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Sustainable Indicators of Water Resource Development Projects in Conservation Areas, Thailand

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Abstract

Water resources development in Thailand is a very considerable aspect due to high variation of hydrological regime. Responsible agencies have to sufficiently supply in terms of quantity and quality raw water for various needs including water supply, agriculture, as well as industrial and other uses. Development of a water reservoir is one of the efficient measures as for water source, in spite of some limitations. Unfortunately, the appropriate locations of potential reservoirs are mostly located in the natural resources conservation area occupied with the abundantly good ecological system, which might lead to the conflict of interest between the line agencies of water resources development and natural resources conservation. Despite the national laws and policies specify to promote sustainable water resource development, specific guidelines and standards for quantity-based consideration of sustainability together with the balance between resources development and conservation of a potential project have not yet been defined in details.

Consequently, the quantitative criteria to establish the sustainable water resource development indicators, applying the principles of self-sufficiency economy and transitioning from the extreme development of high into moderate impact levels with self-sustaining development, will ensure that the future water resources project development can be carried out successfully and effectively towards sustainability. The study is qualitative research using the Del Phi method. The Del Phi's panel comprised selective 20 experts of various related ields, governmental agencies and independent academia. The research conducted firstly by defining draft relevant dimensions, factors, and indicators drawn from the previous related researches, and from in-depth interviewing 7 experts of the key related fields. Then the additional indicators and their scoring ranges were intensively determined and classified from the data and information of the 30 reservoirs' environmental impact assessment (EIA) reports as well as those referenced from the relevant researches, governmental agencies' regulations and announcements. The draft final indicators and scoring ranges were summarized and proposed to the Del Phi's panel not less than two rounds to obtain their majority conclusion on indicators, weighting factors, scoring ranges and recommendations of sustainability level for the future projects.

The study results indicated that the relative importance weighting of four dimensions to be considered were : engineering (20%), natural resources and environment (35%), social (25%), and economics (20%). This research identified 14 main factors of which 7 factors having high significance, including (1) wildlife, (2) forests, (3) ecology system, (4) number of affected people, (5) quality of life, (6) economic feasibility, and (7) social opposition. These 14 factors comprise a total of 29 key indicators, with 12 highly significant indicators including (1) uniqueness, (2) number of opponents, (3) water quality, (4) annual cultivated area per reservoir capacity, (5) design flood rate per reservoir capacity, (6) environmental economic feasibility, (7) economic feasibility, (8) proportion of beneficiaries on sufferers, (9) conservation area type, (10) Number of evacuated households per unit of reservoir capacity, (11) endangered wildlife, and (12) biodiversity of wildlife.

Keywords : Sustainable indicators of water resource development; Conservation area; Water scarcity indicators; Water resources development necessity indicators

Introduction

Thailand is an agricultural country with a total agricultural area of approximately 56% (178 million rai) and a forested area of approximately 32% (104 million rai) (Department of Land Development (DLD), 2020). However, this vast agricultural area often experiences water scarcity issues, with a need for water in various sectors, including agriculture, domestic consumption for 60 million population, industrial, and other uses. To address these challenges, state agencies responsible for water resource development must secure quality water sources in sufficient quantities to meet the needs of all sectors. Water reservoir development has been an efficient approach. Unfortunately the appropriate location of the reservoir is mostly located in natural resources conservation area where natural resources and the ecosystem is in good condition. Additionally, some potential reservoir sites inundate encroached habitats and agricultural land. In the past, reservoir development has primarily focused on maximizing potentials of topography, hydrology, and economics, rather than adhering to principles of economic self-sufficiency and sustainability in all dimensions, including economic, social, and environmental aspects. Although presently, Thailand has a constitution and development strategies that emphasize sustainability and balance between water resource development and natural resources conservation, but detailed guidelines and criteria for feasible and efficient project planning are lacking. Hence development of key sustainable factors and indicators and their weighting factors as a specific guideline for concerned agencies to develop a balanced sustainable water reservoir project should be established.

From the literature review conducted, it is evident that a substantial amount of research has focused on studying the factors and sustainability indicators for water resource development. Most of these studies have aimed to establish indicators for assessing sustainability at both national and regional levels. These indicators are generally categorized into three main groups: natural resources and environment, water resource development, and water resource management.

The sustainable indicators in the category of natural resources proposed by Piyachana [1] in 2003 consists of three main factors including forest abundance, land use, and water quality. The forestry factor include forest type indicator, timber volume indicator, forest growing rate indicator and ecology system value indicator. The land use factor is proportion of inappropriate land use area in conservation areas. Whereas the water quality factor includes water physical, biological, and chemical parameters, and pesticides indicators.

