)	(0.15,0.25,0.42)	2

Table 5.19 (Continued).

	S1	S2	S3	S4	S5	Fuzzy synthetic extent	Rank of alternative
Land instability index (LII) λ_{max} = 5.0845, CI= 0.0211, CR= 0.0188							
S1	(1,1,1)	(1.63,2.23,2.93)	(0.64,0.66,0.69)	(0.28,0.40,0.63)	(3.02,3.61,4.40)	(0.14,0.21,0.33)	3
S2	(0.34,0.45,0.61)	(1,1,1)	(0.25,0.33,0.46)	(0.23,0.28,0.36)	(1.53,2.29,3.29)	(0.07,0.12,0.19)	4
S3	(1.45,1.51,1.56)	(2.17,3.02,4.03)	(1,1,1)	(0.45,0.67,1.16)	(3.18,3.93,4.76)	(0.18,0.27,0.42)	2
S4	(1.59,2.50,3.52)	(2.77,3.56,4.43)	(0.86,1.49,2.22)	(1,1,1)	(3.16,4.01,4.80)	(0.20,0.34,0.54)	1
S5	(0.23,0.28,0.33)	(0.30,0.44,0.65)	(0.21,0.25,0.31)	(0.21,0.25,0.32)	(1,1,1)	(0.04,0.06,0.09)	5
Inundated mineral potentiality (IMP) λmax = 5.0934, CI= 0.0234, CR= 0.0208							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(1.24,1.82,2.36)	(1.95,2.48,3.01)	(0.28,0.35,0.44)	(2,2.55,3.06)	(0.15,0.24,0.36)	2
S2	(0.42,0.55,0.81)	(1,1,1)	(1.12,1.65,2.29)	(0.26,0.31,0.38)	(1.32,2.05,2.84)	(0.10,0.16,0.27)	3
S3	(0.33,0.40,0.51)	(0.44,0.61,0.90)	(1,1,1)	(0.22,0.27,0.32)	(0.70,1.17,1.65)	(0.06,0.10,0.16)	4
S4	(2.27,2.90,3.53)	(2.66,3.25,3.89)	(3.09,3.74,4.56)	(1,1,1)	(2.63,3.35,4.16)	(0.27,0.41,0.62)	1
S5	(0.33,0.39,0.50)	(0.35,0.49,0.76)	(0.61,0.85,1.42)	(0.24,0.30,0.38)	(1,1,1)	(0.06,0.09,0.15)	5
Inundated land use land cover (LULC) λ_{max} = 5.0698, CI= 0.0174, CR= 0.0156							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(0.95,1.22,1.66)	(0.19,0.24,0.34)	(1,1.32,1.78)	(1.84,2.74,3.76)	(0.10,0.17,0.28)	2
S2	(0.60,0.82,1.05)	(1,1,1)	(0.17,0.19,0.24)	(0.40,0.58,0.77)	(1.20,1.49,1.84)	(0.07,0.11,0.16)	4
S3	(2.91,4.09,5.19)	(4.13,5.17,6.06)	(1,1,1)	(3.17,4.29,5.32)	(4.37,5.33,6.24)	(0.33,0.51,0.78)	1
S4	(0.56,0.76,1)	(1.29,1.74,2.48)	(0.19,0.23,0.32)	(1,1,1)	(1.25,1.70,2.20)	(0.09,0.14,0.23)	3
S5	(0.27,0.37,0.54)	(0.54,0.67,0.84)	(0.16,0.19,0.23)	(0.45,0.59,0.80)	(1,1,1)	(0.05,0.07,0.11)	5

Table 5.19 (Continued).

							Rank of alternative
Inundated historic and archeological sites (IHA) λmax = 5.0943, CI= 0.0236, CR= 0.0210							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(1.13,1.17,1.20)	(1.99,2.70,3.32)	(0.31,0.41,0.57)	(1.22,1.24,1.26)	(0.14,0.21,0.32)	3
S2	(0.84,0.86,0.89)	(1,1,1)	(1.84,2.55,3.17)	(0.29,0.38,0.52)	(1.13,1.26,1.53)	(0.03,0.03,0.04)	5
S3	(0.30,0.37,0.50)	(0.32,0.39,0.54)	(1,1,1)	(0.28,0.35,0.41)	(0.37,0.49,0.68)	(0.07,0.11,0.16)	4
S4	(1.74,2.46,3.26)	(1.93,2.65,3.47)	(2.46,2.89,3.51)	(1,1,1)	(2.58,3.21,3.79)	(0.17,0.25,0.37)	2
S5	(0.79,0.81,0.82)	(0.66,0.79,0.89)	(1.48,2.05,2.68)	(0.26,0.31,0.39)	(1,1,1)	(0.28,0.40,0.58)	1
Power generation (P) λmax = 5.1047, CI=0.026175, RI=1.12, CR= 0.02							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(0.22,0.29,0.42)	(0.73,0.84,0.90)	(0.31,0.44,0.70)	(2.53,3.40,4.44)	(0.09,0.14,0.24)	4
S2	(2.36,3.48,4.55)	(1,1,1)	(2.53,3.61,4.65)	(1.49,2.36,3.36)	(4.84,5.79,6.67)	(0.23,0.39,0.64)	1
S3	(1.12,1.20,1.38)	(0.22,0.28,0.39)	(1,1,1)	(0.30,0.42,0.76)	(2.53,3.46,4.53)	(0.10,0.15,0.25)	3
S4	(1.42,2.29,3.27)	(0.30,0.42,0.67)	(1.32,2.36,3.38)	(1,1,1)	(3.73,4.84,5.90)	(0.15,0.26,0.45)	2
S5	(0.23,0.29,0.39)	(0.15,0.17,0.21)	(0.22,0.29,0.39)	(0.17,0.21,0.27)	(1,1,1)	(0.03,0.05,0.07)	5
Tourism attraction (T) λmax = 5.1342, CI= 0.03355, CR=0.065							
	S1	S2	S3	S4	S5		
S1	(1,1,1)	(0.18,0.20,0.24)	(0.28,0.36,0.52)	(0.28,0.37,0.53)	(0.78,0.86,1)	(0.05,0.07,0.10)	5
S2	(4.18,4.93,5.66)	(1,1,1)	(3.99,4.75,5.49)	(3.70,4.49,5.25)	(3.71,4.59,5.38)	(0.35,0.49,0.69)	1
S3	(1.94,2.81,3.61)	(0.18,0.21,0.25)	(1,1,1)	(0.86,0.96,1.05)	(1.49,2.23,2.86)	(0.11,0.18,0.27)	3
S4	(1.88,2.74,3.54)	(0.19,0.22,0.27)	(0.96,1.05,1.17)	(1,1,1)	(1.61,2.32,2.94)	(0.12,0.18,0.27)	2
S5	(1,1.17,1.28)	(0.19,0.22,0.27)	(0.35,0.45,0.67)	(0.34,0.43,0.62)	(1,1,1)	(0.06,0.08,0.12)	4

Table 5.20 Fuzzy weighted summation of alternatives.

Site	Fuzzy weighted summation
Pakbeng (S1)	(0.0508,0.1610,0.5403)
Luangprabang (S2)	(0.1099,0.3178,0.9446)
Xayabury (S3)	(0.0591,0.1864,0.6261)
Paklay (S4)	(0.0709,0.2269,0.7266)
Xanakham (S5)	(0.0329,0.1078,0.3779)

5.3 Defuzzification

The rank expressing relative importance of proposed dam and reservoir sites along the Mekong River in northwest Laos is the main objective of the study. To display the relative importance clearly, the total fuzzy weights summation of all alternative dam sites from Table 5.20 are transformed to crisp values by three methods of defuzzification i.e. fuzzy extent analysis, center-of-area, and α-cut as shown in Table 5.21 and Figure 5.17. Based on three methods, the results of defuzzification provide the same ranking of relative importance. Luangprabang dam (S2) appears to be the highest relative importance, following by Paklay dam (S4), Xayabury dam (S3), Pakbeng dam (S1), and Xanakham dam (S5).

Table 5.21 Relative importance of dam site alternatives based on preference defuzzification methods.

	Defuzzied weight		
	Fuzzy extent analysis		
	$V(\tilde{S}_i \geq \tilde{S}_j)$	Normalized	Priority/ranking
Pakbeng (S1)	0.7329	0.1529	4
Luangprabang (S2)	1.0000	0.2086	1
Xayabury (S3)	0.7971	0.1662	3
Paklay(S4)	0.8715	0.1818	2
Xanakham (S5)	0.5606	0.1169	5

Table 5.21 (Continued).

	α-cut-based method C_λ with λ=0.8 and α=0.8	Normalized	Priority
Pakbeng (S1)	0.2173	0.1595	4
Luangprabang (S2)	0.4098	0.3008	1
Xayabury (S3)	0.2517	0.1848	3
Paklay(S4)	0.3006	0.2207	2
Xanakham (S5)	0.1480	0.1087	5
	Center of area defuzzification ~C	Normalized	Priority
Pakbeng (S1)	0.2507	0.1657	4
Luangprabang (S2)	0.4574	0.3023	1
Xayabury (S3)	0.2905	0.1920	3
Paklay(S4)	0.3415	0.2257	2
Xanakham (S5)	0.1729	0.1142	5

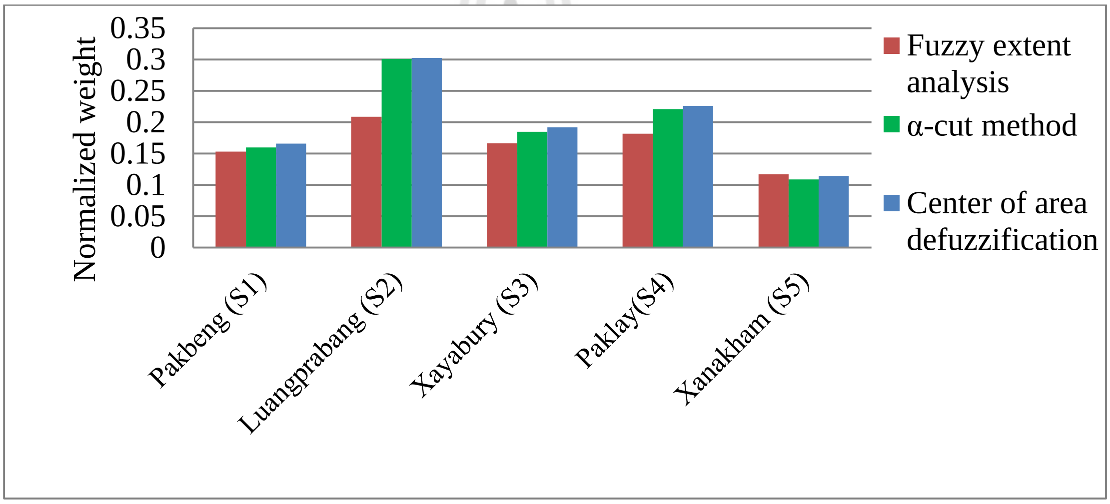

Figure 5.17 Comparison of the relative importance of dam sites obtained from three defuzzification methods.

It can be concluded that there is no significant difference between three methods in specifying site priorities, although the relative weights vary slightly. The center of area and α-cut methods provide the same plot of priority and can distinguish them better than the result from fuzzy extent analysis. Inversely, if three methods provide different priority, then total relative importance should be aggregated to determine a final weight of each alternative.

It is interesting to note that center-of-area method seems to be more scientific in transforming fuzzy relative importance to crisp value. α-cut method depends on α and λ which can be between 0 and 1. The λ assigned indicates attitude of decision maker from being optimistic (1) to pessimistic (0). Varying α between 0 and 1 reflects the confidence of decision maker. The higher confidence provides the narrower range of fuzzy or corresponds to the lower uncertainty. This characteristic allow decision maker to vary these parameters until output is satisfied. This is the advantage of this method for decision maker. In the study, 0.8 is assigned for both λ and α so that the high weights can be obtianed with optimistic confidence and have more chance to be different from other methods. Nevertheless, the results still get along with others.

5.4 Sensitivity analysis

The sensitivity analysis is applied to observe which criterion is most related or influence to the rank of alternatives. It is interesting to realize that how much cost or benefit alone can affect the rank of alternatives and also, how each criterion in attribute level has influence to the ranking of alternatives. This influence can be observed when a criterion is dropped out from the process one at a time.

First, the benefit and cost criteria are dropped one at a time. The fuzzy weighted sum from both criteria resulted from fuzzy pairwise comparison are shown in Table 5.22. The defuzzied weights obtained from those three methods and ranking of alternative dam sites resulted from considering either cost criteria or benefit criteria alone are compared in Table 5.23 and Figure 5.18.

Table 5.22 Fuzzy weighted sum of alternative when either cost criteria or benefit criteria are considered.

Site	Fuzzy weighted sum Cost criteria	Benefit criteria
Pakbeng (S1)	(0.0667,0.2133,0.6853)	(0.0607,0.1275,0.2817)
Luangprabang (S2)	(0.0514,0.1684,0.5696)	(0.1936,0.4133,0.8767)
Xayabury (S3)	(0.0697,0.2296,0.7605)	(0.0759,0.1588,0.3470)
Paklay (S4)	(0.0636,0.1977,0.6272)	(0.1044,0.2456,0.5588)
Xanakham (S5)	(0.0573,0.1910,0.6238)	(0.0298,0.0547,0.1087)

It is interesting to note that, using fuzzy extent analysis, even though there is no zero in fuzzy weighted sum of alternatives, the defuzzified weight can have a chance to be zero. It does not mean that an alternative with zero defuzzied weight expresses no relative importance. In the actual condition, it is more likely to have very low relative importance instead of having no importance.

Table 5.23 Defuzzied, normalized weights, and ranks of alternative dam sites when either cost criteria or benefit criteria are considered.

dam site alternatives	Defuzzied weight cost criteria	benefit criteria	Normalized cost criteria	benefit criteria	Ranks cost criteria	benefit criteria
	Fuzzy extent analysis $V(\tilde{S}_i \geq \tilde{S}_j)$					
Pakbeng (S1)	0.9742	0.2356	0.205	0.1026	2	4
Luangprabang (S2)	0.8908	1	0.188	0.4354	5	1
Xayabury (S3)	1	0.3761	0.211	0.1637	1	3
Paklay(S4)	0.9458	0.6853	0.199	0.2983	3	2
Xanakham (S5)	0.9349	0	0.197	0	4	5
	α-cut-based method λ=0.8 and α=0.8					
Pakbeng (S1)	0.2830	0.1495	0.2120	0.1282	2	4
Luangprabang (S2)	0.2279	0.4787	0.1707	0.4104	5	1
Xayabury (S3)	0.3082	0.1856	0.2308	0.1592	1	3
Paklay(S4)	0.2610	0.2901	0.1955	0.2487	3	2
Xanakham (S5)	0.2549	0.0623	0.1909	0.0535	4	5
	Center of area defuzzification ~C					
Pakbeng (S1)	0.3218	0.1566	0.2110	0.1292	2	4
Luangprabang (S2)	0.2631	0.4945	0.1725	0.4079	5	1
Xayabury (S3)	0.3533	0.1939	0.2316	0.1599	1	3
Paklay(S4)	0.2961	0.3030	0.1942	0.2499	3	2
Xanakham (S5)	0.2907	0.0644	0.1906	0.0531	4	5

From Table 5.23 and Figure 5.18, it reveals that ranks of alternative dam site based on either cost criteria or benefit criteria alone are different. Considering only cost criteria, those 3 methods resulted in the same set of alternative ranking. Xayabury dam site (S3) is ranked to be the most importance followed by Pakbeng (S1), Paklay (S4), Xanakham (S5), and Luangprabang (S2), respectively. This is completely different from considering only benefit criteria alone. Considering only benefit criteria, the most important alternative dam site is at Luangprabang (S2) followed by Paklay (S4), Xayabury (S3), Pakbeng (S1), and Xanakham (S5), respectively. However, the ranks of alternative dam site when considering only benefit criteria are the same from those 3 methods of defuzzification.

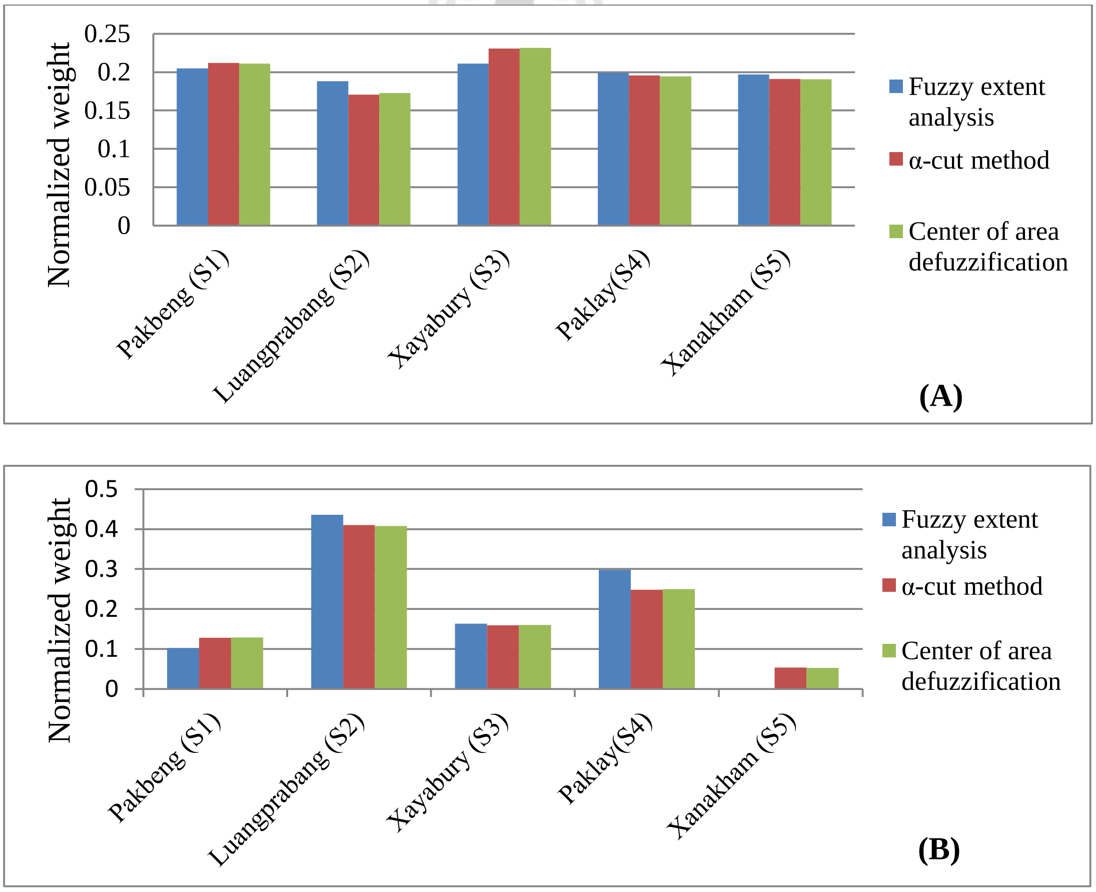

Figure 5.18 The relative importance of dam sites comparison between three methods on the basis of (A) cost criteria and (B) benefit criteria.

It can be noted that the weights showing relative importance when considering cost criteria (Figure 5.18(A)) are very close, not much different while they express higher different when considering benefit criteria. It can be concluded benefit criteria has more influence to the relative importance of alternative dam site than cost criteria.

Comparing ranks of alternative dam site from either benefit criteria or cost criteria to the result when both criteria are considered (Figure 5.17), the ranks from benefit criteria are the same with ranks from both criteria while from cost criteria are different. It can be concluded that benefit criteria are more sensitive than cost criteria because the ranks are changed when they are dropped.

Sensitivity analysis of attribute level is performed by dropping an attribute one at a time in fuzzy pairwise comparison. Their fuzzy weighted sums are defuzzied and ranking is carried out. The results are shown in Table 5.24 and Figure 5.19. It is obvious that the ranking of alternative dam sites is different from ranking of all attribute consideration only when PG attribute is dropped while of the rests are the same. It can be concluded that the PG attribute of benefit criteria is the most sensitive criteria that most affect to the ranking of alternative dam sites. Without consideration of PG, their weights of relative importance become very close to each other or other world, the PG attribute causes more weight difference. Apart from dropped PG consideration, others show little variation in weights of relative importance. Defuzzied weights of S1 and S3 in dropped TA become obviously closer to each other than of the rests. It implies that TA has more influence on S1 and S3 than the others. PG and TA are attributes in the benefit criteria. Conclusively, the sensitivity analysis of attribute level is consistent to the higher level of cost and benefit criteria.

Table 5.24 Defuzzied weights and ranks of alternative dam site when an attribute is dropped one at a time from analysis of fuzzy pairwise comparison.