Poomjamnong [2] in 2017, found that Thailand still lacks clear and specific resource management goals to support sustainable development goal No. 15 (Terrestrial ecosystem). There is also a lack of data and standard criteria for assessing or weighting forest resource indicators for the regional level. Additionally, the study applied key indicators of the forest resources include the proportion of forested areas, the proportion of conservation areas, and the endangered species of wildlife.

Noywuli, in 2019 [3] studied the carrying capacity of river basins in Indonesia, defining five keys factors: (1) land management, (2) water resource management, (3) socio-economic conditions, (4) public utilities related to water, and (5) watershed utilization. Key indicators included the proportion of green areas, water usage per river runoff, agricultural area per farmer, community area, and the proportion of conservation areas to the total area.

Tong, in 2020 [4] established the key carrying capacity indicators of forestry of which indicators are the proportion of forested areas, biological diversity, timber volume, and forest damage per unit area.

The National Park Research Section, National Park Division, Department of National Park, Wildlife and Plant Conservation (DNP), Thailand, in 2019 [5] studied the prioritization of national parks, utilizing six factors: (1) physical aspects, (2) biodiversity, (3) risk level, (4) global significance, (5) tourism, and (6) management complication. Key indicators included area size, forest type, tree species count, ecology system, population in conservation areas, encroachment area, global significance, tourism diversity, and management complication.

For the research group focusing on the sustainable development indicator for water resources development, Smith, et al, in 2007 [6] proposed the following indicators: impact on water quality, water demand and water resources proportion, water demands, and the risk of extinction of rare plants and wildlife species.

Morris, in 2019 [7] introduced economic indicators, which include productivity or Gross Domestic Product (GDP) per unit of raw water and income indicator or GDP per capita. Additionally, there is the ecological footprint indicator or environmental cost per unit of water. Meanwhile Liang et al. [8] in 2018, proposed a social indicator comprising water use per agricultural area, population growth rate, and sustainability indicators related to resources such as water resources per capita, water demand over water resources ratio, water demand per capita, and environmental indicators including environmental water use, land and water loss, and clean water volume per wastewater volume.

For research group on water resources management, Correa, in 2013 [9] presented a framework to address sustainability challenges in water management, focusing on three aspects: water pollution, forest restoration, and soil conservation. The framework includes 18 indicators categorized into groups related to soil erosion, water quality management, water use and water management, and social aspects. These indicators assess the sustainability of water resource management comprising the length of eroded riverbanks, water quality, agricultural land, and conflicts in the context of water management.

The National Statistical Office of Thailand, 2023 [10] developed the water management indicators (WMI) for the country to aid in decision-making and planning for sustainable water resource management. More than 40 government agencies were involved in this effort, and they identified 59 indicators within 8 dimensions, which include: (1) Water resource storage : e.g. (1) water storage per capita, water storage per river runoff, water quality, (2) domestic water supply management, e.g. water supply serviceable households, (3) water security, e.g. proportion of irrigated area to agricultural area, (4) water balance, e.g. water demand per water resources storage, (5) water quality management, e.g. number of good quality water sources, (6) water-related disasters, e.g. probable flood risk area and drought risk area, (7) forest conservation management, e.g. proportion of forested area and catchment area, forest abundance, and (8) water resource management, e.g. numbers of water management organizations, and numbers of water monitoring systems.

Even previous studies of factors and sustainability indicators concern water resources development and management at the national or regional level, however, there are several aspects, factors and indicators that can be applied to assess sustainability at the project level. For natural resources aspect, following factors and indicators include (1) forestry factor include biodiversity indicator, forest abundance, (2) wildlife factors include biodiversity indicator, endangered species status. For environmental aspects, including water quality indicator. For economic aspect, including income indicator, environmental cost, whereas social aspects including conflict of interest indicator. These factors and indicators can be valuable for evaluating the sustainability rating of water resource development at project level.

According to The Royal Irrigation Department (RID)'s guidelines of water resources development planning study [11], four key dimensions are applied for project size and location selection comprising (1) geography and engineering, (2) environments (3) social, and (4) economic. They are complied with the guideline of The Office of Natural Resources and Environmental Policy and Planning (ONEP)'s Environment Impact Assessment (EIA) Report Preparation [12]. The geography and engineering dimension is consequently added to three principally sustainable dimensions comprising economic, social, and environments.