Attribute	Defuzzied weight of alternative dam site					Ranking
Fuzzy extent analysis	S1	S2	S3	S4	S5	
All attributes	0.1529	0.2086	0.1662	0.1818	0.1169	S2,S4,S3,S1,S5
Dropped SE	0.1540	0.2109	0.1625	0.1816	0.0971	S2,S4,S3,S1,S5
Dropped FG	0.1492	0.2098	0.1650	0.1831	0.1119	S2,S4,S3,S1,S5
Dropped CMA	0.1483	0.2086	0.1627	0.1827	0.1172	S2,S4,S3,S1,S5
Dropped AR	0.1434	0.2091	0.1631	0.1836	0.1121	S2,S4,S3,S1,S5
Dropped TL	0.1504	0.2134	0.1679	0.1816	0.1006	S2,S4,S3,S1,S5
Dropped SI	0.1485	0.2066	0.1604	0.1783	0.1082	S2,S4,S3,S1,S5
Dropped LII	0.1495	0.2075	0.1625	0.1779	0.1158	S2,S4,S3,S1,S5
Dropped IPM)	0.1524	0.2107	0.1678	0.1811	0.1173	S2,S4,S3,S1,S5
Dropped LULC	0.1480	0.2047	0.1570	0.1777	0.1138	S2,S4,S3,S1,S5
Dropped IHA	0.1534	0.2110	0.1685	0.1818	0.1167	S2,S4,S3,S1,S5
Dropped PG	0.1847	0.2086	0.1991	0.1901	0.1786	S2,S3,S4,S1,S5
Dropped TA	0.1696	0.2086	0.1763	0.1923	0.1330	S2,S4,S3,S1,S5
α-cut defuzzification	S1	S2	S3	S4	S5	
All attributes	0.1595	0.3008	0.1848	0.2207	0.1087	S2,S4,S3,S1,S5
Dropped SE	0.1694	0.3187	0.1858	0.2294	0.0967	S2,S4,S3,S1,S5
Dropped FG	0.1595	0.3043	0.1835	0.2250	0.1049	S2,S4,S3,S1,S5
Dropped CMA	0.1591	0.3095	0.1855	0.2319	0.1140	S2,S4,S3,S1,S5
Dropped AR	0.1524	0.3149	0.1874	0.2359	0.1095	S2,S4,S3,S1,S5
Dropped TL	0.1611	0.3228	0.1937	0.2254	0.0970	S2,S4,S3,S1,S5
Dropped SI	0.1630	0.3172	0.1858	0.2278	0.1063	S2,S4,S3,S1,S5
Dropped LII	0.1623	0.3144	0.1872	0.2231	0.1131	S2,S4,S3,S1,S5
Dropped IPM)	0.1621	0.3119	0.1915	0.2225	0.1120	S2,S4,S3,S1,S5
Dropped LULC	0.1634	0.3147	0.1803	0.2289	0.1127	S2,S4,S3,S1,S5
Dropped IHA	0.1630	0.3113	0.1919	0.2231	0.1107	S2,S4,S3,S1,S5
Dropped PG	0.1807	0.2398	0.2199	0.1926	0.1670	S2,S3,S4,S1,S5
Dropped TA	0.1763	0.2849	0.1909	0.2323	0.1156	S2,S4,S3,S1,S5
Center of area defuzzification	S1	S2	S3	S4	S5	
All attributes	0.1657	0.3023	0.192	0.2257	0.1142	S2,S4,S3,S1,S5
Dropped SE	0.172	0.313	0.188	0.229	0.098	S2,S4,S3,S1,S5
Dropped FG	0.161	0.306	0.191	0.231	0.111	S2,S4,S3,S1,S5
Dropped CMA	0.161	0.303	0.187	0.232	0.117	S2,S4,S3,S1,S5
Dropped AR	0.154	0.309	0.19	0.236	0.112	S2,S4,S3,S1,S5
Dropped TL	0.163	0.317	0.196	0.224	0.1	S2,S4,S3,S1,S5
Dropped SI	0.165	0.311	0.188	0.227	0.109	S2,S4,S3,S1,S5
Dropped LII	0.164	0.308	0.19	0.222	0.116	S2,S4,S3,S1,S5
Dropped IPM)	0.164	0.305	0.194	0.222	0.115	S2,S4,S3,S1,S5
Dropped LULC	0.165	0.308	0.183	0.228	0.116	S2,S4,S3,S1,S5
Dropped IHA	0.165	0.305	0.194	0.222	0.113	S2,S3,S4,S1,S5
Dropped PG	0.183	0.234	0.222	0.192	0.169	S2,S4,S3,S1,S5
Dropped TA	0.177	0.28	0.193	0.231	0.118	S2,S4,S3,S1,S5

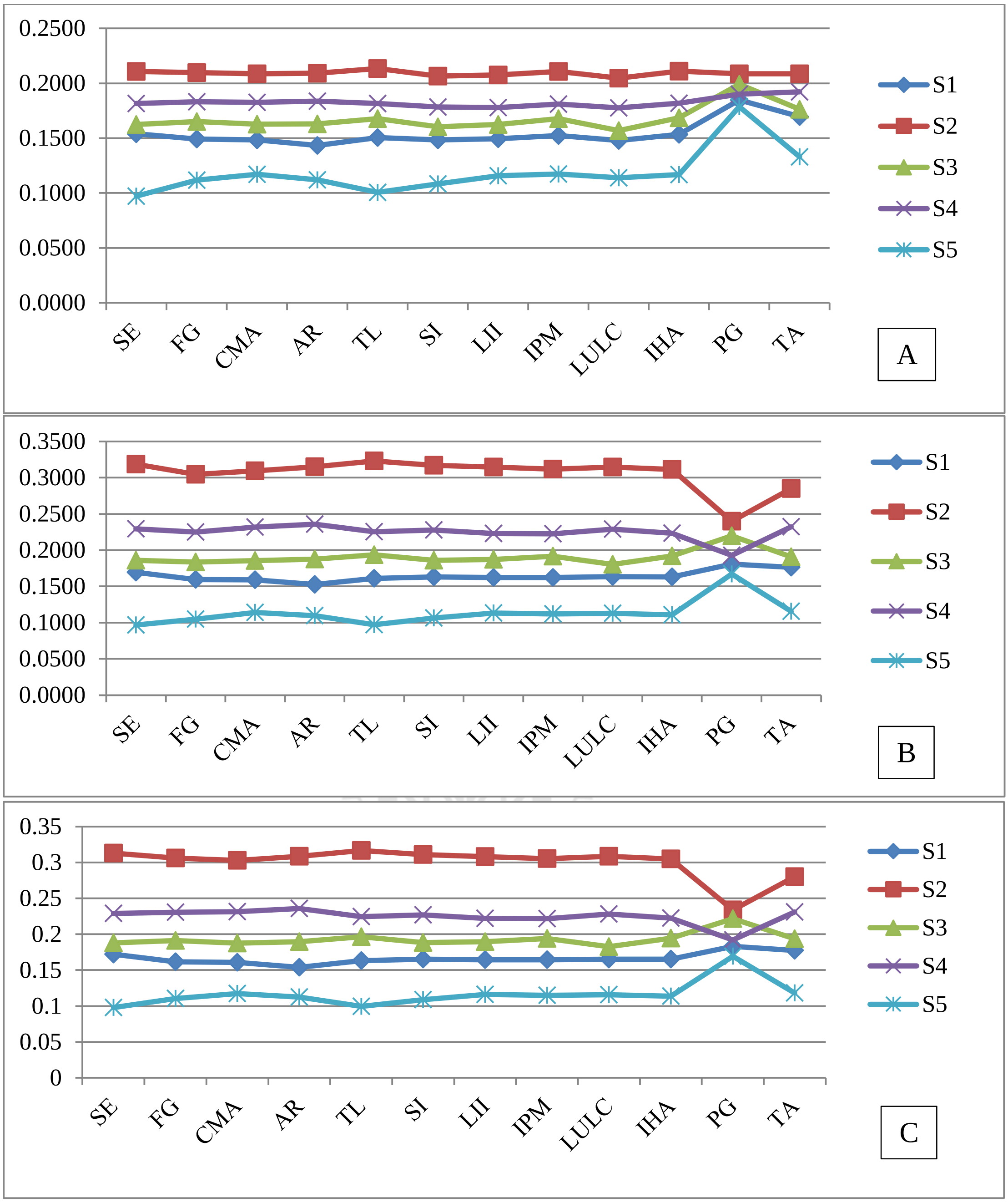

Figure 5.19 Defuzzied weights from 3 methods of defuzzification (A-fuzzy extent analysis, B-α cut method, and C-center of area) when an attribute is dropped one at a time in fuzzy pairwise comparison.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Laos plans to be “the battery of southeast Asia”. There are 8 proposed hydropower projects along Mekong River flowing through the country. For this study, 5 of them are proposed to be in the Northwestern region of Laos and selected to rank their relative importance in term of accurately quantitative values based on their costs and benefits using MADM-FAHP. This information can be certainly used in decision making for development of those alternative projects.

The criteria considered for ranking are selected and prepared in form of hierarchical structure of decision matrix. The matrix is designed to reflect their relationships and weights from levels of cost and benefit, dam- and reservoir-related, and attributes operating on dam site alternatives comparison. The weights are resulted from fuzzy pairwise comparison based on experts’ opinions through the questionnaire survey which provides information from the limited available data and field investigation. GIS is considered as a useful and effective tool for preparing and providing spatial criteria data. Through the questionnaire, 13 volunteer experts include civil engineers and geologies are expressed their preference opinion. From the process of MADM-FAHP, the results reveal that benefit criteria show obviously higher weight or more significance than cost criteria. Cost dam-related criteria are considered having about doubly higher weight than cost reservoir-related criteria. This could be because experts consider that cost dam-related criteria such as seismic, foundation, and construction material availability can immediately affect the cost of construction and the safety of dam while cost reservoir-related criteria such as LII, and settlement impact can affect slowly and can be managed. In attribute level, power generation is considered having the highest weight following by tourist attraction, construction material availability, seismic effect, accessibility requirement, foundation geology, transmission line, settlement impact, land instability index, inundated LU/LC, inundated historic and archeological sites, and inundated potential mineral deposit respectively. The ranking of attributes is consistent to the ranking of cost benefit level because the first two attributes belong to the benefit criteria.

Using 3 different defuzzification methods, the results provide the same ranking of relative importance. Luangprabang dam (S2) appears to be the highest following by Paklay dam (S4), Xayabury dam (S3), Pakbeng dam (S1), and Xanakham dam (S5). Not only there is no difference in ranking but also the relative weights vary only slightly.

Sensitivity analysis is operated to realize that which criteria can affect more to the ranking result. In cost and benefit level, the results show that alternative ranking is changed and their relative importance expresses higher difference when benefit criteria is dropped out of the process. Xayabury dam site (S3) is ranked to be the most importance following by Pakbeng (S1), Paklay (S4), Xanakham (S5), and Luangprabang (S2), respectively. It can be concluded that benefit criteria has more influence to alternative ranking and their relative importance than cost criteria.

In attribute level, the results of sensitivity analysis is consistent to the ones from the cost and benefit level. The ranking of alternative dam sites is different from ranking of all attribute consideration and their relative importance shows more variation only when PG attribute, an attribute of benefit criteria, is dropped while of the rests are the same. Luangprabang is ranked to be the most importance following by Xayabury, Paklay, Pakbeng, and Xanakham, respectively. Therefore, the PG attribute of benefit criteria is the most sensitive criteria that most affect to the ranking of alternative dam sites. However, it is very interesting to note that the ranking is completely different when the benefit criteria (PG and TA) are dropped.

6.2 Recommendations

Recommendations for further studies include:

(1) To be more practical, governmental policies and legal issues should be brought to involve in decision making analysis.

(2) The sediment load and transportation per year, fish migration, and land use and land cover etc. of each dam watershed are not considered in this study due to lacking of data from previous study. With this information the better results can be expected.

(3) The larger scale and more detail of criteria data of each dam and reservoir such as seismicity and mineral potential data can assist experts in working on pairwise comparison of criteria more easily.

(4) Stakeholders or local people should be participated in decision making process.

(5) Delphi technique should be incorporated with criteria pairwise comparison by experts so that all opinions can be revised to be consistent.

(6) The consequence effect to the rest of alternatives should be studied when an alternative is constructed.

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APPENDICES

APPENDIX A

DESCRIPTION OF MAP UNITS

Quaternary-Neogene

aQ2	Holocene: Pebbles, boulders, gravels, grit, sand, clay containing phant humus.
aQ1,2-3	Middle-upper Pleistocene: Sand, pebbles, gravels, grit, clay, plant humus, some peat.
Qv	Alluvium: Sand and gravels.
bN2-Q1	Pliocene-Pleistocene: Spinel-bearing olivine basalt.
N	Pliocene: Conglomerate, gritstone, sandstone, greenish-grey siltstone, some light-grey marl, coaly claystone, brown coal containing: Viviparus cf. margaryaeformis Mans.

Cretaceous

Upper Cretaceous:

K2tg	Siltstones, shale, sandstone and mudstone with beds of gypsum, anhydrite and halite.
r4	Granite, granodiorite.
Mz2-2	Mudstones and evaporitic

Middle

rk	Granite.

Lower Cretaceous:

K1	Calcareous gritstone, light-coloured sandstone, monomineral siltstone, red-violetish claystone.
K1ba	Reddish brown or grey micaceous siltstone with purple and red shales.
K1cp	Bright coloured, massive, cross-bedded pebbly sandstone and conglomerate.

K1kt	Red-brown sandstones, claystones and conglomerates.
K1ns	Reddish-brown and purple micaceous siltstone with brown and grey micaceoucs sandstone and basal limestone conglomerates.
K1pp	White and pink massive, resistant, cross-bedded sandstone with reddish brown or grey shale and micaceous siltstone
K1pp-K1cp	Undiffentiated sediments.
K2sb	Red-brown, cross-bedded sandstone.

Jurassic

Jsb	Purple to buff claystone and sandstones with ocasional limestone horizons
J3	Upper Jurassic: Conglomerate, greenish polymineral sandy gritstone grading upward into red siltstone and claystone.
J1-2	Lower-middle Jurassic: Light-coloured sandstone, light-grey grading upward into red-violetish siltstone and claystone.

Triassic-Jurassic

T	Basalt, alkali basalt, andesite, tuffs, agglomerate.
TJbk	Thin bedded to laminated grey to black claystones, locally with ripple marks

Upper Triassic

T3	Conglomerate, intercalation of grey to violetesh sandstone and siltstone, marl, micro-grained limestone containing: Halobia talauana Waner.

Middle-upper Triassic

T2-3	Conglomerate, breccia, red-violetish gritstone, sandstone, siltsone, grey grading upward into violetesh claystone, containing: Halobia charlyana.

Middle Triassic

d1T2	Phase: Porphyritic biotite granite.
d2T2	Phase: Porphyritic biotite granite.
gd2T2	Porphyritic biotite granite.

	T2	Greenish-grey to dark grey, thin-beded sandstone, siltstone and claystone with some interbeds of felsic effusives and thier tuffs, lensed of limestone, marl and calcareous sandstone
Lower Triassic		
	rT	Granite
Triassic-Permian		
	C2P1nt-T-Jbm	Undifferentiated fine-grained sediments and volcanics.
	Pz3-3	Intermediate and mafic volcanic rocks.
Permian		
	P2pl	Brownish, micaceous sandstones, siltstone and claystone
	P2	Pyroxene andesite and andesitic tuff.
	Pnl	Massive, grey to dark grey crystone line limestones, with chert nodules in upper part
	P1-2	Black clay shale and cherty shale interbeded with grauwacke sandstone, thin beds of limestone and calcareous sandstone grading upward into grey.
Carboniferous-Permian		
	Pz3-2	Intrusion of granodioritic
	P2-C2nl	Massive grey to dark grey crystalline limestone with chert nodules in upper part
	C-P1	Light grey,thick-beded to massive limestone with some interbeds of thin-beded marl
	C2-P1nt	Dark grey, reddish or black claystones, coals, siltstone, massive grey limestone, sandstones and conglomerates
Carboniferous		
	Xc	Hornfels. Contact metamorphic zones around granites
	xC2?	Pyroxenite, serpentinite
	C1	Light-violetesh conglomerate and sandstone, quartzitic sandstone, grey siltstone, claystone, cherty shale, marl with lenses of thin-bedded limestone containing: Crinoidae, Corealla,Brachiopoda.

Devonian-Carboniferous

C2-D3nt	Dark grey, reddish or black claystones, soals, siltstone, massive grey limestone, sandstones and conglomerates

Devonian

D2-D1ns	Massive, grey to fine-grained reefal limestones, grey-reddish cherts with shale partings.

APPENDIX B

QUESTIONNAIRE

The questionnaire is composed of 4 parts: part I: briefly general expert information, part II: general information of the research, part III: Criteria information and comparison of dams and reservoirs, and Part IV: Additional comments.
This information will be useful and important as primary data of the research. Your opinion will not be disclosed.

Part I: Briefly expert information

1.1 Name and surname: ....

1.2 Position:..
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1.3 Education background: ....
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1.4 Work experience: ... .
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1.5 Email address: ....

1.6 Date interview (dd/mm/yyyy): ..../............................./........................

Part II: General information of the research

2.1 Thesis title: APPLICATION OF FUZZY ANALYTICAL HIERARCHY PROCESS TO RANKING THE IMPORTANCE OF HYDROPOWER DAM SITES ALONG THE MEKONG RIVER, NORTHWESTERN REGION OF LAOS

2.2 Objective

To rank the relative importance of dam and reservoir sites along the Mekong River in northwestern Laos in term of accurately quantitative values based on their costs and benefits using MADM-FAHP.

2.3 Hierarchy structure of decision criteria

Five alternatives of dam and reservoir sites have been proposed for ranking of their priority of development. These dams are Pakbeng (S1), Luangprabang (S2), Xayabury (S3), Paklai (S4), and Sanakharm (S5) as shown in Figure 1. The criteria considered to rank the relative importance of dams are separated to be 3 hierarchical levels as shown in Figure 2. The importance of criteria within the same level and the same group will be compared as pairwise to each other. The dam alternatives will be compared to each other based on each characteristic described in each criterion of level 3. The intensity of comparison will be analyzed by Fuzzy Analytical Hierarchy Process (FAHP) method to show the relative importance of dams.

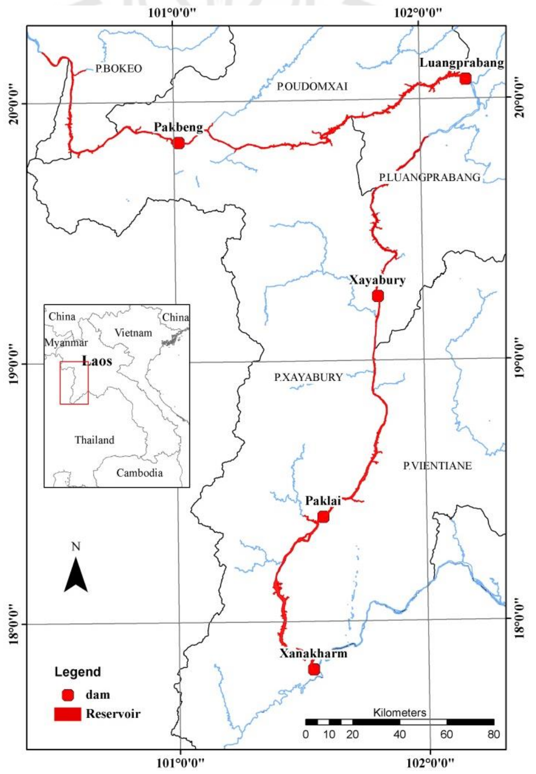

Figure 1 Locations of proposed dam sites along the Mekong River in the northwestern Laos.

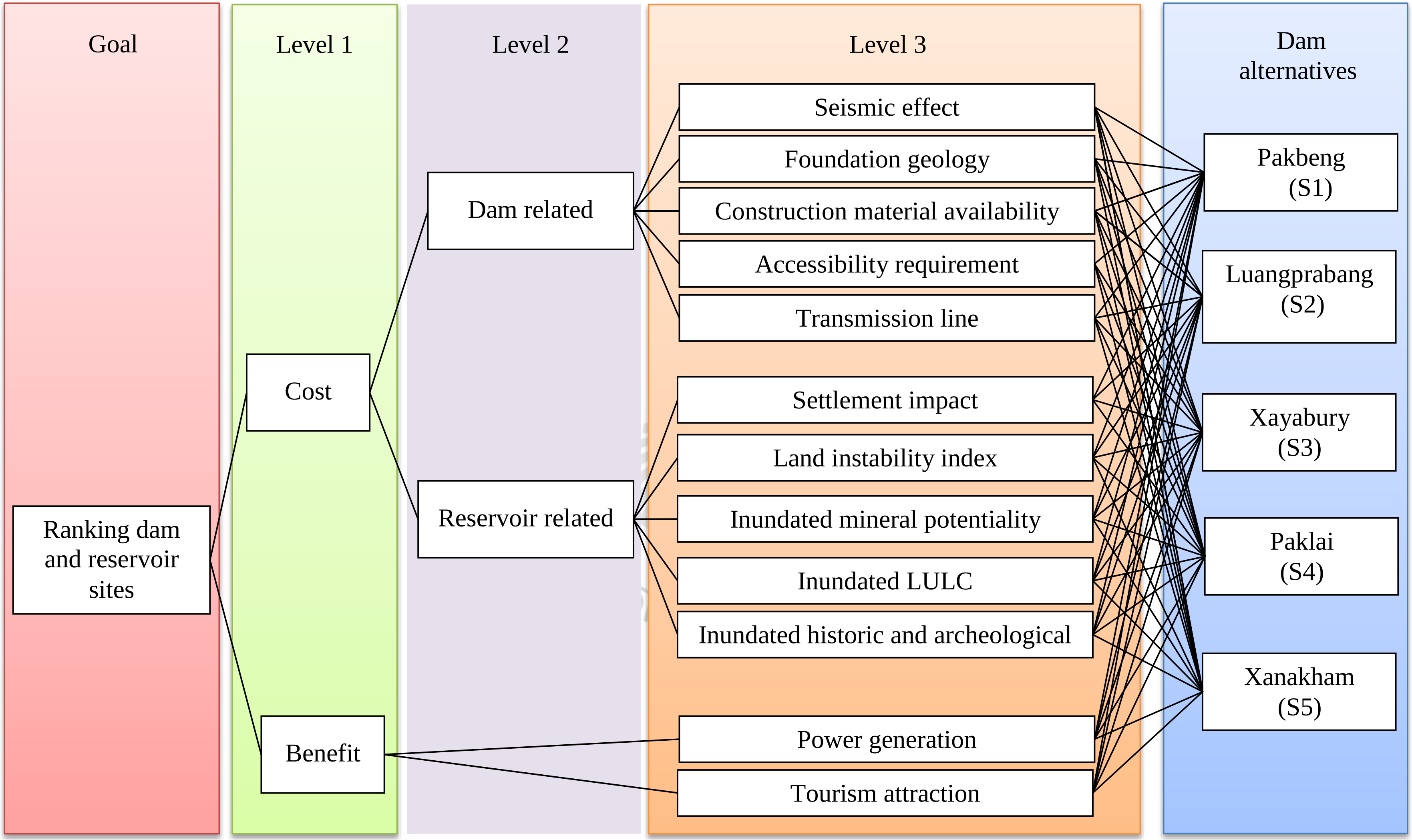

Figure 2 Hierarchy structures of criteria for making decision of five proposed dams and reservoirs

2.4 Criteria and dam sites comparison method

Comparison of the relative importance of dams and reservoirs in the state of prefeasibility study can be difficult and fuzzy for experts to express their opinion. FAHP is therefore designed to cope with this fuzziness. Nine level measurements of intensity of importance are designed by Saaty (1980) for pairwise comparison, as shown in Table 1, of criteria in the same level and the same group as shown in Figure 2.

Table 1 Intensity of importance based on linguistic preferences.

Preferences expressed in linguistic variables	Intensity of importance
Equal importance	1
Equal to moderate importance	2
Moderate importance	3
Moderate to strong importance	4
Strong importance	5
Strong to very Strong importance	6
Very strong importance	7
Very strong to extremely strong importance	8
Extreme importance	9

An expert can express his/her opinion by selecting the proper scale of important while comparing the importance of criterion to criterion in level 1 and level 2 or importance of dam to dam based on each specific criterion in level 3.

The example is shown below.

If an expert has an opinion that benefit criterion is more important than cost criterion in the level of "strong importance", the score should be ticked in the form as shown below.

.

Criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria
cost													✓					benefit
Extreme importance									Equal									Extreme importance

If an expert has an opinion that cost criterion is more important than benefit criterion in the level of "moderate importance", the score should be ticked in the form as shown below.

Criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria
cost							✓											benefit
Extreme importance									Equal									Extreme importance

Part III: Criteria information and comparison of dams and reservoirs

3.1 Dam-related cost criteria

(1) Seismic effect

The seismic effect of a dam site mainly influences to the dam safety. 10% Probable Horizontal Peak Ground Acceleration (PGA) with return period of 50 and 100 years in this region was estimated using probabilistic seismic hazard carried out by (Pailoplee, Sugiyama, and Charusiri, 2009). From the study the PGA points with spacing 1/4^{o} were estimated. These points falling into 30 km buffering around each dam site are adopted for interpolation to obtain PGA at the site. The PGA of two different return periods at each dam site is shown in Table 2. The seismic effect is expressed in term of gravity which seems to be very high because only 10% occurrence probability is considered.

The dam site with **less seismic effect** should be considered to take less risk and gain comparatively **higher preference or score**.

Table 2 PGA with return period of 50 and 100 years at each dam site.

	S1	S2	S3	S4	S5
PGA10y100	1/212091	1/26115	1/25641	1/2675	1/23249
PGA10y50	0.4083	0.4035	0.40256	0.4035	0.3995

Please compare the importance (or preference) of each pair of dams based on seismic effect.

Alternative	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(2) Foundation geology

Foundation of a dam site mainly influences to the cost of construction. Foundation of the dam site is evaluated based on geologic conditions which include rock types and structure. This information can be extracted from geologic maps and additional field investigation. The foundation, which is not sound, can require very big budget for ground preparation before dam construction.

Available information at each dam is described in following:

- S1 (Pakbeng) dam: the Channel bed geology is characterized by folded interlaminated argillaceous limestone, with intercalated very thin- to medium-bedded limestone to dolomitic limestone, moderate dipping, partly covered by gravel deposits in depression area. Clastic rocks, interbedding of sandstone, siltstone, and shale mapped as J1-2, appear at the left abutment (Figure 3).

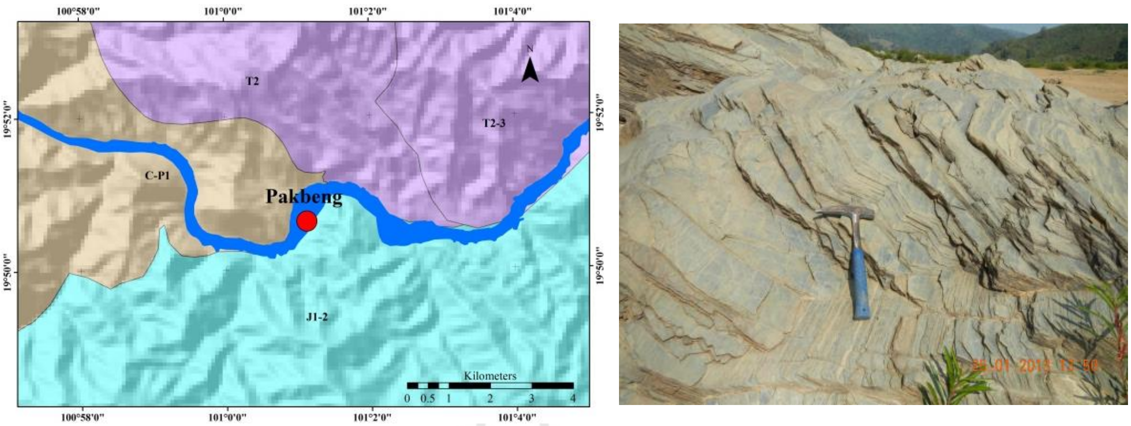

Figure 1 Geologic map and field photo at Pakbeng dam site.

- S2 (Luangprabang) dam: Channel bed geology is characterized by jointed volcanic rocks, andesitic agglomerate and tuff, flow structure with dip direction/angle: 50°/45°. Left and right abutments are thick-bedded to massive limestone of C-P1 unit as mapped (Figure 4).

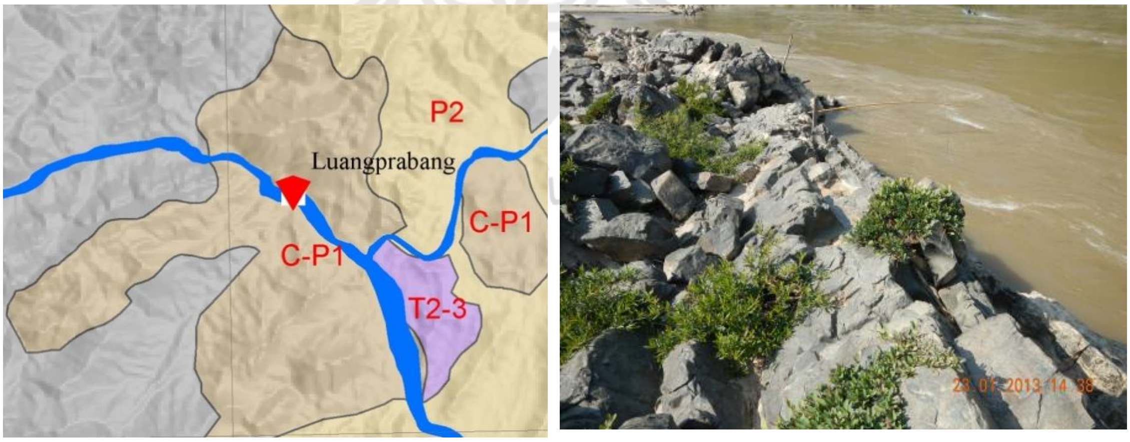

Figure 2 Geologic map and field photo at Luangprabang dam site.

- S3 (Xayabury) dam is a first site of 5 proposed dams under construction. The geology at the base of dam site is characterized by thin-bedded limestone, wavy folded and faulted. both abutments are limestone of unit Pnl as well (Figure 3).

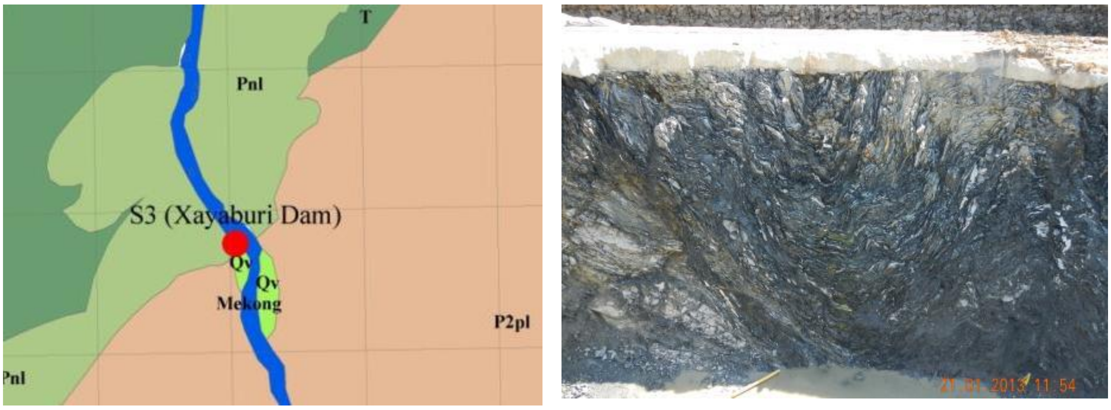

Figure 3 Geologic map and field photo at Xayaburi dam site.

- S4 (Paklai) dam is located in Phalat Formation (P2pl) which are composed of sandstone, siltstone, and slaty to phyllitic shale, brown to brownish-gray, micaceous, with plant fossils. Both abutments fall into P2pl as well. Right abutment could be interbedded clastic rocks while left abutment is more likely to be sandstone (Figure 4).

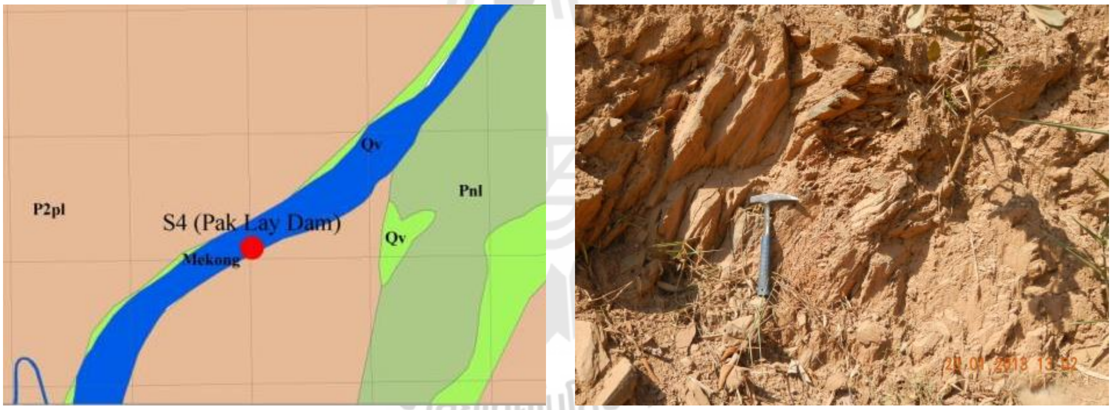

Figure 4 Geologic map and field photo at Pak lay dam site.

- S5 (Xanakham) dam is located upstream close to the border of Laos-Thailand in Phalat Formation (Figure 5). From the DEM data, the left abutment could be interbedded clastic rocks while the right abutment is more likely to be sandstone.

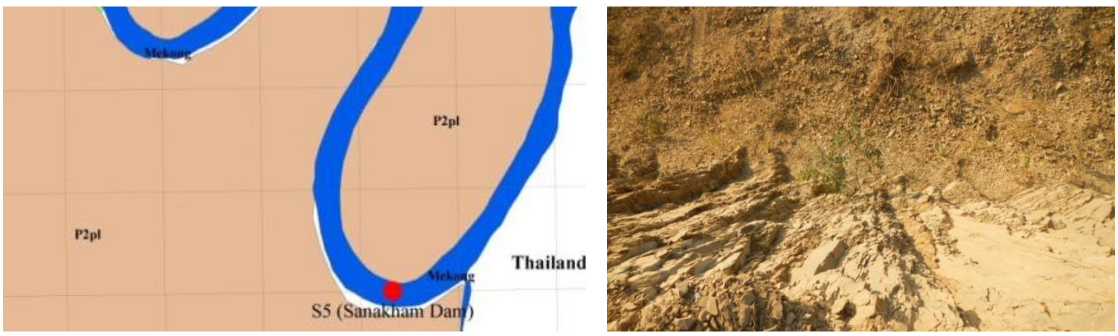

Figure 5 Geologic map at Xanakham dam site.

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on foundation geology.

The dam site with **sounder foundation geology** should be considered to be more stable and gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Alternative	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(3) Construction material availability

To save cost, the construction materials should be available nearby the dam site. The quarries and borrow pits are used to provide material included rock, sand and gravel for aggregates, and soils for lining. They all are for dam construction and complementary works. According to geologic map and field survey, the potential of construction material availability of each dam is described below:

- S1 (Pakbeng): limestone cliffs on top of hills next to dam site in the west and northwest direction could be potential quarries for construction material as shown in Figure 6.

Figure 6 Cliff limestone on top of hills in the west of dam site.

- S2 (Luangprabang): there is limestone hill being potential quarry site next to the north of dam site as shown in Figure 7.

Figure 7 Limestone hill next to north of dam site**.**

- S3 (Xayabury): the current limestone quarries are located about 1 km and 1.5 km to the southwest and the north of dam site as shown in Figure 8.

Figure 8 Available limestone quarry and the crushing mill located next to the southwest of dam site.

- S4 (Paklai): limestone hill that can be potential quarry of construction material appear about 2 km away in the east of the dam site as shown in Figure 9

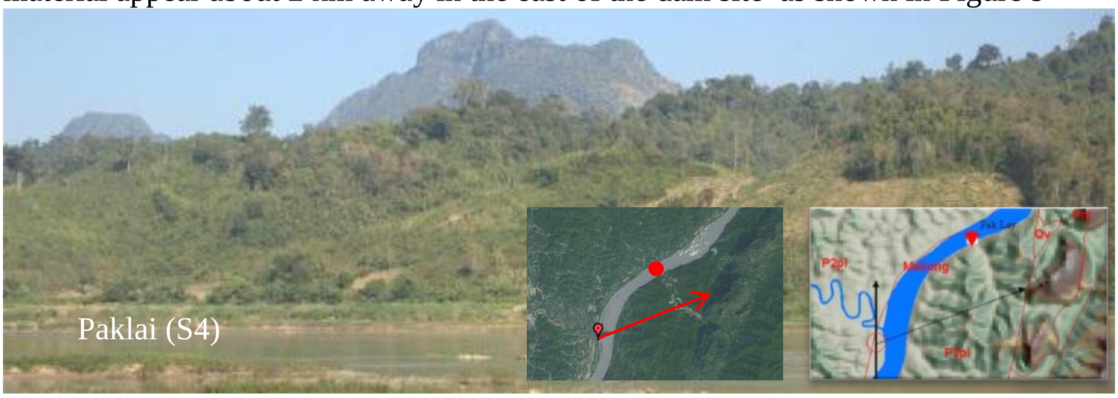

Figure 9 Limestone hill in the east of dam site (photo taken from Mekong River in direction about 60°).

- S5 (Xanakham): from geologic map it seems to have no limestone available in the vicinity. However, to the south of dam site resistant sandstone could be available (Figure 10).

Figure 10 Location of Xanakham dam site from a distance (look WSW along Mekong River).

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on availability of construction material.

The dam site having **construction material available nearby** the site should be considered to gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Alternative	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(4) Accessibility requirement

The connection from main road to dam site construction is most significant for materials and equipment transportation. The distance of accessible roads proposed to construct from the existing main road network to dam sites are listed in Table 3.

Table 3 The distance of accessible road from existing main road network to dam site.

	S1	S2	S3	S4	S5
Accessible roads (km)	16	15 and 1 bridge	25	62	44

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on accessibility from existing road network to the sites.

The dam site with **short distance** to main road network should be considered as a good accessibility and gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Alternative	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(5) Transmission lines

The approximate lengths of transmission lines from dam sites to the border of Laos and neighboring countries to be serviced are listed in Table 4.

Table 4 Lengths of transmission lines to serviced countries.

	S1	S2	S3	S4	S5
Transmission lines (km)	80	400	220	66	2
serviced countries	Thailand	Vietnam	Thailand	Thailand	Thailand

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on the lengths of transmission line.

The dam site with **short transmission line to the serviced country** should gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(6) Comparison of dam-related cost criteria

To be able to rank the importance of dams base on dam-related cost criteria, the comparison of all pairs of these criteria should performed as well. These criteria include seismic effect, foundation, construction material availability, accessibility requirement, and transmission line.

Please compare their importance in the form below:

dam-related cost criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6		7	8	9	dam-related cost criteria
Seismic effect																			Foundation
Seismic effect																			Construction material availability
Seismic effect																			Accessibility requirement
Seismic effect																			Transmission line
Foundation																			Construction material availability
Foundation																			Accessibility requirement
Foundation																			Transmission line
Construction material availability																			Accessibility requirement
Construction material availability																			Transmission line
Accessibility requirement																			Transmission line
Extreme importance									Equal										Extreme importance

3.2 Reservoir-related Cost criteria

(1) Settlement impact

Settlement impact can be assessed using a number of potentially inundated existing villages, households, schools, and monastery including cemetery. Unfortunately, only information of each dam on numbers of villages, households, and people to be inundated and impacted are reported by ICEM (2009) as shown in Table 5. The more inundated properties indicate the more adverse impact.

Table 5 Number of inundated villages and household and impacted people after dam construction.

	S1	S2	S3	S4	S5
Villages	28	36	10	16	10
households	774	2,516	391	643	800
people	6,700	12,966	2,130	6,129	4,000

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on settlement impact.

The reservoir with less inundated villages and household and impacted people should be considered to gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(2) Land instability index (LII)

LII directly affect a reservoir in terms of potential landslide and erosion in an area surrounding the reservoir. The product of landslide and erosion might cause dam break and increasing sediment load to shorten dam life. In this study the potential of landslide and erosion in regional scale were determined in form of LII of each reservoir. This can result from compilation of slope and rock types extracted from geologic maps including their coverage area surrounding a reservoir in which the product can occur and flow into. The LII of each reservoir is displayed in Table 6. The higher LII indicates more chance of adverse impact to the reservoir.

Table 6 LII of each reservoir

	S1	S2	S3	S4	S5
LII	1/27	0.85	1/26	0.42	1.00

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on LII.

The reservoir with less LII should be considered to gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(3) Inundated land use and land cover (LULC)

Inundated LULC can be assessed using the areas of inundated agricultural land and forest. The more inundated properties indicate the more adverse impact. The expectedly inundated areas of forest and agricultural land are reported by ICEM (2009) as shown in Table 7.

Table 7 Inundated LULC after dam construction.

Inundated LULC	S1	S2	S3	S4	S5
Reservoir (sq. km)	86.51	72.39	49	70	94
Agricultural land inundated (sq. km)	13.25	1.94	0.18	8.21	60
forest (sq. km)	4	41.81	1.62	21.80	14

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on inundated LULC.

The reservoir with less inundated agricultural land and forest should be considered to gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(4) Inundated mineral potentiality

Mineral potential is economic related criterion and can be lost in the inundated reservoir area. Related to the impact of mineral potential, the expectedly inundated types and areas are considered. This information is obtained from mineral potential map provided by the Department of Geology and Mines (DGM) as listed in Table 8.

Table 8 Expectedly inundated types and areas of mineral potential of each reservoir.

Potential area (km^2)	S1	S2	S3	S4	S5
Alluvial gold (Au)	39.50	0.6	0	0	0
Alluvial gold (Au) and chromite	1.60	5	0	0	0
Base metal sulfide	0	23.5	34.8	16	0
Alluvial gold (Au) and Cu-Zn in quartz vein	0	23.1	26.7	0	0
Gold in quartz vein and alluvial deposits	0	0	0	0	74.5
Totally inundated mineral potentiality Areas (km^2)	41.1	52.2	61.5	16	74.5

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on inundated mineral potential.

The reservoir with less inundated types and areas of mineral potential should be considered to gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(5) Inundated historic and archeological sites

Historic and archeological sites are a criterion influence on social impact. Their inundation in the reservoir affects directly to traditional culture. This information is obtained from the Ministry of Information and Culture. The more inundated historic and archeological sites indicate more adversely impact.

Table 9 Inundated historic and archeological site.

Inundated historic and archeological	S1	S2	S3	S4	S5
Temple	3	3	4	1	3
Cemeteries	0	0	1	0	0
Archeology site	NA	NA	NA	NA	NA

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on inundated historic and archeological sites.

The reservoir with less inundated historic and archeological sites should be considered to gain comparatively **higher preference or score**.

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(6) Comparison of reservoir-related criteria

To be able to rank the importance of dams base on **reservoir-related cost criteria**, the comparison of all pairs of these criteria should performed as well. These criteria include settlement impact, landslide potential, inundated potential mineral deposit, inundated LULC, and inundated historic and archeological sites.

Please compare their importance in the form below:

reservoir-related cost criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	reservoir-related cost criteria
Settlement impact																		Land instability index
Settlement impact																		Inundated mineral potentiality
Settlement impact																		Inundated LULC
Settlement impact																		Inundated historic and archeological
Land instability index																		Inundated mineral potentiality
Land instability index																		Inundated LULC
Land instability index																		Inundated historic and archeological
inundated mineral potentiality																		Inundated LULC
inundated mineral potentiality																		Inundated historic and archeological
Inundated LULC																		Inundated historic and archeological
Extreme importance								Equal			Extreme importance							

3.3 Comparison of dam-related cost and reservoir-related cost

Considering the importance of dams, the weights of dam-related and reservoir-related cost criteria can be equal or different. This can affect to weight-score of subsequent criteria in the next level.