In addition, in responsible agencies' practice for considering a water resource development for any requested drought agricultural area, water scarcity level would be assessed to classify the necessity level of the water resource development. Five factors including (1) geography, (2) existence of water resource development, (3) hydrology, (4) water demand, and (5) poverty are considered. Decision of the project development would also take the water scarcity issue into account together with other aspects including socio-economic and environments. Since there has not been researched on the establishment of a sustainable indicators and their appropriate level for water resource development in conservation areas in Thailand at the project based level and different water scarcity status, therefore conducting a study to develop such indicators and sustainable level for different water scarcity level would be valuable guidelines applied for assessing well-balanced sustainability across various dimensions of the water resource development projects. The results could also be applied for relevant agencies responsible in both water resource development and natural resource conservation and environmental quality control to consider project's sustainability and feasibility.

Objectives

1) To study key factors and sustainability indicators of water resource development projects in natural resource conservation areas in Thailand,

2) To develop key factors and indicators to measure the severity of water scarcity problems or necessity of water resources development in the agricultural areas of Thailand, and

3) To establish the sustainability score level for the water resource development projects in natural resource conservation areas.

Methodology

Qualitative research through in-depth interviews with selective 7 qualified experts, along with the Del Phi method using questionnaire surveys of 20 experts in relevant fields related to water resources development, including both government agencies and independent experts.

Design criteria of qualification of all experts were specified in accordance with both related academic background and working experiences as follow;

- Academic	:	Bachelor's degree or higher degree.
- Work experience	:	direct or related fields of water resources development projects more than 30 years.
- Occupation	:	government officers, university lecturers, & organization's professionals, and independent consultants

1) The In-depth interview for questionnaire design group consists of 7 experts from three main aspects,

1.1) Engineering : a senior officer of DWR[1]

1.2) Natural resources : 5 senior officers of RFD[2], &Environments DNP[3], and RID[4], independent consultants in forestry, and wildlife

1.3) Socio & Economic: a senior officer of RID

2) Del Phi's panel group comprising 20 experts from three main aspects,

2.1) Engineering : 4 senior government officers of RID, DWR, ORDPB[5], and ONWR[6]

2.2) Natural resources: 8 senior government and Environments officers each from RFD, DNP, ONWR, DMR[7], RID, watershed committee, and two from ONEP[8] and 4 senior independent consultants in forestry, wildlife, environment, and geologist,

2.3) Socio&economic : 2 senior government officers of RID, NESDC[9], and 2 senior independent consultants in social and economic,

Where,
DWR[1] denotes Department of Water Resource Department,
RFD[2] denotes Royal Forest Department,
DNP[3] denotes Department of National Parks, Wildlife and Plant Conservation,
RID[4] denotes Royal Irrigation Department,
ORDPB[5] denotes Office of the Royal Development Projects Board,
ONWR[6] denotes Office of the National Water Resources,
DMR[7] denotes Department of Mineral Resources,
ONEP[8] denotes Office of Natural Resources and Environmental Policy and Planning, and
NESDC[9] denotes Office of the National Economic and Social Development Council.

Study Procedure

The study procedures is presented in Fig. 1 and described as follows,

1) Data compilation and literature review including researches and studies, concerned agencies' regulations, orders, and announcements, as well as feasibility study (FS) and EIA reports, and in-depth interview with the experts.

2) Study and fact finding of water resources development projects including area problems, stakeholders, constraints and limitation, project potential, and factors and indicators concerned.

3) Screening and defining key indicators and scoring ranges of project's sustainability level, and project's water scarcity level or water resources development necessity level.

4) Questionnaire design covering key dimensions, factors, indicators with scoring ranges, and project sustainability level, additionally factors, indicators with scoring ranges, and project water scarcity level.

5) Summarizing the results of factors and indicators with their weighting ranges (1-100%) and Multi Criteria Analysis (MCA) method by assessing through questionnaires surveys from qualified expertise informants of Del Phi Group at least twice to obtain majority results which equal to or greater than the 75 percentile.

6) Application of the results with data from environmental impact assessment reports of 30 project studies.

7) Summarizing the results of sustainable indicators and corresponding weighting score level and recommendations.