Please compare their importance in the form below:

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
dam-related																		**reservoir-related**
Extreme importance									Equal									Extreme importance

3.4 Comparison of dam sites based on benefit criteria

(1) Power generation

Most of dams are constructed for power generation proposed. 90% of the power will be exported to Thailand. Only the one generated by the Luangprabang dam is exported to Vietnam. Each dam has different install capacity shown in Table 10.

Table 10 Installing capacity of power generation of each dam.

	S1	S2	S3	S4	S5
Power generation	1230 MW	1410 MW	1260 MW	1320 MW	700 MW

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on power generation.

The reservoir with height capacity of power generation should be considered to gain comparatively **higher preference or score.**

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(2) Tourism attraction

In this study tourist attraction is one of decision criteria for dam site evaluation. Once constructed, a dam is a by-product tourist attraction. To be more attractive, an alternative dam site should be near to the other tourist attraction sites.

Other tourist attractions within 30 km surrounding a dam are listed in Table 11. This distance should be suitable to be back and forth in a day.

Table 11 Number of tourist attraction site within 30 km from dam site.

Tourists attraction	S1	S2	S3	S4	S5
Natural site	3	5	6	7	2
History and Cultural site	4	40	4	3	5
Totally tourist site	7	45	10	10	7

According to information mentioned above, please compare the importance (or preference) of each pair of dams based on tourism attraction.

The region of dams having more and nearby tourist attraction sites should be considered to gain comparatively **higher preference or score.**

Please compare their importance in the form below:

Dams	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dams
S1																		S2
S1																		S3
S1																		S4
S1																		S5
S2																		S3
S2																		S4
S2																		S5
S3																		S4
S3																		S5
S4																		S5
Extreme importance									Equal									Extreme importance

(3) Comparison of power generation and tourist attraction

To be able to rank the importance of dams based on benefit criteria, the comparison of all pairs of power generation and tourist attraction criteria should be performed in the form below as well.

Please compare their importance in the form below:

Power generation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Tourist attraction
Extreme importance									Equal									Extreme importance

3.5 Comparison of cost and benefit

Generally, each dam has its own characteristics, which results in the difference of benefits and impacts. The benefits include hydropower and water resource productivity, flood and drought control system, etc. while the impacts can be environmental, social, and economic. Ranking of dams and reservoirs based on their benefits and impacts should be carried out before the priority of dam construction is determined.

Considering the importance of dams, the weights of cost and benefit criteria can be equal or different. This can affect to weight-score of subsequent criteria in the next level**.**

Please compare their importance in the form below:

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cost																		Benefit
Extreme importance									Equal									Extreme importance

Part IV: Additional comments

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APPENDIX C

SURVEYED EXPERTS' OPINIONS

Experts	1	2	3	4	5	6	7	8	9	10	11	12	13	
Cost	4	1/3	7	1/4	1/5	1/5	1/4	1	1	1/5	1	1/9	1/3	Benefit
Dam related	3	3	4	4	1/2	1/3	3	1/3	1	4	1	5	4	Reservoir related
Seismic effect (SE)														
S1	5	1/3	2	1/2	1/4	3	1/4	1/2	1/3	1/5	1/7	1/3	6	S2
S1	1/4	1/5	2	1/2	1/6	1	1/4	1/2	1/4	1/5	1/6	1/4	5	S3
S1	1	1/5	2	1/2	1/7	1	1/4	1/2	1/3	1/4	1/6	1/4	6	S4
S1	1	1/7	2	1/3	1/9	3	1/4	1/2	1/5	1/7	1/5	1/5	3	S5
S2	1/3	1/3	1	1/2	1/3	1	1/3	1	1/2	1/3	1/3	1/3	2	S3
S2	1	2	1	1	1/5	1	1/3	1	1	1	1/6	1/3	1	S4
S2	1/2	1/6	2	1/2	1/7	2	1/3	1/2	1/3	1/3	1/5	1/4	2	S5
S3	3	2	1	1/2	1/3	1	3	1	2	4	1/6	3	2	S4
S3	4	1/4	2	1/2	1/5	3	1/2	1/2	1/2	1/5	1/5	1/4	3	S5
S4	1		2	1/2	1/4	3	1/2	1/2	1/3	1/5	1/5	1/4	4	S5
Foundation geology (FG)														
S1	3	2	1/2	1/5	1/4	5	1/3	1/2	5	1	1/6	1/4	5	S2
S1	2	3	1	4	1/2	3	1/4	2	2	1	1/7	1/5	6	S3
S1	3	7	1	5	1/6	1/6	3	3	3	6	1/6	1/5	1/4	S4
S1	2	7	1	5	1/7	4	3	1/3	4	5	1/7	1/8	1/2	S5
S2	1	3	2	5	1/4	1/5	1/4	3	1/2	1	1/7	1/3	2	S3
S2	2	5	2	8	1/6	4	3	4	1/2	6	1/7	1/4	1/3	S4
S2	1	5	2	8	1/7	5	4	1/4	1/2	5	1/6	1/4	1/4	S5
S3	5	3	1	4	1/5	1/5	4	2	2	6	2	1	1/6	S4
S3	1	3	1	4	1/5	5	4	1/5	3	5	1/7	1	1/6	S5
S4	3	2	1	1	1/6	5	3	1/3	2	1	1/5	1	1/2	S5
Construction material availability (CMA)														
S1	1	1/3	2	1/6	2	1/5	1/3	1	1	1	1/4	1	1	S2
S1	1	1/7	3	1/6	4	5	1/4	2	2	1	1/7	5	2	S3
S1	1/2	2	4	1/3	4	5	1/3	2	3	1	1/6	6	4	S4
S1	1/3	1/5	5	7	7	3	3	5	6	1	1/8	9	6	S5
S2	1	1/4	2	1	3	5	1/4	2	2	1	1/8	5	4	S3
S2	2	3	3	4	5	5	3	2	3	1	1/6	6	5	S4
S2	1	1/2	4	8	6	5	3	5	5	1	1/6	9	6	S5
S3	1/3	7	2	4	5	5	4	2	2	1	1	4	2	S4
S3	1/2	2	3	8	6	3	4	5	5	1	1	7	3	S5
S4	2	1/4	2	6	3	3	3	5	4	1	1	5	4	S5
Accessibility requirement (AR)														
S1	1	1	1	1/6	6	3	1/3	3	2	1	1	2	2	S2
S1	1/2	4	1/2	1/6	5	3	1/3	4	3	3	1	5	3	S3
S1	1/4	9	1/2	1/3	5	5	3	5	5	6	1	9	6	S4
S1	1/3	7	1/2	7	3	5	1/3	4	4	5	1	8	5	S5
S2	1/2	4	1/2	1	1/5	1/3	1/3	1/3	2	3	1	4	5	S3
S2	1/4	9	1/2	4	1/3	1/4	3	3	4	6	1	9	7	S4
S2	1	7	1/2	8	1/4	1/4	3	1/2	3	5	1	8	6	S5
S3	1/2	7	1/2	4	4	5	3	4	2	4	1	8	7	S4
S3	1/3	3	1/2	8	3	3	3	3	2	4	2	7	6	S5
S4	1/3	1/5	1/2	6	2	3	3	1/5	1/2	1/3	1/2	1/2	1/5	S5

Transmission line (TL)														
S1	4	6	5	8	5	6	1/3	6	5	7	2	6	6	S2
S1	2	4	3	5	3	5	1/3	5	3	6	4	5	4	S3
S1	1	1/2	1/2	1/2	1	3	4	2	1/2	1/2	1/3	1/2	1/3	S4
S1	1/4	1/6	1/8	1/4	1/4	5	1/3	1/3	1/4	1/4	1/8	1/6	1/7	S5
S2	1/3	1/4	1/7	1/6	1/4	3	3	1/3	1/3	1/4	3	1/5	1/5	S3
S2	1/4	1/8	1/8	1/8	1/5	6	1/2	1/5	1/6	1/5	1/7	1/7	1/7	S4
S2	1/5	1/9	1/9	1/8	1/6	6	3	1/6	1/8	1/9	1/7	1/9	1/8	S5
S3	1/2	1/8	1/7	1/5	1/4	6	3	1/4	1/4	1/4	1/6	1/4	1/5	S4
S3	1/2	1/8	1/9	1/5	1/3	5	3	1/3	1/6	1/8	1/8	1/7	1/8	S5
S4	1/3	1/3	1/7	1/3	1/4	3	3	1/3	1/4	1/3	1/8	1/2	1/9	S5
dam-related cost criteria														
SE	4	2	1/5	3	6	1/5	1/4	1	1/5	5	1/7	1/9	1/4	FG
SE	3	3	1/5	7	9	1/5	3	1/3	2	5	1/5	1/8	1/4	CMA
SE	2	1/4	1/8	8	9	1/3	3	1/4	3	2	1/4	1/9	1/4	AR
SE	2	1/7	1/8	9	9	1/3	1/3	1/5	4	1/7	1/7	1/8	1/3	TL
FG	1	2	1/7	5	6	4	1/3	1/3	3	1/3	1/6	2	5	CMA
FG	1	1/4	1/6	8	8	5	3	1/3	4	1/4	1/6	2	5	AR
FG	2	1/8	1/6	9	6	5	3	1/5	5	1/8	1/5	7	5	TL
CMA	3	1/6	7	4	4	3	4	2	4	1/8	1/3	1	3	CMA
CMA	3	1/8	6	6	5	1	4	1/5	4	1/8	1/2	6	3	AR
AR	3	1/5	6	3	3	1	3	1	3	1/5	1	4	3	TL
Settlement impact (SI)														
S1	1/2	7	5	7	1/4	4	1/3	2	3	5	5	6	1/6	S2
S1	2	1/7	1/7	1/5	7	1	1/4	1/2	1/7	1/7	6	5	4	S3
S1	2	1/2	1	1	5	2	3	1	1/5	1/5	1	2	2	S4
S1	2	1/3	1/3	1/3	7	3	3	1/2	1/6	1/6	1/2	3	5	S5
S2	3	1/8	1/9	1/9	9	1/3	1/4	1/4	1/5	1/8	7	1/7	5	S3
S2	2	1/5	1/6	1/7	4	3	3	1/4	1/3	1/4	5	1/5	4	S4
S2	2	1/4	1/5	1/8	6	3	4	1/4	1/4	1/7	4	1/6	6	S5
S3	1/2	3	5	6	1/6	1/3	4	3	3	4	4	1/2	4	S4
S3	1	2	4	3	1/4	1/3	4	2	2	2	3	1/2	1/3	S5
S4	2	1/2	1/2	1/3	1/2	3	3	1/3	1/2	1/5	2	2	1/3	S5
Land instability index (LII)														
S1	1/3	5	3	6	3	1/2	3	3	3	5	1/4	1/3	1/5	S2
S1	1	1	1	1	1/5	1	1/3	1	1	1	1/2	1/8	2	S3
S1	2	1/3	1/2	1/3	1/7	2	1/4	1/2	1/2	1/3	1/4	1/5	4	S4
S1	1/4	7	7	7	5	1/3	3	3	4	5	1/3	4	1/8	S5
S2	2	1/4	1/3	1/6	1/4	2	1/4	1/3	1/4	1/3	1/2	1/4	6	S3
S2	3	1/6	1/5	1/8	1/6	2	1/3	1/4	1/4	1/4	1/5	1/3	7	S4
S2	1/2	3	8	4	3	1	3	2	2	1/2	1/3	6	1/6	S5
S3	2	1/2	1/2	1/3	1/3	2	4	1/2	1/2	1/2	1/5	4	3	S4
S3	1/3	7	6	7	4	1/3	4	4	4	4	1/6	9	1/7	S5
S4	1/4	8	6	8	7	1/2	4	5	5	4	1/8	4	1/8	S5
Inundated potential mineral deposit (IPM)														
S1	4	2	3	4	4	1/5	3	2	2	1	1	1/7	3	S2
S1	4	3	4	6	5	1/3	1/3	3	5	1	1/4	1/6	4	S3
S1	3	1/5	1/5	1/6	1/4	5	1/3	1/4	1/2	1	1/4	1/9	1/6	S4
S1	2	5	5	7	7	1/3	3	5	3	1	1	1/8	1	S5
S2	1/2	2	1/3	3	3	1/2	1/3	2	3	1	1/3	5	2	S3
S2	3	1/6	1/7	1/5	1/6	2	1/3	1/4	1/6	1	1/4	1/4	1/4	S4
S2	2	4	2	4	5	1/2	3	2	2	1	1/4	1/2	1	S5
S3	2	1/7	1/7	1/7	1/7	4	3	1/4	1/5	1	1/4	1/6	5	S4
S3	2	2	2	2	2	1	3	1/3	2	1	1/3	1/5	1/2	S5
S4	1/2	8	7	9	7	1/5	3	5	3	1	1/4	2	4	S5

Inundated LU/LC (LULC)														
S1	1/2	8	9	6	1/3	1/3	2	3	1/3	1/4	1/2	1/3	1/5	S2
S1	1/3	1/2	1/2	1/5	1/6	2	1/2	1/4	1/4	1/7	1/3	1/8	1/7	S3
S1	3	5	4	6	1/4	1/5	1/3	4	1/2	1/3	1/3	1/5	4	S4
S1	2	3	3	6	1/2	1/5	2	5	2	4	1/6	4	6	S5
S2	1/3	1/9	1/9	1/9	1/6	3	1/3	1/5	1/2	1/4	1/3	1/5	1/6	S3
S2	2	1/4	1/6	1	1/4	2	1/2	1/3	2	2	1	1/4	1/5	S4
S2	3	1/5	1/4	1	1/3	3	2	5	4	6	1/3	6	4	S5
S3	2	6	7	9	4	1/3	3	3	3	6	1/4	3	7	S4
S3	3	4	4	9	6	1/3	3	5	5	6	1/7	9	4	S5
S4	3	1/3	1/4	1	4	3	3	2	3	4	1/5	5	3	S5
Inundated historic and archeological sites (IHA)														
S1	1	1	1	1	4	1	3	1	1	1	1	1	1	S2
S1	1	2	3	6	5	1/2	1/3	2	3	1	1/4	7	2	S3
S1	2	1/3	1/5	1/8	1/3	2	1/3	1/2	1/3	1	1/4	1/3	1/4	S4
S1	1	1	1	1	7	1	3	1	1	1	1	1	1	S5
S2	1	2	3	6	3	1/2	1/3	2	3	1	1/3	7	2	S3
S2	2	1/3	1/5	1/8	1/6	2	1/3	1/2	1/3	1	1/4	1/3	1/4	S4
S2	1	1	1	1	4	1	1/3	2	1	1	1/4	1	1	S5
S3	2	1/5	1/6	1/9	1/7	5	2	3	1/5	1	1/4	1/9	5	S4
S3	1	1/2	1/3	1/6	2	2	2	1/2	1/3	1	1/3	1/6	1/2	S5
S4	1	3	4	8	6	1/2	1/3	3	3	1	1/4	7	4	S5
reservoir-related cost criteria														
SI	2	3	1	8	1/5	1/3	1/3	1	2	1	1/3	1/5	1/3	LII
SI	1/2	2	1	6	4	3	3	1	3	1	1/2	1/4	1/4	IPM
SI	1/2	4	1	4	3	1/3	3	1	2	1/6	1	3	1/4	LULC
SI	1/3	5	1	4	6	1/3	3	1	3	1/6	1/2	5	1/4	IHA
LII	1/3	1/2	1	1/3	4	5	3	1	2	5	1/2	5	3	IPM
LII	1/2	3	1	1/3	7	5	3	1	1	1/3	1/2	7	3	LULC
LII	1/3	3	1	1/6	6	3	3	1	2	1/3	1/2	8	3	IHA
IPM	2	3	1	1/4	1/4	1/5	1/3	1	1/2	1/7	1/2	5	2	LULC
IPM	2	4	1	1/4	1/6	1/3	1/3	1	1	1/7	1/2	6	2	IHA
LULC	1	2	1	1	4	3	3	1	2	4	1/2	2	1/2	IHA
Power generation (PG)														
S1	1/2	1/4	1/3	1/5	1/5	1/3	1/3	1/3	1/3	1/2	1/2	1/7	1/3	S2
S1	1/2	1	1	1	1/5	1	1/3	1	2	1	1	1	1/2	S3
S1	1/3	1/3	1/2	1/3	1/4	1/3	1/3	1/2	2	1/2	1	1/4	1/4	S4
S1	3	6	4	7	1/2	2	3	5	3	4	1/3	4	5	S5
S2	3	4	4	4	5	2	3	3	3	2	1/5	6	1/3	S3
S2	4	3	2	3	4	3	3	1/2	2	2	1/6	4	2	S4
S2	4	7	5	9	8	3	3	5	4	4	1/8	9	2	S5
S3	1/2	1/2	1/2	1/3	1/3	1/2	3	1/2	1/2	1/2	1/2	1/4	2	S4
S3	3	6	4	7	5	3	1/3	4	2	1/2	1/3	7	5	S5
S4	3	7	5	8	6	3	1/3	4	3	3	1/4	8	5	S5
Tourist attraction (TA)														
S1	1	1/5	1/7	1/8	1/5	1/5	1/4	1/5	1/5	1/7	1/8	1/7	1/9	S2
S1	1	1/3	1/2	1/3	1/5	1/2	1/3	1/2	1/3	1/4	1/3	1/5	1/4	S3
S1	1	1/3	1/2	1/3	1/4	1/2	1/3	1/2	1/3	1/4	1	1/5	1/4	S4
S1	1	1	1	1	1/2	1	3	1	1	1/2	1	1	1	S5
S2	1	4	7	7	5	5	4	5	6	6	1/5	7	5	S3
S2	1	4	7	7	3	4	4	5	6	6	1/5	7	5	S4
S2	1	5	8	8	7	5	4	5	5	2	1/8	8	6	S5
S3	1	1	1	1	1/3	1	4	1	2	1	1	1	1	S4
S3	1	2	1	3	4	2	4	2	2	2	1/3	7	3	S5
S4	1	2	4	3	5	2	3	2	2	1	1	4	3	S5
Benefit criteria														
PG	3	1/3	7	3	5	1/3	3	3	7	1/5	1	9	1/3	TA

APPENDIX D

FUZZY PAIRWISE ANALYSIS FROM EXPERTS' OPINIONS

This appendix provides information of experts' opinions on fuzzy pairwise comparison of criteria in all levels including their consistency ratio analysis. The opinions with CR < 0.1 are considered valid and further used for their aggregation and fuzzy weight analysis.