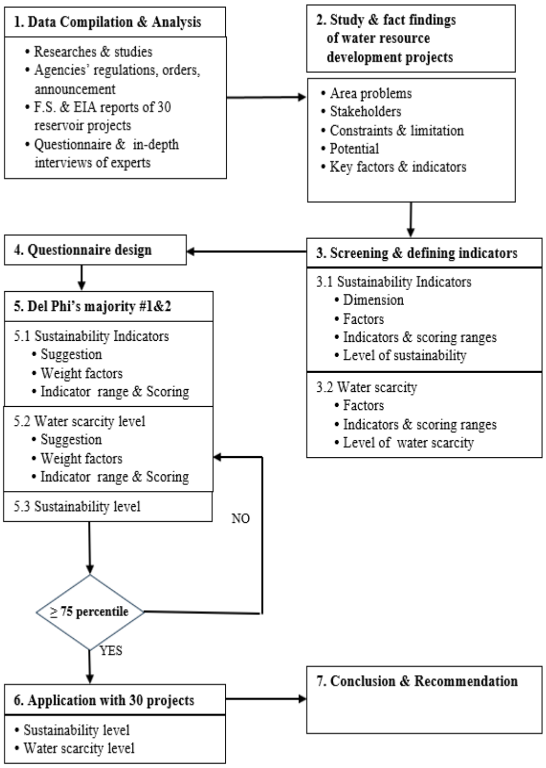

Figure 1 Study Approaches and Procedures

Studying the key indicators of both project's sustainability and water scarcity level were basically determined from literature reviews, in-depth interviews, related agencies' practices and EIA report review, respectively. Additionally, detail indicators were adjusted and modified basing on data accessibility and simplicity of their representing basis for practically applied. Data and information for indicators' ranging scales were manipulated from (1) the FS and EIA reports of water resource development projects, and (2) reference materials from research works, academic papers, regulations, orders, and announcements of relevant government agencies.

Study Data

1) Primary data comprised those from semi structured in-depth interviews together with open-ended questionnaire survey of seven selective expert informants to analyze principals, concepts, and reasons in project defining and prioritizing important dimensions, factors, and indicators that affecting projects sustainability.

2) Secondary data includes data and information documents, statistics of projects from 30 EIA reports of water resource development projects. For the water scarcity assessment, Geographic Information System (GIS) maps of the indicators were referenced from related agencies.

The 30 reservoir projects were selected from different regions of Thailand of which locations presented in Fig 2. 17 projects are located in the northern region (57%), 6 projects are in the eastern region (20%), 3 projects are in the southern region (10%), 3 projects are in the northeastern region (10%), and 1 project is in the central region (3%). These projects have storage capacities ranging from 2 to 295 million cubic meters, covering surface areas ranging from 123 to 16,250 rai. Some of these areas are partially located within conservation areas, including national parks, wildlife sanctuaries area, watershed classification level 1, and conservation zone (Zone C) of national reserved forests excluding wetland and world heritage site.

For Analysis of data, descriptively statistic method, percentile, and MCA are applied, Table 1 presents summary of data collection tools and analysis methods.

Study Results

Results of draft indicators

1. Results from literatures

Even most of literatures are based on regional and national levels, however some indicators are significant for the study which is scoping on project based in conservation areas. 17 from 70 indicators in the four dimensions were screened and modified for first draft key indicators. In the domain of water resources engineering, key indicators encompassed flood discharge, average water volume, and the ratio of water usage per water source. In the aspect of natural resources, it was identified that crucial factors include forest-related aspects with significant indicators such as forest status, proportion of forested areas, biodiversity, vulnerability, and uniqueness. Regarding wildlife, vital factors included biodiversity and the status of endangered species. In terms of environmental quality, the factor of impacted water quality was taken into account. Social aspects involved impacted households and conflict level. On the economic front, considerations included income per capita and ecology cost.

2. Results of in-depth interviews

The remarkable key issues suggested from the in-depth interviews included following items, i.e. consideration of engineering dimension, the importance of the environmental dimension, area uniqueness, recognizing uniqueness in the habitat of endangered wildlife species, reservoir location, natural resource abundance and biodiversity, the status of forest resources, the significance level of conservation area types, project conflicts of interest, and social opposition to the project. These issues were considered and included in the questionnaire design.