D1.1 Frist expert:

D1.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.1707, CI=0.0427, RI=1.12, CR = 0.038					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)
S2	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)
S3	(3,4,5)	(2,3,4)	(1,1,1)	(2,3,4)	(3,4,5)
S4	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)
Foundation Geology (FG) n =5, λ_{max}=5.40, CI=0.1, RI=1.12, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1,2,3)	(2,3,4)	(1,2,3)
S2	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)
S3	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1/3,1/2)	(1,1,1)
S4	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)
Construction material availability (CMA) n =5 λ_{max}=5.44, CI=1/9, RI=1.12, CR = 0.10					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
S4	(1,2,3)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(1,2,3)
S5	(2,3,4)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.22, CI=0.06, RI=1.12, CR = 0.05					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S2	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1,1,1)
S3	(1,2,3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)
S4	(3,4,5)	(3,4,5)	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)
S5	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)	(1,1,1)
Transmission lines (TL) n =5, λ_{max}=5.31, CI=0.08, RI=1.12, CR = 0.07					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(3,4,5)	(1,2,3)	(1,1,1)	(1/5,1/4,1/3)
S2	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/6,1/5,1/4)
S3	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
S4	(1,1,1)	(3,4,5)	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)
S5	(3,4,5)	(4,5,6)	(1,2,3)	(2,3,4)	(1,1,1)
Comparison of dam-related cost criteria n =5, λ_{max}=5.22, CI=0.06, RI=1.12, CR = 0.05					
	SE	FG	CMA	AR	TL
SE	(1,1,1)	(3,4,5)	(2,3,4)	(1,2,3)	(1,2,3)
FG	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
CMA	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(2,3,4)	(2,3,4)
AR	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
TL	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/41/3,1/2)	(1,1,1)

D-1.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.14, CI=0.06, RI=1.12, CR = 0.03					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1,2,3)	(2,3,4)	(1,2,3)
S2	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)
S3	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1/3,1/2)	(1,1,1)
S4	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)
Land instability index (LII) n =5, λ_{max}=5.08, CI=0.02, RI=1.12, CR = 0.02					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(1/3,1/4,1/3)
S2	(2,3,4)	(1,1,1)	(1,2,3)	(2,3,4)	(1/3,1/2,1)
S3	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)
S4	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/5,1/4,1/3)
S5	(3,4,5)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)
Land use, land cover (LULC) n =5, λ_{max}=5.42, CI=0.02, RI=1/9, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(2,3,4)	(1,2,3)
S2	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(2,3,4)
S3	(2,3,4)	(2,3,4)	(1,1,1)	(1,2,3)	(2,3,4)
S4	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(2,3,4)
S5	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Inundated mineral potentiality (IMP) n =5, λ_{max}=5.39, CI=0.1, RI=1.12, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(3,4,5)	(3,4,5)	(2,3,4)	(1,2,3)
S2	(1/5,1/4,1/3)	(1,1,1)	(1/3,1/2,1)	(2,3,4)	(1,2,3)
S3	(1/5,1/4,1/3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)
S4	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
S5	(1/3,1/2,1)	(1/3,1/2,1,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=5.06, CI=0.01, RI=1.12, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)
S4	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Comparison of reservoir-related criteria n =5, λ_{max}=5.15, CI=0.04, RI=1.12, CR = 0.05					
	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(3,4,5)	(2,3,4)	(1,2,3)	(1,2,3)
LII	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
IMP	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(2,3,4)	(2,3,4)
LULC	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
IHA	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/41/3,1/2)	(1,1,1)

D-1.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(2,3,4)
reservoir-related	(1/4,1/3,1/2)	(1,1,1)

D-1.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.39, CI=0.1, RI=1.12, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1/2)	(1/4,1/3,1/2)	(2,3,4)
S2	(1,2,3)	(1,1,1)	(2,3,4)	(3,4,5)	(3,4,5)
S3	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(2,3,4)
S4	(2,3,4)	(1/5,1/4,1/3)	(1,2,3)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Tourism attraction n =5, λ_{max}=5, CI=0.1, RI=1.12, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

Comparison of power generation and tourist attraction		
	Power generation	Tourism attraction
Power generation	(1,1,1)	(2,3,4)
Tourism attraction	(1/4,1/3,1/2)	(1,1,1)

D-1.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(2,3,4)
Benefit	(1/4,1/3,1/2)	(1,1,1)

D-2 Second expert:

D-2.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.357, CI=0.089, RI=1.12, CR = 0.0798

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/8,1/7,1/6)
S2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(1/7,1/6,1/5)
S3	(4,5,6)	(2,3,4)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)
S4	(4,5,6)	(1/3,1/2,1)	(1/3,1/2,1.00)	(1,1,1)	(1,1,1)
S5	(6,7,8)	(6,7,8)	(3,4,5)	(1,1,1)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=5.4, CI=0.1, RI=1.12, CR = 0.09

	S1	S2	S3	S4	S5
S1	(1,1,1)	1,2,3	(2,3,4)	(6,7,8)	(6,7,8)
S2	(1/3,1/2,1)	1,1,1	(2,3,4)	(4,5,6)	(4,5,6)
S3	(1/4,1/3,1/2)	1/4,1/3,1/2	(1,1,1)	(2,3,4)	(2,3,4)
S4	(1/8,1/7,1/6)	1/6,1/5,1/4	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)
S5	(1/8,1/7,1/6)	1/6,1/5,1/4	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.11, CI=1/9, RI=0.028, CR = 0.0246

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,2,3)	1/6,1/5,1/4
S2	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(1/3,1/2,1)
S3	(6,7,8)	(3,4,5)	(1,1,1)	(6,7,8)	(1,2,3)
S4	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,1,1)	(1/5,1/4,1/3)
S5	(4,5,6)	(1,2,3)	(1/3,1/2,1)	(3,4,5)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.22, CI=0.06, RI=1.12, CR = 0.05

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(3,4,5)	(9,9,9)	(6,7,8)
S2	(1,1,1)	(1,1,1)	(3,4,5)	(9,9,9)	(6,7,8)
S3	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(6,7,8)	(2,3,4)
S4	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/8,1/7,1/6)	(1,1,1)	(1/6,1/5,1/4)
S5	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}= 5.4068, CI=0.102, RI=1.12, CR = 0.0908

	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(3,4,5)	(1/3,1/2,1)	(1/7,1/6,1/5)
S2	(1/7,1/6,1/5)	(1,1,1)	(1/5,1/4,1/3)	(1/9,1/8,1/7)	(1/9,1/9,1/9)
S3	(1/5,1/4,1/3)	(3,4,5)	(1,1,1)	(1/9,1/8,1/7)	(1/9,1/8,1/7)
S4	(1,2,3)	(7,8,9)	(7,8,9)	(1,1,1)	(1/4,1/3,1/2)
S5	(5,6,7)	(9,9,9)	(7,8,9)	(2,3,4)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.27, CI=0.068, RI=1.12, CR = 0.0603

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1,2,3)	(2,3,4)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
FG	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1/9,1/8,1/7)
CMA	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/7,1/6,1/5)	(1/9,1/8,1/7)
AR	(3,4,5)	(3,4,5)	(5,6,7)	(1,1,1)	(1/6,1/5,1/4)
TL	(6,7,8)	(7,8,9)	(7,8,9)	(4,5,6)	(1,1,1)

D-2.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.364, CI=0.091, RI=1.12, CR = 0.0813

	S1	S2	S3	S4	S5
S1	(1,1,1)	(6,7,8)	(1/8,1/7,1/6)	(1/3,1/2,1)	(1/4,1/3,1/2)
S2	(1/8,1/7,1/6)	(1,1,1)	(1/9,1/8,1/7)	(1/6,1/5,1/4)	(1/5,1/4,1/3)
S3	(6,7,8)	(7,8,9)	(1,1,1)	(2,3,4)	(1,2,3)
S4	(1,2,3)	(4,5,6)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)
S5	(2,3,4)	(3,4,5)	(1/3,1/2,1)	(1,2,3)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=5.159, CI=0.04, RI=1.12, CR = 0.0356

	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(1,1,1)	(1/4,1/3,1/2)	(6,7,8)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(2,3,4)
S3	(1,1,1)	(3,4,5)	(1,1,1)	(1/3,1/2,1)	(6,7,8)
S4	(2,3,4)	(5,6,7)	(1,2,3)	(1,1,1)	(7,8,9)
S5	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.214, CI=0.053, RI=1/9, CR = 0.0471

	S1	S2	S3	S4	S5
S1	(1,1,1)	(7,8,9)	(1/3,1/2,1)	(4,5,6)	(2,3,4)
S2	(1/9,1/8,1/7)	(1,1,1)	(1/9,1/9,1/9)	(1/5,1/4,1/3)	(1/6,1/5,1/4)
S3	(1,2,3)	(9,9,9)	(1,1,1)	(5,6,7)	(3,4,5)
S4	(1/6,1/5,1/4)	(3,4,5)	(1/7,1/6,1/5)	(1,1,1)	(1/4,1/3,1/2)
S5	(1/4,1/3,1/2)	(4,5,6)	(1/5,1/4,1/3)	(2,3,4)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=5.1759, CI=0.044, RI=1.12, CR = 0.0392

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(2,3,4)	(1/6,1/5,1/4)	(4,5,6)
S2	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/7,1/6,1/5)	(3,4,5)
S3	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/8,1/7,1/6)	(1,2,3)
S4	(4,5,6)	(5,6,7)	(6,7,8)	(1,1,1)	(7,8,9)
S5	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/9,1/8,1/7)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=5.004, CI=0.001, RI=1.12, CR = 0.0008

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)
S3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)
S4	(2,3,4)	(2,3,4)	(4,5,6)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5.1206, CI=0.03, RI=1.12, CR = 0.0269

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(2,3,4)	(1,2,3)	(3,4,5)	(4,5,6)
LII	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(2,3,4)	(2,3,4)
IMP	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(2,3,4)	(3,4,5)
LULC	(1/5,1/4,1/3)	(1,1/3,3)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)
IHA	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)

D-2.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(2,3,4)
reservoir-related	(1/4,1/3,1/2)	(1,1,1)

D-2.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.2658, CI=0.0664, RI=1.12, CR = 0.0593					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(5,6,7)
S2	(3,4,5)	(1,1,1)	(3,4,5)	(2,3,4)	(6,7,8)
S3	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)	(1/3,1/2,1)	(5,6,7)
S4	(2,3,4)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(6,7,8)
S5	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(1,1,1)
Tourism attraction n =5, λ_{max}=5, CI=0.1, RI=1.12, CR = 0.09					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
S2	(4,5,6)	(1,1,1)	(3,4,5)	(3,4,5)	(4,5,6)
S3	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,2,3)
S4	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,2,3)
S5	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(2,3,4)
Tourism attraction	(1/4,1/3,1/2)	(1,1,1)

D-2.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/4,1/3,1/2)
Benefit	(2,3,4)	(1,1,1)

D-3 Third expert:

D-3.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.0586, CI=0.0147, RI=1.12, CR = 0.0131					
	S1	S2	S3	S4	S5
S1	(1,1,1))	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)
S2	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
S3	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
S4	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
S5	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)
Foundation Geology (FG) n =5, λ_{max}=5, CI=0.0000, RI=1.12, CR = 0.000					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)
S3	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,1,1)
Construction material availability (CMA) n =5 λ_{max}=5.0681, CI=0.017, RI=1.12, CR = 0.152					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)
S2	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)
S3	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(2,3,4)
S4	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)
S5	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)
Accessibility requirement (AR) n =5, λ_{max}=5.1364, CI=0.0341, RI=1.12, CR = 0.0304					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)
S2	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)
S3	(1,2,3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
S4	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)
S5	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)
Transmission lines (TL) n =5, λ_{max}=5.4324, CI=0.1081, RI=1.12, CR = 0.0965					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(2,3,4)	(1/3,1/2,1)	(1/9,1/8,1/7)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1/9,1/9,1/9)
S3	(1/4,1/3,1/2)	(6,7,8)	(1,1,1)	(1/8,1/7,1/6)	(1/9,1/9,1/9)
S4	(1,2,3)	(7,8,9)	(6,7,8)	(1,1,1)	(1/8,1/7,1/6)
S5	(7,8,9)	(9,9,9)	(9,9,9)	(6,7,8)	(1,1,1)
Comparison of dam-related cost criteria n =5, λ_{max}=5.393, CI=0.0982, RI=1.12, CR = 0.0877					
	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(1/9,1/8,1/7)
FG	(4,5,6)	(1,1,1)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/7,1/6,1/5)
CMA	(4,5,6)	(6,7,8)	(1,1,1)	(6,7,8)	(5,6,7)
AR	(7,8,9)	(5,6,7)	(1/8,1/7,1/6)	(1,1,1)	(5,6,7)
TL	(7,8,9)	(5,6,7)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1,1,1)

D-3.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.2771, CI=0.0693, RI=1.12, CR = 0.0619

	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/9,1/9,1/9)	(1/7,1/6,1/5)	(1/6,1/5,1/4)
S3	(6,7,8)	(9,9,9)	(1,1,1)	(4,5,6)	(3,4,5)
S4	(1,1,1)	(5,6,7)	(1/6,1/5,1/4)	(1,1,1)	(1/3,1/2,1)
S5	(2,3,4)	(4,5,6)	(1/5,1/4,1/3)	(1,2,3)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=5.2771, CI=0.0897, RI=1.12, CR = 0.0801

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(6,7,8)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(7,8,9)
S3	(1,1,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(5,6,7)
S4	(1,2,3)	(4,5,6)	(1,2,3)	(1,1,1)	(5,6,7)
S5	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.4046, CI=0.1012, RI=1/9, CR = 0.0903

	S1	S2	S3	S4	S5
S1	(1,1,1)	(9,9,9)	(1/3,1/2,1)	(3,4,5)	(2,3,4)
S2	(1/9,1/9,1/9)	(1,1,1)	(1/9,1/9,1/9)	(1/7,1/6,1/5)	(1/5,1/4,1/3)
S3	(1,2,3)	(9,9,9)	(1,1,1)	(6,7,8)	(3,4,5)
S4	(1/5,1/4,1/3)	(5,6,7)	(1/8,1/7,1/6)	(1,1,1)	(1/5,1/4,1/3)
S5	(1/4,1/3,1/2)	(3,4,5)	(1/5,1/4,1/3)	(3,4,5)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=5.3656, CI=0.0914, RI=1.12, CR = 0.0816

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(3,4,5)	(1/6,1/5,1/4)	(4,5,6)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,2,3)
S3	(1/5,1/4,1/3)	(2,3,4)	(1,1,1)	(1/8,1/7,1/6)	(1,2,3)
S4	(4,5,6)	(6,7,8)	(6,7,8)	(1,1,1)	(6,7,8)
S5	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1/8,1/7,1/6)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=5.0925, CI=0.0914, CR = 0.0816

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1/7,1/6,1/5)	(1/4,1/3,1/2)
S3	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/7,1/6,1/5)	(1/4,1/3,1/2)
S4	(4,5,6)	(4,5,6)	(5,6,7)	(1,1,1)	(3,4,5)
S5	(1,1,1)	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5, CI=0.000, RI=1.12, CR = 0.000

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
LII	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
IMP	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
LULC	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
IHA	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

D-3.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(3,4,5)
reservoir-related	(1/5,1/4,1/3)	(1,1,1)

D-3.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.2658, CI=0.0664, RI=1.12, CR = 0.0593					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S2	(2,3,4)	(1,1,1)	(3,4,5)	(1,2,3)	(4,5,6)
S3	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S4	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(4,5,6)
S5	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)
Tourism attraction n =5, λ_{max}=5.0932, CI=0.0233, RI=1.12, CR = 0.0208					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/8,1/7,1/6)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)
S2	(6,7,8)	(1,1,1)	(6,7,8)	(6,7,8)	(7,8,9)
S3	(1,2,3)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(1,2,3)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(3,4,5)
S5	(1,1,1)	(1/9,1/8,1/7)	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(6,7,8)
Tourism attraction	(1/8,1/7,1/6)	(1,1,1)

D-3.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(3,4,5)
Benefit	(1/5,1/4,1/3)	(1,1,1)

D-4 Fourth expert:

D-4.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.1693, CI=0.0423, RI=1.12, CR = 0.0378

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)
S2	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
S3	(1,2,3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
S4	(1,2,3)	(1,1,1)	(1,2,3)	(1,1,1)	(1/3,1/2,1)
S5	(2,3,4)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=5.3724, CI=0.0931, RI=1.12, CR = 0.0831

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(3,4,5)	(4,5,6)	(4,5,6)
S2	(4,5,6)	(1,1,1)	(4,5,6)	(7,8,9)	(7,8,9)
S3	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)	(3,4,5)
S4	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)
S5	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.4416, CI=0.1104, CR = 0.0986

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(6,7,8)
S2	(5,6,7)	(1,1,1)	(1,1,1)	(3,4,5)	(7,8,9)
S3	(5,6,7)	(1,1,1)	(1,1,1)	(3,4,5)	(7,8,9)
S4	(2,3,4)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(5,6,7)
S5	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1/9,1/8,1/7)	(1/7,1/6,1/5)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.4898, CI=0.06, RI=0.1225, CR = 0.1093

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(3,4,5)	(7,8,9)	(5,6,7)
S2	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(6,7,8)	(4,5,6)
S3	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)	(5,6,7)	(6,7,8)
S4	(1/9,1/8,1/7)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1,1,1)	(1/4,1/3,1/2)
S5	(1/7,1/6,1/5)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(2,3,4)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}=5.4146, CI=0.1037, RI=1.12, CR = 0.0925

	S1	S2	S3	S4	S5
S1	(1,1,1)	(7,8,9)	(4,5,6)	(1/3,1/2,1)	(1/5,1/4,1/3)
S2	(1/9,1/8,1/7)	(1,1,1)	(1/7,1/6,1/5)	(1/9,1/8,1/7)	(1/7,1/8,1/9)
S3	(1/6,1/5,1/4)	(5,6,7)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)
S4	(1,2,3)	(7,8,9)	(4,5,6)	(1,1,1)	(1/4,1/3,1/2)
S5	(3,4,5)	(9,8,7)	(4,5,6)	(2,3,4)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.479, CI=0.06, RI=1.1198, CR = 0.1069

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(2,3,4)	(6,7,8)	(7,8,9)	(9,9,9)
FG	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)	(7,8,9)	(9,9,9)
CMA	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)	(5,6,7)
AR	(1/9,1/8,1/7)	(1/9,1/8,1/7)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
TL	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1,1,1)

D-4.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.3163, CI=0.0791, RI=1.12, CR = 0.0706					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(6,7,8)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)
S2	(1/8,1/7,1/6)	(1,1,1)	(1/9,1/9,1/9)	(1/8,1/7,1/6)	(1/9,1/8,1/7)
S3	(4,5,6)	(9,9,9)	(1,1,1)	(5,6,7)	(2,3,4)
S4	(1,1,1)	(6,7,8)	(1/7,1/6,1/5)	(1,1,1)	(1/4,1/3,1/2)
S5	(2,3,4)	(7,8,9)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)
Land instability index (LII) n =5, λ_{max}=5.3404, CI=0.0851, RI=1.12, CR = 0.0760					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(1,1,1)	(1/4,1/3,1/2)	(6,7,8)
S2	(1/7,1/6,1/5)	(1,1,1)	(1/7,1/6,1/5)	(1/9,1/8,1/7)	(3,4,5)
S3	(1,1,1)	(5,6,7)	(1,1,1)	(1/4,1/3,1/2)	(6,7,8)
S4	(2,3,4)	(7,8,9)	(2,3,4)	(1,1,1)	(7,8,9)
S5	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1,1,1)
Land use, land cover (LULC) n =5, λ_{max}=5.1824, CI=0.0456, RI=1.12, CR = 0.0407					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(1/6,1/5,1/4)	(5,6,7)	(5,6,7)
S2	(1/7,1/6,1/5)	(1,1,1)	(1/9,1/9,1/9)	(1,1,1)	(1,1,1)
S3	(4,5,6)	(9,9,9)	(1,1,1)	(9,9,9)	(9,9,9)
S4	(1/7,1/6,1/5)	(1,1,1)	(1/9,1/9,1/9)	(1,1,1)	(1,1,1)
S5	(1/7,1/6,1/5)	(1,1,1)	(1/9,1/9,1/9)	(1,1,1)	(1,1,1)
Inundated mineral potentiality (IMP) n =5, λ_{max}=5.4481, CI=0.112, RI=1.12, CR = 0.1					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(3,4,5)	(5,6,7)	(1/7,1/6,1/5)	(6,7,8)
S2	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(3,4,5)
S3	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(1,2,3)
S4	(5,6,7)	(4,5,6)	(6,7,8)	(1,1,1)	(9,9,9)
S5	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/9,1/9,1/9)	(1,1,1)
Inundated historic and archeological (IHA) n =5, λ_{max}=5.366, CI=0.091, RI=1.12, CR = 0.081					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(5,6,7)	(1/9,1/8,1/7)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(5,6,7)	(1/9,1/8,1/7)	(1,1,1)
S3	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1,1,1)	(1/9,1/9,1/9)	(1/7,1/6,1/5)
S4	(7,8,9)	(7,8,9)	(9,9,9)	(1,1,1)	(7,8,9)
S5	(1,1,1)	(1,1,1)	(5,6,7)	(1/9,1/8,1/7)	(1,1,1)
Comparison of reservoir-related criteria n =5, λ_{max}=5.244, CI=0.061, RI=1.12, CR = 0.0545					
	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(7,8,9)	(5,6,7)	(3,4,5)	(3,4,5)
LII	(1/9,1/8,1/7)	(1,1,1)	(1/4,1/3,1/2)	(1/7,1/6,1/5)	(1/7,1/6,1/5)
IMP	(1/7,1/6,1/5)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
LULC	(1/5,1/4,1/3)	(2,3,4)	(3,4,5)	(1,1,1)	(1,1,1)
IHA	(1/5,1/4,1/3)	(5,6,7)	(3,4,5)	(1,1,1)	(1,1,1)

D-4.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(3,4,5)
reservoir-related	(1/5,1/4,1/3)	(1,1,1)

D-4.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.2658, CI=0.0664, RI=1.12, CR = 0.0593

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(6,7,8)
S2	(4,5,6)	(1,1,1)	(3,4,5)	(2,3,4)	(9,9,9)
S3	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(6,7,8)
S4	(2,3,4)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(7,8,9)
S5	(1/8,1/7,1/6)	(1/9,1/9,1/9)	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1,1,1)

Tourism attraction n =5, λ_{max}=5.0932, CI=0.0233, RI=1.12, CR = 0.0208

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/9,1/8,1/7)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
S2	(7,8,9)	(1,1,1)	(6,7,8)	(6,7,8)	(7,8,9)
S3	(2,3,4)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(2,3,4)
S4	(2,3,4)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1/9,1/8,1/7)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(2,3,4)
Tourism attraction	(1/4,1/3,1/2)	(1,1,1)

D-4.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/5,1/4,1/3)
Benefit	(3,4,5)	(1,1,1)

D-5 Fifth expert:

D-5.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.358, CI=0.089, RI=1.12, CR = 0.08

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/6,1/5)	(1/7,1/8,1/6)	(1/9,1/9,1/9)
S2	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/7,1/8,1/6)
S3	(5,6,7)	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)
S4	(6,7,8)	(4,5,6)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)
S5	(9,9,9)	(6,7,8)	(4,5,6)	(3,4,5)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=5.121, CI=0.03, RI=1.12, CR = 0.027

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/8,1/6,1/5)	(1/7,1/8,1/6)
S2	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/6,1/5)	(1/7,1/8,1/6)
S3	(1,2,3)	(3,4,5)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)
S4	(5,6,7)	(5,6,7)	(4,5,6)	(1,1,1)	(1/8,1/6,1/5)
S5	(6,7,8)	(6,7,8)	(4,5,6)	(5,6,7)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.403, CI=0.101, RI=1.12, CR = 0.09

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(3,4,5)	(3,4,5)	(6,7,8)
S2	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(4,5,6)	(5,6,7)
S3	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)	(5,6,7)
S4	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)
S5	(1/7,1/8,1/6)	(1/8,1/6,1/5)	(1/8,1/6,1/5)	(1/4,1/3,1/2)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.417, CI=0.104, RI=1.12, CR = 0.093

	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(4,5,6)	(4,5,6)	(2,3,4)
S2	(1/8,1/6,1/5)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)
S3	(1/6,1/5,1/4)	(4,5,6)	(1,1,1)	(3,4,5)	(2,3,4)
S4	(1/6,1/5,1/4)	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)	(1,2,3)
S5	(1/4,1/3,1/2)	(3,4,5)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}=5.427, CI=0.107, RI=1.12, CR = 0.095

	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/8,1/6,1/5)
S3	(1/4,1/3,1/2)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S4	(1,1,1)	(4,5,6)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)
S5	(3,4,5)	(5,6,7)	(2,3,4)	(3,4,5)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.79, CI=0.198, RI=1.12, CR = 0.176

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(5,6,97.0)0,(9,9,9)	(9,9,9)	(9,9,9)	
FG	(0.01,1/6,1/5)	(1,1,1)	(5,6,7)	(7,8,9)	(5,6,7)
CMA	(1/9,1/9,1/9)	(1/8,1/6,1/5)	(1,1,1)	(3,4,5)	(4,5,6)
AR	(1/9,1/9,1/9)	(1/9,1/7,1/8)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
TL	(1/9,1/9,1/9)	(1/8,1/6,1/5)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)

D-5.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.364, CI=0.091, RI=1.12, CR = 0.081

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(6,7,8)	(4,5,6)	(6,7,8)
S2	(3,4,5)	(1,1,1)	(9,9,9)	(3,4,5)	(5,6,7)
S3	(1/7,1/8,1/6)	(1/9,1/9,1/9)	(1,1,1)	(1/8,1/6,1/5)	(1/5,1/4,1/3)
S4	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(5,6,7)	(1,1,1)	(1/3,1/2,1)
S5	(1/7,1/8,1/6)	(1/8,1/6,1/5)	(3,4,5)	(1,2,3)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=5.16, CI=0.04, RI=1.12, CR = 0.036

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(1/7,1/8,1/6)	(4,5,6)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/6,1/5)	(2,3,4)
S3	(4,5,6)	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)	(3,4,5)
S4	(6,7,8)	(5,6,7)	(2,3,4)	(1,1,1)	(6,7,8)
S5	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/7,1/8,1/6)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.211, CI=0.053, RI=1.12, CR = 0.047

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/8,1/6,1/5)	(1/5,1/4,1/3)	(1/3,1/2,1)
S2	(2,3,4)	(1,1,1)	(1/8,1/6,1/5)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S3	(5,6,7)	(5,6,7)	(1,1,1)	(3,4,5)	(5,6,7)
S4	(3,4,5)	(3,4,5)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)
S5	(1,2,3)	(2,3,4)	(1/8,1/6,1/5)	(1/5,1/4,1/3)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=5.176, CI=0.044, RI=1.12, CR = 0.039

	S1	S2	S3	S4	S5
S1	(1,1,1)	(3,4,5)	(4,5,6)	(1/5,1/4,1/3)	(6,7,8)
S2	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)	(1/8,1/6,1/5)	(4,5,6)
S3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/7,1/8,1/6)	(1,2,3)
S4	(3,4,5)	(5,6,7)	(6,7,8)	(1,1,1)	(6,7,8)
S5	(1/7,1/8,1/6)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/7,1/8,1/6)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=5.004, CI=0.001, RI=1.12, CR = 0.001

	S1	S2	S3	S4	S5
S1	(1,1,1)	(3,4,5)	(4,5,6)	(1/4,1/3,1/2)	(6,7,8)
S2	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)	(1/8,1/6,1/5)	(3,4,5)
S3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/7,1/8,1/6)	(1,2,3)
S4	(2,3,4)	(5,6,7)	(6,7,8)	(1,1,1)	(5,6,7)
S5	(1/7,1/8,1/6)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/8,1/6,1/5)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5.121, CI=0.03, RI=1.12, CR = 0.027

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1/6,1/5,1/4)	(3,4,5)	(2,3,4)	(5,6,7)
LII	(4,5,6)	(1,1,1)	(3,4,5)	(6,7,8)	(5,6,7)
IMP	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/6,1/5)
LULC	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(3,4,5)	(1,1,1)	(3,4,5)
IHA	(1/8,1/6,1/5)	(1/8,1/6,1/5)	(5,6,7)	(1/5,1/4,1/3)	(1,1,1)

D-5.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(1/3,1/2,1)
reservoir-related	(1,2,3)	(1,1,1)

D-5.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.266, CI=0.066, RI=1.12, CR = 0.059

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/3,1/2,1)
S2	(4,5,6)	(1,1,1)	(4,5,6)	(3,4,5)	(7,8,9)
S3	(4,5,6)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(4,5,6)
S4	(3,4,5)	(1/5,1/4,1/3)	(2,3,4)	(1,1,1)	(5,6,7)
S5	(1,2,3)	(1/9,1/7,1/8)	(1/6,1/5,1/4)	(1/8,1/6,1/5)	(1,1,1)

Tourism attraction n =5, λ_{max}=5.093, CI=0.023, RI=1.12, CR = 0.021

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/3,1/2,1)
S2	(4,5,6)	(1,1,1)	(4,5,6)	(2,3,4)	(6,7,8)
S3	(4,5,6)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(3,4,5)
S4	(3,4,5)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(4,5,6)
S5	(1,2,3)	(1/7,1/8,1/6)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(4,5,6)
Tourism attraction	(1/6,1/5,1/4)	(1,1,1)

D-5.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/6,1/5,1/4)
Benefit	(4,5,16)	(1,1,1)

D-6 Sixth expert:

D-6.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.133, CI=0.033, RI=1.12, CR = 0.03					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1,1,1)	(1,1,1)	(2,3,4)
S2	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)
S4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Foundation Geology (FG) n =5, λ_{max}=8.441, CI=0.86, RI=1.12, CR = 0.767					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(2,3,4)	(1/7,1/6,1/5)	(3,4,5)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/6,1/5,1/4)	(3,4,5)	(4,5,6)
S3	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)	(1/6,1/5,1/4)	(4,5,6)
S4	(5,6,7)	(1/5,1/4,1/3)	(4,5,6)	(1,1,1)	(4,5,6)
S5	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)
Construction material availability (CMA) n =5 λ_{max}=5.926, CI=0.232, RI=1.12, CR = 0.207					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(4,5,6)	(4,5,6)	(2,3,4)
S2	(4,5,6)	(1,1,1)	(4,5,6)	(4,5,6)	(4,5,6)
S3	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(4,5,6)	(2,3,4)
S4	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Accessibility requirement (AR) n =5, λ_{max}=5.871, CI=0.218, RI=1.12, CR = 0.194					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(2,3,4)	(4,5,6)	(4,5,6)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
S3	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(4,5,6)	(2,3,4)
S4	(1/6,1/5,1/4)	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)
S5	(1/6,1/5,1/4)	(3,4,5)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Transmission lines (TL) n =5, λ_{max}=6.076, CI=0.269, RI=1.12, CR = 0.24					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(4,5,6)	(2,3,4)	(4,5,6)
S2	(1/7,1/6,1/5)	(1,1,1)	(2,3,4)	(5,6,7)	(5,6,7)
S3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(5,6,7)	(4,5,6)
S4	(1/4,1/3,1/2)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1,1,1)	(2,3,4)
S5	(1/6,1/5,1/4)	(1/7,1/6,1/5)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)
Comparison of dam-related cost criteria n =5, λ_{max}=5.287, CI=0.072, RI=1.12, CR = 0.064					
	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
FG	(4,5,6)	(1,1,1)	(3,4,5)	(4,5,6)	(4,5,6)
CMA	(4,5,6)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)	(1,1,1)
AR	(2,3,4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)
TL	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,1,1)

D-6.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=6.74, CI=0.435, RI=1.12, CR = 0.388

	S1	S2	S3	S4	S5
S1	(1,1,1)	(3,4,5)	(1,1,1)	(1,2,3)	(2,3,4)
S2	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)
S3	(1,1,1)	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
S4	(1/3,1/2,1)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=5.16, CI=0.04, RI=1.12, CR = 0.036

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)
S2	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,1,1)
S3	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)
S4	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
S5	(2,3,4)	(1,1,1)	(2,3,4)	(1,2,3)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.151, CI=0.038, RI=1/9, CR = 0.034

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)
S2	(2,3,4)	(1,1,1)	(2,3,4)	(1,2,3)	(2,3,4)
S3	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
S4	(4,5,6)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(2,3,4)
S5	(4,5,6)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=5.55, CI=0.139, RI=1.12, CR = 0.124

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)
S2	(4,5,6)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(1/3,1/2,1)
S3	(2,3,4)	(1,2,3)	(1,1,1)	(3,4,5)	(1,1,1)
S4	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1,1,1)	(1/3,1/5,1/4)
S5	(2,3,4)	(1,2,3)	(1,1,1)	(4,5,3)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=5.006, CI=0.002, RI=1.12, CR = 0.001

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)
S3	(1,2,3)	(1,2,3)	(1,1,1)	(4,5,6)	(1,2,3)
S4	(1/3,1/2,1)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1,1,1)	(1/3,1/2,1)
S5	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5.54, CI=0.135, RI=1.12, CR = 0.120

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
LII	(2,3,4)	(1,1,1)	(4,5,6)	(4,5,6)	(2,3,4)
IMP	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)
LULC	(2,3,4)	(1/6,1/5,1/4)	(4,5,6)	(1,1,1)	(2,3,4)
IHA	(2,3,4)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)

D-6.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(1,1,1)
reservoir-related	(1,1,1)	(1,1,1)

D-6.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.266, CI=0.066, RI=1.12, CR = 0.059					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)
S2	(2,3,4)	(1,1,1)	(1,2,3)	(2,3,4)	(2,3,4)
S3	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(2,3,4)
S4	(2,3,4)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(2,3,4)
S5	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Tourism attraction n =5, λ_{max}=5.093, CI=0.023, RI=1.12, CR = 0.021					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)
S2	(4,5,6)	(1,1,1)	(4,5,6)	(3,4,5)	(4,5,6)
S3	(1,2,3)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,2,3)
S4	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,2,3)
S5	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)

Comparison of power generation and tourist attraction		
	Power generation	Tourism attraction
Power generation	(1,1,1)	(1/4,1/3,1/2)
Tourism attraction	(2,3,4)	(1,1,1)

D-6.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/6,1/5,1/4)
Benefit	(4,5,6)	(1,1,1)

D-7 Seventh expert:

D-7.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.378, CI=0.094, RI=1.12, CR = 0.084					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
S2	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
S3	(3,4,5)	(2,3,4)	(1,1,1)	(2,3,4)	(1/3,1/2,1)
S4	(3,4,5)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)
S5	(3,4,5)	(2,3,4)	(1,2,3)	(1,2,3)	(1,1,1)
Foundation Geology (FG) n =5, λ_{max}=5.484, CI=0.121, RI=1.12, CR = 0.108					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
S2	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
S3	(3,4,5)	(2,3,4)	(1,1,1)	(2,3,4)	(1/3,1/2,1)
S4	(3,4,5)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)
S5	(3,4,5)	(2,3,4)	(1,2,3)	(1,2,3)	(1,1,1)
Construction material availability (CMA) n =5 λ_{max}=5.499, CI=0.125, RI=1.12, CR = 0.111					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(2,3,4)
S2	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(2,3,4)
S3	(3,4,5)	(3,4,5)	(1,1,1)	(3,4,5)	(3,4,5)
S4	(2,3,4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)
Accessibility requirement (AR) n =5, λ_{max}=6, CI=0.25, RI=1.12, CR = 0.223					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)
S2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)
S3	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)
S4	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Transmission lines (TL) n =5, λ_{max}=6.894, CI=0.473, RI=1.12, CR = 0.423					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(3,4,5)	(1/4,1/3,1/2)
S2	(2,3,4)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(2,3,4)
S3	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(2,3,4)
S4	(1/5,1/4,1/3)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Comparison of dam-related cost criteria n =5, λ_{max}=7.472, CI=0.618, RI=1.12, CR = 0.552					
	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)
FG	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)
CMA	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(3,4,5)	(3,4,5)
AR	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
TL	(2,3,4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)

D-7.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.484, CI=0.121, RI=1.12, CR = 0.108					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(2,3,4)	(2,3,4)
S2	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(3,4,5)
S3	(3,4,5)	(3,4,5)	(1,1,1)	(3,4,5)	(3,4,5)
S4	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)
Land instability index (LII) n =5, λ_{max}=5.565, CI=0.141, RI=1.12, CR = 0.126					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(2,3,4)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(2,3,4)
S3	(2,3,4)	(3,4,5)	(1,1,1)	(3,4,5)	(3,4,5)
S4	(3,4,5)	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)
S5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)
Land use, land cover (LULC) n =5, λ_{max}=5.284, CI=0.071, RI=1/9, CR = 0.063					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,2,3)
S2	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)
S3	(1,2,3)	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)
S4	(2,3,4)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Inundated mineral potentiality (IMP) n =5, λ_{max}=5.499, CI=0.125, RI=1.12, CR = 0.111					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
S3	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)
S4	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Inundated historic and archeological (IHA) n =5, λ_{max}=6.305, CI=0.326, RI=1.12, CR = 0.291					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)
S3	(2,3,4)	(2,3,4)	(1,1,1)	(1,2,3)	(1,2,3)
S4	(2,3,4)	(2,3,4)	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)
S5	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(2,3,4)	(1,1,1)
Comparison of reservoir-related criteria n =5, λ_{max}=5.499, CI=0.125, RI=1.12, CR = 0.111					
	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(2,3,4)
LII	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)
IMP	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
LULC	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(2,3,4)
IHA	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)

D-7.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(2,3,4)
reservoir-related	(1/4,1/3,1/2)	(1,1,1)

D-7.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=6.508, CI=0.377, RI=1.12, CR = 0.337					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
S2	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)
S3	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)
S4	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)
Tourism attraction n =5, λ_{max}=5.571, CI=1.43, RI=1.12, CR = 0.127					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
S2	(3,4,5)	(1,1,1)	(3,4,5)	(3,4,5)	(3,4,5)
S3	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)	(3,4,5)
S4	(2,3,4)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(2,3,4)
Tourism attraction	(1/4,1/3,1/2)	(1,1,1)

D-7.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/5,1/4,1/3)
Benefit	(3,4,5)	(1,1,1)

D-8 Eighth expert:

D-8.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.059, CI=0.015, RI=1.12, CR = 0.013

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)
S2	(1,2,3)	(1,1,1)	(1,1,1)	(1,1,1)	(1/3,1/2,2)
S3	(1,2,3)	(1,1,1)	(1,1,1)	(1,1,1)	(1/3,1/2,3)
S4	(1,2,3)	(1,1,1)	(1,1,1)	(1,1,1)	(1/3,1/2,4)
S5	(1,2,3)	(1/2,2,3)	(1/3,2,3)	(1/4,2,3)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=5.326, CI=0.082, RI=1.12, CR = 0.073

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(2,3,4)	(1/4,1/3,1/2)
S2	(1,2,3)	(1,1,1)	(2,3,4)	(3,4,5)	(1/5,1/4,1/3)
S3	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(1/6,1/5,1/4)
S4	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)
S5	(2,3,4)	(3,4,5)	(4,5,6)	(2,3,4)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.136, CI=0.034, RI=1.12, CR = 0.03

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,2,3)	(1,2,3)	(4,5,6)
S2	(1,1,1)	(1,1,1)	(1,2,3)	(1,2,3)	(4,5,6)
S3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(4,5,6)
S4	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(4,5,6)
S5	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.44, CI=0.11, RI=1.12, CR = 0.098

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(3,4,5)	(4,5,6)	(3,4,5)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/3,1/2,1)
S3	(1/5,1/4,1/3)	(2,3,4)	(1,1,1)	(3,4,5)	(2,3,4)
S4	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)	(1/6,1/5,1/4)
S5	(1/5,1/4,1/3)	(1,2,3)	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}=5.424, CI=0.106, RI=1.12, CR = 0.095

	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(4,5,6)	(1,2,3)	(1/4,1/3,1/2)
S2	(0.14,1/6,1/5)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(0.14,1/6,1/4)
S3	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S4	(1/3,1/2,1)	(4,5,6)	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)
S5	(2,3,4)	(4,6,7)	(2,3,4)	(2,3,4)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.42, CI=0.105, RI=1.12, CR = 0.094

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/6,1/5,1/4)
FG	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)
CMA	(2,3,4)	(2,3,4)	(1,1,1)	(1,2,3)	(1/6,1/5,1/4)
AR	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(1,1,1)	(1,1,1)
TL	(4,5,6)	(4,5,6)	(4,5,6)	(1,1,1)	(1,1,1)

D-8.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.191, CI=0.048, RI=1.12, CR = 0.043					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
S2	(1/3,1/2,1)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
S3	(1,2,3)	(3,4,5)	(1,1,1)	(2,3,4)	(1,2,3)
S4	(1,1,1)	(3,4,5)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)
S5	(1,2,3)	(3,4,5)	(1/3,1/2,1)	(2,3,4)	(1,1,1)
Land instability index (LII) n =5, λ_{max}=5.053, CI=0.013, RI=1.12, CR = 0.012					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(2,3,4)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,2,3)
S3	(1,1,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S4	(1,2,3)	(3,4,5)	(1,2,3)	(1,1,1)	(4,5,6)
S5	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)
Land use, land cover (LULC) n =5, λ_{max}=6.206, CI=0.302, RI=1/9, CR = 0.269					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	(3,4,5)	(4,5,6)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(4,5,6)
S3	(3,4,5)	(4,5,6)	(1,1,1)	(2,3,4)	(4,5,6)
S4	(1/5,1/4,1/3)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)
S5	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,1,1)
Inundated mineral potentiality (IMP) n =5, λ_{max}=5.422, CI=0.105, RI=1.12, CR = 0.094					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(2,3,4)	(1/5,1/4,1/3)	(4,5,6)
S2	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,2,3)
S3	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S4	(3,4,5)	(3,4,5)	(3,4,5)	(1,1,1)	(4,5,6)
S5	(1/6,1/5,1/4)	(1/3,1/2,1)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)
Inundated historic and archeological (IHA) n =5, λ_{max}=6.042, CI=0.261, RI=1.12, CR = 0.233					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1,2,3)
S3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1/3,1/2,1)
S4	(1,2,3)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)
Comparison of reservoir-related criteria n =5, λ_{max}=5, CI=0.000, RI=1.12, CR = 0.00					
	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
LII	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
IMP	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
LULC	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
IHA	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

D-8.3 Comparison of dam-related cost and reservoir-related cost

	Dam-related	Reservoir-related
Dam-related	(1,1,1)	(1/4,1/3,1/2)
Reservoir-related	(2,3,4)	(1,1,1)

D-8.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.271, CI=0.068, RI=1.12, CR = 0.06					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(4,5,6)
S2	(2,3,4)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(4,5,6)
S3	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S4	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(3,4,5)
S5	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)
Tourism attraction n =5, λ_{max}=5.078, CI=0.019, RI=1.12, CR = 0.017					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)
S2	(4,5,6)	(1,1,1)	(4,5,6)	(4,5,6)	(4,5,6)
S3	(1,2,3)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,2,3)
S4	(1,2,3)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,2,3)
S5	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(2,3,4)
Tourism attraction	(1/4,1/3,1/2)	(1,1,1)

D-8.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1,1,1)
Benefit	(1,1,1)	(1,1,1)

D-9 Ninth expert:

D-9.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.057, CI=0.014, RI=1.12, CR = 0.013

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/6,1/5,1/4)
S2	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)
S3	(3,4,5)	(1,2,3)	(1,1,1)	(1,2,1)	(1/3,1/2,1)
S4	(2,3,4)	(1,1,1)	(1,1/2,1)	(1,1,1)	(1/4,1/3,1/2)
S5	(4,5,6)	(2,3,4)	(1,2,3)	(2,3,4)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=5.121, CI=0.03, RI=1.12, CR = 0.027

	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(1,2,3)	(2,3,4)	(3,4,5)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)
S3	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)
S4	(1/4,1/3,1/2)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	(1,2,3)
S5	(1/5,1/4,1/3)	(1,2,3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.098, CI=0.024, RI=1.12, CR = 0.022

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,2,3)	(2,3,4)	(5,6,7)
S2	(1,1,1)	(1,1,1)	(1,2,3)	(2,3,4)	(4,5,6)
S3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(4,5,6)
S4	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(3,4,5)
S5	(0.14,1/6,1/5)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.065, CI=0.016, RI=1.12, CR = 0.015

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(2,3,4)	(4,5,6)	(3,4,5)
S2	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(3,4,5)	(2,3,4)
S3	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1,2,3)
S4	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
S5	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}=5.24, CI=0.06, RI=1.12, CR = 0.054

	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(2,3,4)	(1/3,1/2,1)	(1/5,1/4,1/3)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(0.14,1/6,1/5)	(1/9,1/7,0.14)
S3	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(0.14,1/6,1/5)
S4	(1,2,3)	(5,6,7)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)
S5	(3,4,5)	(7,8,9)	(5,6,7)	(3,4,5)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.268, CI=0.067, RI=1.12, CR = 0.06

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/6,1/5,1/4)	(1,2,3)	(2,3,4)	(3,4,5)
FG	(4,5,6)	(1,1,1)	(2,3,4)	(3,4,5)	(4,5,6)
CMA	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(3,4,5)	(3,4,5)
AR	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)
TL	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)

D-9.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.376, CI=0.094, RI=1.12, CR = 0.084

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/7,1/6,1/5)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)
S3	(6,7,8)	(4,5,6)	(1,1,1)	(2,3,4)	(1,2,3)
S4	(4,5,6)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)
S5	(5,6,7)	(3,4,5)	(1/3,1/2,1)	(1,2,3)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=5.066, CI=0.016, RI=1.12, CR = 0.015

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S2	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,2,3)
S3	(1,1,1)	(3,4,5)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S4	(1,2,3)	(3,4,5)	(1,2,3)	(1,1,1)	(3,5,6)
S5	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/6,1/5,1/3)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.066, CI=0.016, RI=1.12, CR = 0.015

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,2,3)
S2	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(3,4,5)
S3	(3,4,5)	(1,2,3)	(1,1,1)	(2,3,4)	(4,5,6)
S4	(1,2,3)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
S5	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=5.275, CI=0.069, RI=1.12, CR = 0.061

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(4,5,6)	(1/3,1/2,1)	(2,3,4)
S2	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1/7,1/6,1/5)	(1,2,3)
S3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1,2,3)
S4	(1,2,3)	(5,6,7)	(4,5,6)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=5.001, CI=0.001, RI=1.12, CR = 0.001

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)
S3	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)
S4	(2,3,4)	(2,3,4)	(4,5,6)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5.013, CI=0.03, RI=1.12, CR = 0.003

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1,2,3)	(2,3,4)	(1,2,3)	(2,3,4)
LII	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1,1,1)	(1,2,3)
IMP	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1,1,1)
LULC	(1/3,1/2,1)	(1/3,1,1)	(1,2,3)	(1,1,1)	(1,2,3)
IHA	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1,1,1)

D-9.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(1,1,1)
reservoir-related	(1,1,1)	(1,1,1)

D-9.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.208, CI=0.052, RI=1.12, CR = 0.046					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(1,2,3)	(2,3,4)
S2	(2,3,4)	(1,1,1)	(2,3,4)	(1,2,3)	(3,4,5)
S3	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(1,2,3)
S4	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(2,3,4)
S5	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)
Tourism attraction n =5, λ_{max}=5.27, CI=0.067, RI=1.12, CR = 0.06					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
S2	(4,5,6)	(1,1,1)	(5,6,7)	(5,6,7)	(4,5,6)
S3	(2,3,4)	(0.14,1/6,1/5)	(1,1,1)	(1,2,3)	(1,2,3)
S4	(2,3,4)	(0.14,1/6,1/5)	(1/3,1/2,1)	(1,1,1)	(1,2,3)
S5	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)

Comparison of power generation and tourist attraction		
	Power generation	Tourism attraction
Power generation	(1,1,1)	(6,7,8)
Tourism attraction	(1/7,0.14,1/6)	(1,1,1)

D-9.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1,1,1)
Benefit	(1,1,1)	(1,1,1)

D-10 Tenth expert:

D-10.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.388, CI=0.097, RI=1.12, CR = 0.087					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
S2	(4,5,6)	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)
S3	(4,5,6)	(1,2,3)	(1,1,1)	(3,4,5)	(1/6,1/5,1/4)
S4	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)	(1/6,1/5,1/4)
S5	(6,7,8)	(2,3,4)	(4,5,6)	(4,5,6)	(1,1,1)
Foundation Geology (FG) n =5, λ_{max}=5.004, CI=0.001, RI=1.12, CR = 0.001					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(5,6,7)	(4,5,6)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(5,6,7)	(4,5,6)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(5,6,7)	(4,5,6)
S4	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)
S5	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)
Construction material availability (CMA) n =5 λ_{max}=5, CI=0.000, RI=1.12, CR = 0.000					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Accessibility requirement (AR) n =5, λ_{max}=5.221, CI=0.055, RI=1.12, CR = 0.049					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(2,3,4)	(5,6,7)	(4,5,6)
S2	(1,1,1)	(1,1,1)	(2,3,4)	(5,6,7)	(4,5,6)
S3	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(3,4,5)	(3,4,5)
S4	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)
S5	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(2,3,4)	(1,1,1)
Transmission lines (TL) n =5, λ_{max}=5.408, CI=0.102, RI=1.12, CR = 0.091					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(6,7,8)	(5,6,7)	(1/3,1/2,1/2)	(1/5,1/4,1/3)
S2	(1/8,1/7,1/6)	(1,1,1)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/9,1/9,1/9)
S3	(1/7,1/6,1/5)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	(1/9,1/8,1/7)
S4	(2,2,3)	(4,5,6)	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)
S5	(3,4,5)	(9,9,9)	(7,8,9)	(2,3,4)	(1,1,1)
Comparison of dam-related cost criteria n =5, λ_{max}=5.418, CI=0.105, RI=1.12, CR = 0.093					
	SE	FG	CMA	AR	TL
SE	(1,1,1)	(4,5,6)	(4,5,6)	(1,2,3)	(1/8,1/7,1/6)
FG	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/9,1/8,1/7)
CMA	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(1/9,1/8,1/7)	(1/9,1/8,1/7)
AR	(1/3,1/2,1)	(3,4,5)	(7,8,9)	(1,1,1)	(1/6,1/5,1/4)
TL	(6,7,8)	(7,8,9)	(7,8,9)	(4,5,6)	(1,1,1)

D-10.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.434, CI=0.109, RI=1.12, CR = 0.097					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/7,1/6,1/5)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/9,1/8,1/7)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
S3	(6,7,8)	(7,8,9)	(1,1,1)	(3,4,5)	(1,2,3)
S4	(4,5,6)	(3,4,5)	(1/5,1/4,1/3)	(1,1,1)	(1/6,1/5,1/4)
S5	(5,6,7)	(6,7,8)	(1/3,1/2,1)	(4,5,6)	(1,1,1)
Land instability index (LII) n =5, λ_{max}=5.268, CI=0.067, RI=1.12, CR = 0.06					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(1,1,1)	(1/4,1/3,1/2)	(4,5,6)
S2	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)
S3	(1,1,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S4	(2,3,4)	(3,4,5)	(1,2,3)	(1,1,1)	(3,4,5)
S5	(1/6,1/5,1/4)	(1,2,3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)
Land use, land cover (LULC) n =5, λ_{max}=5.434, CI=0.108, RI=1/9, CR = 0.097					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(3,4,5)
S2	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	(1,2,3)	(5,6,7)
S3	(6,7,8)	(3,4,5)	(1,1,1)	(5,6,7)	(5,6,7)
S4	(2,3,4)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(3,4,5)
S5	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1,1,1)
Inundated mineral potentiality (IMP) n =5, λ_{max}=5, CI=0.000, RI=1.12, CR = 0.000					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Inundated historic and archeological (IHA) n =5, λ_{max}=5, CI=0.000, RI=1.12, CR = 0.000					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Comparison of reservoir-related criteria n =5, λ_{max}=5.435, CI=0.109, RI=1.12, CR = 0.097					
	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1,1,1)	(1,1,1)	(1/7,1/6,1/5)	(1/7,1/6,1/5)
LII	(1,1,1)	(1,1,1)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
IMP	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)	(1/8,1/7,1/6)	(1/8,1/7,1/6)
LULC	(5,6,7)	(1/6,3,1/4)	(6,7,8)	(1,1,1)	(3,4,5)
IHA	(5,6,7)	(2,3,4)	(6,7,8)	(1/5,1/4,1/3)	(1,1,1)

D-10.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(3,4,5)
reservoir-related	(1/5,1/4,1/3)	(1,1,1)

D-10.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.429, CI=0.107, RI=1.12, CR = 0.096

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(3,4,5)
S2	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(3,4,5)
S3	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
S4	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(2,3,4)
S5	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)

Tourism attraction n =5, λ_{max}=5.404, CI=0.101, RI=1.12, CR = 0.09

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/3,1/2,1)
S2	(6,7,8)	(1,1,1)	(5,6,7)	(5,6,7)	(1,2,3)
S3	(3,4,5)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	(1,2,3)
S4	(3,4,5)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,2,3)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(4,5,6)
Tourism attraction	(1/6,1/5,1/4)	(1,1,1)

D-10.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/6,1/5,1/4)
Benefit	(4,5,6)	(1,1,1)

D-11 Eleventh expert:

D-11.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=6.461, CI=0.365, RI=1.12, CR = 0.326

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/6,1/5,1/4)
S2	(6,7,8)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)
S3	(5,6,7)	(2,3,4)	(1,1,1)	(1/7,1/6,1/5)	(1/6,1/5,1/4)
S4	(5,6,7)	(4,5,6)	(5,6,7)	(1,1,1)	(1/6,1/5,1/4)
S5	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=6.081, CI=0.27, RI=1.12, CR = 0.241

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/8,1/7,1/6)
S2	(5,6,7)	(1,1,1)	(1,1,1)	(1/8,1/7,1/6)	(1/7,1/6,1/5)
S3	(6,7,8)	(1,1,1)	(1,1,1)	(1,2,3)	(1/8,1/7,1/6)
S4	(5,6,7)	(6,7,8)	(1/3,1/2,1)	(1,1,1)	(1,1,1)
S5	(6,7,8)	(5,6,7)	(6,7,8)	(1,1,1)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.243, CI=0.061, RI=1.12, CR = 0.054

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/9,1/8,1/7)
S2	(3,4,5)	(1,1,1)	(1/9,1/8,1/7)	(1/7,1/6,1/5)	(1/7,1/6,1/5)
S3	(6,7,8)	(7,8,9)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(5,6,7)	(5,6,7)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(7,8,9)	(5,6,7)	(1,1,1)	(1,1,1)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.16, CI=0.04, RI=1.12, CR = 0.036

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)
S4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/3,1/2,1)
S5	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}=5.588, CI=0.147, RI=1.12, CR = 0.131

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(3,4,5)	(1/2,0.67,1/2)	(1/9,1/8,1/7)
S2	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1/8,1/7,1/6)	(1/8,1/7,1/6)
S3	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/9,1/8,1/7)
S4	(2,1.50,2)	(6,7,8)	(3,4,5)	(1,1,1)	(1/9,1/8,1/7)
S5	(7,8,9)	(6,7,8)	(7,8,9)	(7,8,9)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.555, CI=0.139, RI=1.12, CR = 0.124

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
FG	(6,7,8)	(1,1,1)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/6,1/5,1/4)
CMA	(3,4,5)	(5,6,7)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
AR	(3,4,5)	(5,6,7)	(2,3,4)	(1,1,1)	(1,1,1)
TL	(6,7,8)	(4,5,6)	(1,2,3)	(1,1,1)	(1,1,1)

D-11.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=7.842, CI=0.711, RI=1.12, CR = 0.634

	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(5,6,7)	(1,1,1)	(1/3,1/2,1)
S2	(1/6,1/5,1/4)	(1,1,1)	(6,7,8)	(4,5,6)	(3,4,5)
S3	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(1,1,1)	(3,4,5)	(2,3,4)
S4	(1,1,1)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(1,2,3)
S5	(1,2,3)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=6.224, CI=0.306, RI=1.12, CR = 0.273

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S2	(3,4,5)	(1,1,1)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)
S3	(1,2,3)	(1,2,3)	(1,1,1)	(1/6,1/5,1/4)	(1/7,1/6,1/5)
S4	(3,4,5)	(4,5,6)	(4,5,6)	(1,1,1)	(1/9,1/8,1/7)
S5	(2,3,4)	(2,3,4)	(5,6,7)	(7,8,9)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.711, CI=0.178, RI=1/9, CR = 0.159

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/7,1/6,1/5)
S2	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)
S3	(2,3,4)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
S4	(2,3,4)	(1,1,1)	(3,4,5)	(1,1,1)	(1/6,1/5,1/4)
S5	(5,6,7)	(2,3,4)	(6,7,8)	(4,5,6)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=6.198, CI=0.299, RI=1.12, CR = 0.267

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,1,1)	(1/8,1/7,1/6)	(1/3,1/2,1)
S2	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S3	(1,1,1)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
S4	(6,7,8)	(3,4,5)	(2,3,4)	(1,1,1)	(1/9,1/8,1/7)
S5	(1,2,3)	(2,3,4)	(1,2,3)	(7,8,9)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=6.125, CI=0.281, RI=1.12, CR = 0.251

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
S3	(3,4,5)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
S4	(3,4,5)	(3,4,5)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)
S5	(1,1,1)	(3,4,5)	(2,3,4)	(3,4,5)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5.416, CI=0.104, RI=1.12, CR = 0.093

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
LII	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)
IMP	(1,2,3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
LULC	(1,1,1)	(1,3,3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)
IHA	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)

D-11.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(3,4,5)
reservoir-related	(1/5,1/4,1/3)	(1,1,1)

D-11.4 Comparison of dam sites based on benefit criteria

	S1	S2	S3	S4	S5
Power generation n =5, λ_{max}=5.790, CI=0.197, RI=1.12, CR = 0.176					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)
S2	(1,2,3)	(1,1,1)	(1/6,1/5,1/4)	(1/7,1/6,1/5)	(1/9,1/8,1/7)
S3	(1,1,1)	(4,5,6)	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)
S4	(1,1,1)	(5,6,7)	(1,2,3)	(1,1,1)	(1/5,1/4,1/3)
S5	(2,3,4)	(7,8,9)	(2,3,4)	(3,4,5)	(1,1,1)
Tourism attraction n =5, λ_{max}=7.370, CI=0.593, RI=1.12, CR = 0.529					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/9,1/8,1/7)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)
S2	(7,8,9)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/9,1/8,1/7)
S3	(2,3,4)	(4,5,6)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)
S4	(1,1,1)	(4,5,6)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(1,1,1)	(7,8,9)	(2,3,4)	(1,1,1)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(1,1,1)
Tourism attraction	(1,1,1)	(1,1,1)

D-11.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1,1,1)
Benefit	(1,1,1)	(1,1,1)

D-12 twelfth expert:

D-12.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.446, CI=0.112, RI=1.12, CR = 0.1

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/6,1/5,1/4)
S2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/5,1/4,1/3)
S3	(3,4,5)	(2,3,4)	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)
S4	(3,4,5)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)
S5	(4,5,6)	(3,4,5)	(3,4,5)	(3,4,5)	(1,1,1)

Foundation Geology (FG) n =5, λ_{max}=5.132, CI=0.033, RI=1.12, CR = 0.029

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/9,1/8,1/7)
S2	(3,4,5)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
S3	(4,5,6)	(2,3,4)	(1,1,1)	(1,1,1)	(1,1,1)
S4	(4,5,6)	(3,4,5)	(1,1,1)	(1,1,1)	(1,1,1)
S5	(7,8,9)	(3,4,5)	(1,1,1)	(1,1,1)	(1,1,1)

Construction material availability (CMA) n =5 λ_{max}=5.439, CI=0.11, RI=1.12, CR = 0.098

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(4,5,6)	(5,6,7)	(9,9,9)
S2	(1,1,1)	(1,1,1)	(4,5,6)	(5,6,7)	(9,9,9)
S3	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)	(6,7,8)
S4	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1,1,1)	(4,5,6)
S5	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1,1,1)

Accessibility requirement (AR) n =5, λ_{max}=5.401, CI=0.1, RI=1.12, CR = 0.09

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(4,5,6)	(9,9,9)	(7,8,9)
S2	(1/3,1/2,1)	(1,1,1)	(3,4,5)	(9,9,9)	(7,8,9)
S3	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(7,8,9)	(6,7,8)
S4	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/9,1/8,1/7)	(1,1,1)	(1/3,1/2,1)
S5	(1/9,1/8,1/7)	(1/9,1/8,1/7)	(1/8,1/7,1/6)	(1,2,3)	(1,1,1)

Transmission lines (TL) n =5, λ_{max}=5.446, CI=0.111, RI=1.12, CR = 0.1

	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(4,5,6)	(1/3,1/2,1/2)	(1/7,1/6,1/5)
S2	(1/7,1/6,1/5)	(1,1,1)	(1/5,1/5,1/4)	(1/8,1/7,1/6)	(1/9,1/9,1/9)
S3	(1/6,1/5,1/4)	(4,5,5)	(1,1,1)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
S4	(2,2,3)	(6,7,8)	(3,4,5)	(1,1,1)	(1/3,1/2,1)
S5	(5,6,7)	(9,9,9)	(6,7,8)	(1,2,3)	(1,1,1)

Comparison of dam-related cost criteria n =5, λ_{max}=5.41, CI=0.103, RI=1.12, CR = 0.092

	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/9,1/9,1/9)	(1/9,1/8,1/7)	(1/9,1/9,1/9)	(1/9,1/8,1/7)
FG	(9,9,9)	(1,1,1)	(1,2,3)	(1,2,3)	(6,7,8)
CMA	(7,8,9)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(5,6,7)
AR	(9,9,9)	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(3,4,5)
TL	(7,8,9)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1,1,1)

D-12.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=5.325, CI=0.081, RI=1.12, CR = 0.072					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(4,5,6)	(1,2,3)	(2,3,4)
S2	(1/7,1/6,1/5)	(1,1,1)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/7,1/6,1/5)
S3	(1/6,1/5,1/4)	(6,7,8)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
S4	(1/3,1/2,1)	(4,5,6)	(1,2,3)	(1,1,1)	(1,2,3)
S5	(1/4,1/3,1/2)	(5,6,7)	(1,2,3)	(1/3,1/2,1)	(1,1,1)
Land instability index (LII) n =5, λ_{max}=5.446, CI=0.112, RI=1.12, CR = 0.1					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/9,1/8,1/7)	(1/6,1/5,1/4)	(3,4,5)
S2	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(5,6,7)
S3	(7,8,9)	(3,4,5)	(1,1,1)	(3,4,5)	(9,9,9)
S4	(4,5,6)	(2,3,4)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)
S5	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1/9,1/9,1/9)	(1/5,1/4,1/3)	(1,1,1)
Land use, land cover (LULC) n =5, λ_{max}=5.434, CI=0.108, RI=1/9, CR = 0.097					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/9,1/8,1/7)	(1/6,1/5,1/4)	(3,4,5)
S2	(2,3,4)	(1,1,1)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(5,6,7)
S3	(7,8,9)	(4,5,6)	(1,1,1)	(2,3,4)	(9,9,9)
S4	(4,5,6)	(3,4,5)	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)
S5	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1/9,1/9,1/9)	(1/6,1/5,1/4)	(1,1,1)
Inundated mineral potentiality (IMP) n =5, λ_{max}=5.417, CI=0.104, RI=1.12, CR = 0.093					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(1/9,1/9,1/9)	(1/9,1/8,1/7)
S2	(6,7,8)	(1,1,1)	(4,5,6)	(1/5,1/4,1/3)	(1/3,1/2,1)
S3	(5,6,7)	(1/6,1/5,1/4)	(1,1,1)	(1/7,1/6,1/5)	(1/6,1/5,1/4)
S4	(9,9,9)	(3,4,5)	(5,6,7)	(1,1,1)	(1,2,3)
S5	(7,8,9)	(1,2,3)	(4,5,6)	(1/3,1/2,1)	(1,1,1)
Inundated historic and archeological (IHA) n =5, λ_{max}=5.222, CI=0.056, RI=1.12, CR = 0.05					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(6,7,8)	(1/4,1/3,1/2)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(6,7,8)	(1/4,1/3,1/2)	(1,1,1)
S3	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1,1,1)	(1/9,1/9,1/9)	(1/7,1/6,1/5)
S4	(2,3,4)	(2,3,4)	(9,9,9)	(1,1,1)	(6,7,8)
S5	(1,1,1)	(1,1,1)	(5,6,7)	(1/8,1/7,1/6)	(1,1,1)
Comparison of reservoir-related criteria n =5, λ_{max}=5.418, CI=0.104, RI=1.12, CR = 0.093					
	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(2,3,4)	(4,5,6)
LII	(4,5,6)	(1,1,1)	(4,5,6)	(6,7,8)	(7,8,9)
IMP	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(4,5,6)	(5,6,7)
LULC	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,2,3)
IHA	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(1/7,1/6,1/5)	(1/3,1/2,1)	(1,1,1)

D-12.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(4,5,6)
reservoir-related	(1/6,1/5,1/4)	(1,1,1)

D-12.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.391, CI=0.098, RI=1.12, CR = 0.087					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/8,1/7,1/6)	(1,1,1)	(1/5,1/4,1/3)	(3,4,5)
S2	(6,7,8)	(1,1,1)	(5,6,7)	(3,4,5)	(9,9,9)
S3	(1,1,1)	(1/7,1/6,1/5)	(1,1,1)	(1/5,1/4,1/3)	(6,7,8)
S4	(3,4,5)	(1/5,1/4,1/3)	(3,4,5)	(1,1,1)	(7,8,9)
S5	(1/5,1/4,1/3)	(1/9,1/9,1/9)	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1,1,1)
Tourism attraction n =5, λ_{max}=5.44, CI=0.11, RI=1.12, CR = 0.098					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)
S2	(6,7,8)	(1,1,1)	(6,7,8)	(6,7,8)	(7,8,9)
S3	(4,5,6)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(6,7,8)
S4	(4,5,6)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(3,4,5)
S5	(1,1,1)	(1/9,1/8,1/7)	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(9,9,9)
Tourism attraction	(1/9,1/9,1/9)	(1,1,1)

D-12.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(9,9,9)
Benefit	(1/9,1/9,1/9)	(1,1,1)

D-13 Thirteenth expert:

D-13.1 Dam-related cost criteria

Seismic effect (SE) n =5, λ_{max}=5.612, CI=0.0427, RI=1.153, CR = 0.137					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(4,5,6)	(5,6,7)	(2,3,4)
S2	(1/7,1/6,1/5)	(1,1,1)	(1,2,3)	(1,1,1)	(1,2,3)
S3	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(2,3,4)
S4	(1/7,1/6,1/5)	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(3,4,5)
S5	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)
Foundation Geology (FG) n =5, λ_{max}=5.417, CI=0.104, RI=1.12, CR = 0.093					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(4,5,6)	(5,6,7)	(1/5,1/4,1/3)	(1/3,1/2,1)
S2	(1/6,1/5,1/4)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1/5,1/4,1/3)
S3	(1/7,1/6,1/5)	(1/3,1/2,1)	(1,1,1)	(1/7,1/6,1/5)	(1/7,1/6,1/5)
S4	(3,4,5)	(2,3,4)	(5,6,7)	(1,1,1)	(1/3,1/2,1)
S5	(1,2,3)	(3,4,5)	(5,6,7)	(1,2,3)	(1,1,1)
Construction material availability (CMA) n =5 λ_{max}=5.189, CI=0.047, RI=1.12, CR = 0.042					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,2,3)	(3,4,5)	(5,6,7)
S2	(1,1,1)	(1,1,1)	(3,4,5)	(4,5,6)	(5,6,7)
S3	(1/3,1/2,1)	(1/5,1/4,1/3)	(1,1,1)	(1,2,3)	(2,3,4)
S4	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,1,1)	(3,4,5)
S5	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)
Accessibility requirement (AR) n =5, λ_{max}=5.584, CI=0.146, RI=1.12, CR = 0.13					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,2,3)	(2,3,4)	(5,6,7)	(4,5,6)
S2	(1/3,1/2,1)	(1,1,1)	(4,5,6)	(6,7,8)	(5,6,7)
S3	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	(6,7,8)	(5,6,7)
S4	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1,1,1)	(1/6,1/5,1/4)
S5	(1/6,1/5,1/4)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(4,5,6)	(1,1,1)
Transmission lines (TL) n =5, λ_{max}=5.891, CI=0.178, RI=1.12, CR = 0.159					
	S1	S2	S3	S4	S5
S1	(1,1,1)	(5,6,7)	(3,4,5)	(1/4,1/3,1/2)	(1/8,1/7,1/6)
S2	(1/7,1/6,1/5)	(1,1,1)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/9,1/8,1/7)
S3	(1/5,1/4,1/3)	(4,5,6)	(1,1,1)	(1/6,1/5,1/4)	(1/9,1/8,1/7)
S4	(2,3,4)	(6,7,8)	(4,5,6)	(1,1,1)	(1/9,1/9,1/9)
S5	(6,7,8)	(7,8,9)	(7,8,9)	(9,9,9)	(1,1,1)
Comparison of dam-related cost criteria n =5, λ_{max}=5.599, CI=0.150, RI=1.12, CR = 0.134					
	SE	FG	CMA	AR	TL
SE	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/8,1/7,1/6)
FG	(3,4,5)	(1,1,1)	(4,5,6)	(4,5,6)	(4,5,6)
CMA	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)	(2,3,4)
AR	(3,4,5)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
TL	(6,7,8)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)

D-13.2 Reservoir-related Cost criteria

Settlement impact (SI) n =5, λ_{max}=6.058, CI=0.264, RI=1.12, CR = 0.236

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/7,1/6,1/5)	(3,4,5)	(1,2,3)	(4,5,6)
S2	(5,6,7)	(1,1,1)	(4,5,6)	(3,4,5)	(5,6,7)
S3	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)	(1/4,1/3,1/2)
S4	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)
S5	(1/6,1/5,1/4)	(1/7,1/6,1/5)	(2,3,4)	(2,3,4)	(1,1,1)

Land instability index (LII) n =5, λ_{max}=5.555, CI=0.139, RI=1.12, CR = 0.124

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1,2,3)	(3,4,5)	(1/9,1/8,1/7)
S2	(4,5,6)	(1,1,1)	(5,6,7)	(6,7,8)	(1/7,1/6,1/5)
S3	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(2,3,4)	(1/8,1/7,1/6)
S4	(1/5,1/4,1/3)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1,1,1)	(1/9,1/8,1/7)
S5	(7,8,9)	(5,6,7)	(6,7,8)	(7,8,9)	(1,1,1)

Land use, land cover (LULC) n =5, λ_{max}=5.427, CI=0.607, RI=1.12, CR = 0.542

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(3,4,5)	(5,6,7)
S2	(4,5,6)	(1,1,1)	(1/7,1/6,1/5)	(1/6,1/5,1/4)	(3,4,5)
S3	(6,7,8)	(5,6,7)	(1,1,1)	(6,7,8)	(3,4,5)
S4	(1/5,1/4,1/3)	(4,5,6)	(1/8,1/7,1/6)	(1,1,1)	(2,3,4)
S5	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)

Inundated mineral potentiality (IMP) n =5, λ_{max}=5.436, CI=0.109, RI=1.12, CR = 0.097

	S1	S2	S3	S4	S5
S1	(1,1,1)	(2,3,4)	(3,4,5)	(1/7,1/6,1/5)	(2,3,4)
S2	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/7,1/6,1/5)	(2,3,4)
S3	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)	(1/9,1/8,1/7)	(2,3,4)
S4	(5,6,7)	(5,6,7)	(7,8,9)	(1,1,1)	(7,8,9)
S5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/9,1/8,1/7)	(1,1,1)

Inundated historic and archeological (IHA) n =5, λ_{max}=7.2, CI=0.55, RI=1.12, CR = 0.491

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)
S2	(1,1,1)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)
S3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(4,5,6)	(1/3,1/2,1)
S4	(3,4,5)	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)
S5	(1,1,1)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)

Comparison of reservoir-related criteria n =5, λ_{max}=5.381, CI=0.095, RI=1.12, CR = 0.085

	SI	LII	IMP	LULC	IHA
SI	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
LII	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)
IMP	(3,4,5)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(1,2,3)
LULC	(3,4,5)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)
IHA	(3,4,5)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1,1,1

D-13.3 Comparison of dam-related cost and reservoir-related cost

	dam-related	reservoir-related
dam-related	(1,1,1)	(3,4,5)
reservoir-related	(1/5,1/4,1/3)	(1,1,1)

D-13.4 Comparison of dam sites based on benefit criteria

Power generation n =5, λ_{max}=5.668, CI=0.167, RI=1.12, CR = 0.149

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/5,1/4,1/3)	(4,5,6)
S2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(1,2,3)
S3	(1,2,3)	(2,3,4)	(1,1,1)	(1,2,3)	(4,5,6)
S4	(3,4,5)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(4,5,6)
S5	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)

Tourism attraction n =5, λ_{max}=5.133, CI=0.033, RI=1.12, CR = 0.03

	S1	S2	S3	S4	S5
S1	(1,1,1)	(1/9,1/9,1/9)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)
S2	(9,9,9)	(1,1,1)	(4,5,6)	(4,5,6)	(5,6,7)
S3	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(2,3,4)
S4	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(2,3,4)
S5	(1,1,1)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)

Comparison of power generation and tourist attraction

	Power generation	Tourism attraction
Power generation	(1,1,1)	(3,4,5)
Tourism attraction	(1/5,1/4,1/3)	(1,1,1)

D-13.5 Comparison of cost and benefit

	Cost	Benefit
Cost	(1,1,1)	(1/4,1/3,1/2)
Benefit	(2,3,4)	(1,1,1)

APPENDIX E

EXAMPLE OF DEFUZZIFICATION

E-1 Fuzzy extent analysis

First, the results of the degree of possibility for $\tilde{S}_i \geq \tilde{S}_j$ is computed from fuzzy weighted summation can be shown as following:

$V(\tilde{S}_1 \geq \tilde{S}_2) = 0.7329$, $V(\tilde{S}_1 \geq \tilde{S}_3) = 0.9498$, $V(\tilde{S}_1 \geq \tilde{S}_4) = 0.8769$, $V(\tilde{S}_1 \geq \tilde{S}_5) = 1$;

$V(\tilde{S}_2 \geq \tilde{S}_1) = 1$, $V(\tilde{S}_2 \geq \tilde{S}_3) = 1$, $V(\tilde{S}_2 \geq \tilde{S}_4) = 1$, $V(\tilde{S}_2 \geq \tilde{S}_5) = 1$;

$V(\tilde{S}_3 \geq \tilde{S}_1) = 1$, $V(\tilde{S}_3 \geq \tilde{S}_2) = 0.7971$, $V(\tilde{S}_3 \geq \tilde{S}_4) = 0.9320$, $V(\tilde{S}_3 \geq \tilde{S}_5) = 1$;

$V(\tilde{S}_4 \geq \tilde{S}_1) = 1$, $V(\tilde{S}_4 \geq \tilde{S}_2) = 0.8715$, $V(\tilde{S}_4 \geq \tilde{S}_3) = 1$, $V(\tilde{S}_3 \geq \tilde{S}_5) = 1$;

$V(\tilde{S}_5 \geq \tilde{S}_1) = 0.8602$, $V(\tilde{S}_5 \geq \tilde{S}_2) = 0.5606$, $V(\tilde{S}_5 \geq \tilde{S}_3) = 0.8022$, $V(\tilde{S}_5 \geq \tilde{S}_4) = 0.7205$.

Then, the degree of possibility of $\tilde{S}_i$ and it should be greater than all the other (n-1) convex fuzzy numbers $\tilde{S}_j$ by:

$V(\tilde{S}_1 \geq \tilde{S}_j | j=1, 2, \ldots n, j \neq i) = \min[(\tilde{S}_{S1} \geq \tilde{S}_{S2}), (\tilde{S}_{S1} \geq \tilde{S}_{S3}), (\tilde{S}_{S1} \geq \tilde{S}_{S4}), (\tilde{S}_{S1} \geq \tilde{S}_{S5})] =$ $\min(0.7329, 0.9498, 0.8769, 1) = 0.7329$;

$V(\tilde{S}_2 \geq \tilde{S}_j | j=1, 2, \ldots n, j \neq i) = \min[(\tilde{S}_{S1} \geq \tilde{S}_{S2}), (\tilde{S}_{S1} \geq \tilde{S}_{S3}), (\tilde{S}_{S1} \geq \tilde{S}_{S4}), (\tilde{S}_{S1} \geq \tilde{S}_{S5})] =$ $\min(1, 1, 1, 1) = 1$;

$V(\tilde{S}_3 \geq \tilde{S}_j | j=1, 2, \ldots n, j \neq i) = \min[(\tilde{S}_{S1} \geq \tilde{S}_{S2}), (\tilde{S}_{S1} \geq \tilde{S}_{S3}), (\tilde{S}_{S1} \geq \tilde{S}_{S4}), (\tilde{S}_{S1} \geq \tilde{S}_{S5})] =$ $\min(1, 0.7971, 0.9320, 1) = 0.7971$;

$V(\tilde{S}_4 \geq \tilde{S}_j | j=1, 2, \ldots n, j \neq i) = \min[(\tilde{S}_{S1} \geq \tilde{S}_{S2}), (\tilde{S}_{S1} \geq \tilde{S}_{S3}), (\tilde{S}_{S1} \geq \tilde{S}_{S4}), (\tilde{S}_{S1} \geq \tilde{S}_{S5})] =$ $\min(1, 0.8715, 1, 1) = 0.8715$;

$V(\tilde{S}_5 \geq \tilde{S}_j | j=1, 2,...n, j\neq i) =$ min[$(\tilde{S}_{S1} \geq \tilde{S}_{S2})$, $(\tilde{S}_{S1} \geq \tilde{S}_{S3})$, $(\tilde{S}_{S1} \geq \tilde{S}_{S4})$, $(\tilde{S}_{S1} \geq \tilde{S}_{S5})$] = min(0.8602, 0.5606, 0.8022, 0.7205) = 0.5606.

Finally, the priority vector $w = (w_1,\ldots w_n)^T$ of the fuzzy comparison matrix as:

$$w_1 = \frac{V(\tilde{S}_1 \geq \tilde{S}_j | j=1,\ldots,n, j\neq i)}{\sum_{k=1}^{n} V(\tilde{S}_k \geq \tilde{S}_j | j=1,\ldots,n, j\neq k)} . = \frac{0.7329}{0.7329+1+0.7971+0.8715+0.5606} = 0.1529;$$

$w_2 = 0.286$; $w_3 = 0.1662$; $w_4 = 0.1818$; $w_5 = 0.169$.

E-2 α-cut method

The fuzzy weighted summation (Table 5.21) is transformed into the fuzzy weight matrix ($\tilde{p}$) as following:

$$\tilde{P} = \begin{pmatrix} 0.0508, 0.1610, 0.5403 \\ 0.1099, 0.3178, 0.9446 \\ 0.0591, 0.1864, 0.6261 \\ 0.0709, 0.2269, 0.7266 \\ 0.0329, 0.1078, 0.3779 \end{pmatrix}$$

In addition, matrix ($\tilde{p}$) is than transform into interval performance matrices by α-cut confidents α=0.8.

$$\tilde{P}_{\propto} = \begin{pmatrix} (\alpha Left_1, \alpha Right_1) \\ (\alpha Left_2, \alpha Right_2) \\ \vdots \\ (\alpha Left_n, \alpha Right_n) \end{pmatrix}$$

$$\alpha Left = [\alpha * (m\text{-}l)] + l \text{ , } \alpha Right = u - [\alpha * (u\text{-}m)]$$

$\alpha Left_1 = (0.8 \times (0.1610 - 0.0508)) + 0.0508 = 0.1289$,
$\alpha Right_1 = 0.5403 - (0.8 \times (0.5403 - 0.1610) = 0.2368$. The αLeft and αRight of other site are calculated and resulted below:

$$\tilde{P}_{\alpha} = \begin{pmatrix} 0.1289, 0.2368 \\ 0.2763, 0.4432 \\ 0.1610, 1/5744 \\ 0.1957, 0.3268 \\ 0.0928, 0.1618 \end{pmatrix}$$

Matrix $\tilde{P}_{\alpha}$ is converted into crisp value C_{λ} by using the optimistic attitude λ=0.8.

$$C_{\lambda}=\begin{pmatrix} C_{\lambda 1} \\ C_{\lambda 2} \\ \vdots \\ C_{\lambda n} \end{pmatrix}$$

$$C_{\lambda} = \lambda \ \text{x} \ \alpha\text{Right} + (1-\lambda) \ \text{x} \ \alpha\text{Left},$$

$C_{\lambda 1}$ = 0.8×1/5368 + [(1-0.8) ×1/889)] = 1/5173, and calulate $C_{\lambda 2}$, $C_{\lambda 3}$, $C_{\lambda 4}$,and $C_{\lambda 5}$ as well. The result of C_{λ} is whown as following:

$$C_{\lambda}=\begin{pmatrix} 0.2173 \\ 0.4098 \\ 0.2517 \\ 0.3006 \\ 0.1480 \end{pmatrix}$$

E-3 Centre of area defuzzification

The fuzzy weighted summation (Table 5.21) can be defuzzified to crispy value by using centre of area defuzzification as example of Pakbeng (S1) dam site bellowing:

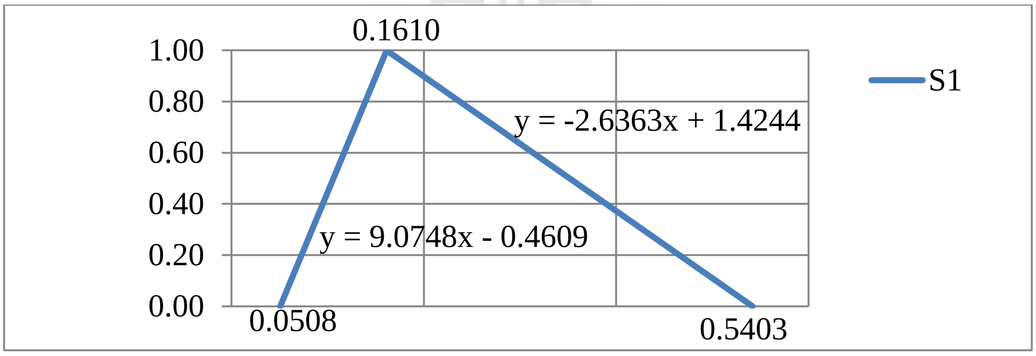

Figure D-3 Fuzzy weight summation membership function of Pakbeng (S1) dam site.

$$x^{*}=\frac{\int \mu_{\tilde{c}}(x)dx}{\int \mu_{\tilde{c}}dx},$$

$$X^{*}=\frac{\int \mu_{\tilde{c}}xdx}{\int \mu_{\tilde{c}}dx}=\frac{\left[\int_{0.0508}^{0.1610}(9.0748x - 0.4609)\,xdx+\int_{1/2403}^{01610}(-2.6363x + 1.4244)xdx\right]}{\left[\int_{0.0508}^{0.1610}(9.0748x - 0.4609)\,dx+\int_{1/2403}^{01610}(-2.6363x + 1.4244)dx\right]}$$

X^{*} = 0.2507

APPENDIX F

PHOTOS FROM FIELD SURVEY

F-1 Pakbeng dam

Figure F-1.1 Tophography and folded interlaminated argillaceous limestone at Pakbeng dam site.

Figure F-1.2 Native gold panning which is local activity and folded interlaminated argillaceous limestone at downstream of Pakbeng dam site.

F-2 Luangprabang dam

Figure F-2.1 Outcrop geology investigation on the way to Luangprabang dam site.

Figure F-2.2 Jointed volcanic rocks, andesitic agglomerate and tuff with flow structure, and topography of left abutment which is thick-bedded to massive limestone at Luangprabang dam site.

F-3 Xayabury dam

Figure F-3.1 Topography at Xayabury dam site.

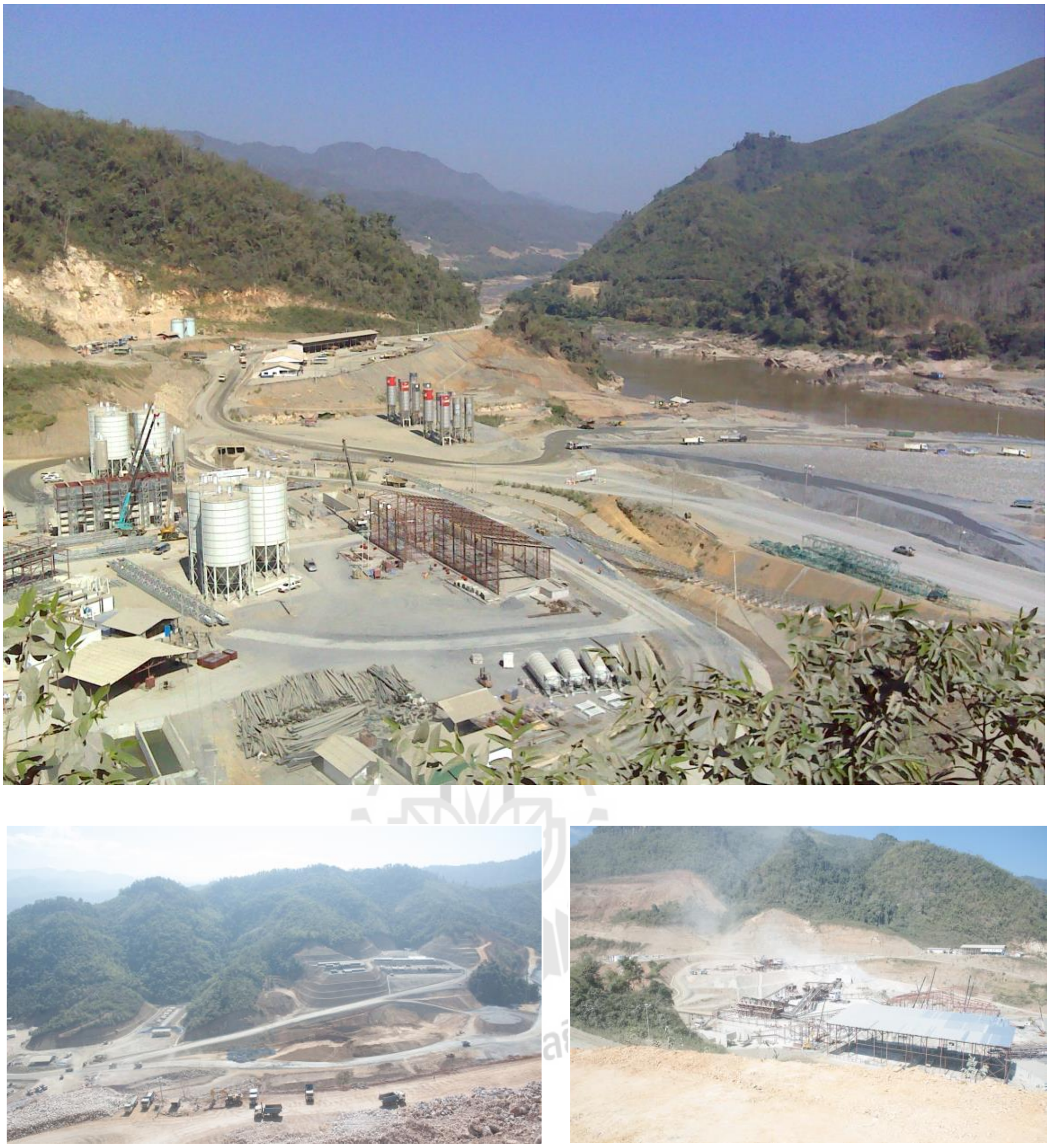

Figure F-3.3 Construction at Xayabury dam site**.**

F-4 Paklay dam

Figure F-4.1 Road condition along the way from Paklay town to Paklay dam site.

Figure F-4.2 Topography and Limestone cliff near Paklay dam site.

F-5 Xanakham dam

Figure F-5 proposed Xanakham dam site (look upstream).

Figure F-5.2 Xanakham dam site (look downstream).

F-6 Field investigation team

Figure F-6.1 Survey team.

Figure F-6.2 Field equipment.

CURRICULUM VITAE

Name	Mr. Phetphoumin PAPHAPHANH
Date of Birth	March 11, 1985
Place of Birth	Dongdok village, Xaythany District, Vientiane capital, Lao PDR
Education	
	2006-2007 a Bachelor of engineering, major in electronics (Computer), Faculty of Engineering, National University of Laos (NUOL).
Grants and Fellowships	
	ASEA-UNINET (ASEAN-European Academic University Network) scholarship 2010.