Table 1 Summary of data collection, tools, and analysis methods

NO	Objectives	Data Resources /Informants	Tool of data collection	Analysis Methods
1	To study context, concerning factors& indicators, constraints & limitations, and potentials	1) Secondary Data - Study reports of project feasibility and environment impact assessment, researches, agencies' documentations 2) Primary data - In-dept interview questionnaire of experts in engineering, forestry, wildlife, social, economic, environment	1) Secondary Data, Review of study reports of project feasibility and Environment impact assessment, documentations, researches 2) In-depth interview	1) Descriptive Statistics
2	To study dimensions, key factors, indicators and corresponding scoring ranges	1) 20 related expert informants from - Water resources development agencies (RID, WRD, ORDPB) - Natural resources conservation agencies (RFD, DNP, DMR) - Policy and control agencies (ONEP, NESDB, ONWR), Watershed Committee - Related private specialists and consultants	1) Del Phi 's Questionnaire survey	1) Descriptive Statistics 2) Multi Criteria Analysis (MCA) 3) Percentile
3	To apply indicators with 30 projects	1) 30 study reports of project feasibility and environmental impact assessment (EIA)	1) Spreadsheets 2) Geographic Information System (GIS)	1) Descriptive Statistics 2) MCA

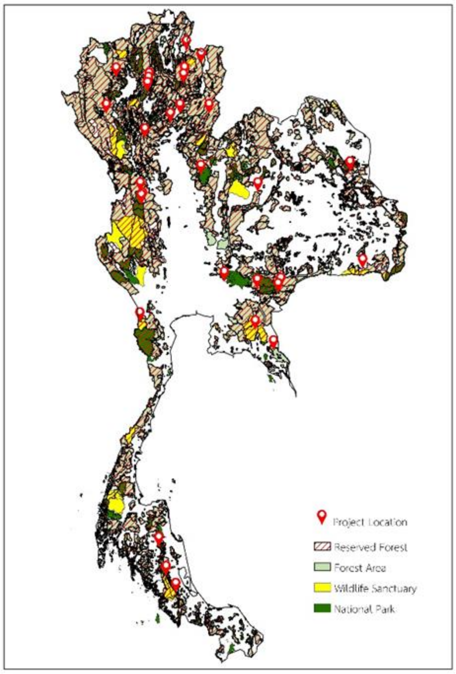

Figure 2 Location of 30 potential reservoirs in the conservation areas

3. Results of agencies' practices and EIA reports

Considering normal practices of most feasible project planning and guidelines of preparing EIA reports, selection of type of water resource development structures, site location and project size would consider following indicators.

For the geography and engineering of which main indicators applied were as follows; i.e. retention area per unit of storage, dam section, geologic conditions, hydrologic conditions, and irrigation area size.

For the environments, indicators mostly applied were size of inundated reservoir area comparable to conservative area, type of conservative areas, abundance or density of trees per area, bio-diversity, status of both forest and wildlife, ecology system, and impacted water quality.

For social dimension, indicators mostly concerned were number of impacted households, encroachment area, and project protestors.

For economic dimension, mostly indicators applied were investment cost per unit of storage volume, and internal rate of return.

These indicators were applied in the second draft indicators proposed in the first Del Phi's questionnaire.

Results of study of the dimensions, factors, and key sustainability indicators from the Del Phi.

1) The main dimensions considered are 4 components consisting of engineering, natural resources and environment, social, and economics.

2) There are 14 significant factors considered for sustainable aspects as follows: (1) engineering dimension comprising 4 factors namely geography, hydrology, geology, and engineering. (2) natural resources and environmental dimension consisting of 4 key factors namely forests, wildlife, water quality, and ecosystem. (3) social dimension concerning 3 core factors namely project opposition, affected stakeholders, and life value or uniqueness. (4) economic dimension comprising 3 factors namely benefits, costs, and feasibility level.

3) The project sustainable indicator comprises 29 indicators as follows: (1) engineering dimension with 6 indicators, (2) natural resources and environmental dimension with 12 indicators, (3) social dimension with 5 indicators, and (4) economic dimension with 6 indicators.

Results of the sustainable indicators

1. Engineering dimension

Engineering dimension consists of 4 key factors:

1.1 Geographic factor consists of two indicators: (1) The dam section per reservoir unit capacity specified from the simplified area of the dam cross section area per reservoir unit capacity, and (2) The reservoir area per reservoir unit capacity.

1.2 Hydrologic factor includes one indicator which is design flood rates per reservoir unit capacity.

1.3 Geologic factor includes two indicators: (1) the seismic indicator, specifying the range of values based on the intensity levels according to the Mercalli intensity scale at the project location, referencing the earthquake risk map by the Department of Mineral Resources (DMR) as shown in Fig.3, and (2) the permeability indicator, specifying the indicator ranges based on permeability level or the type of bedrock.

1.4 Engineering factor includes one indicator which is the size of the irrigated area per reservoir unit capacity.

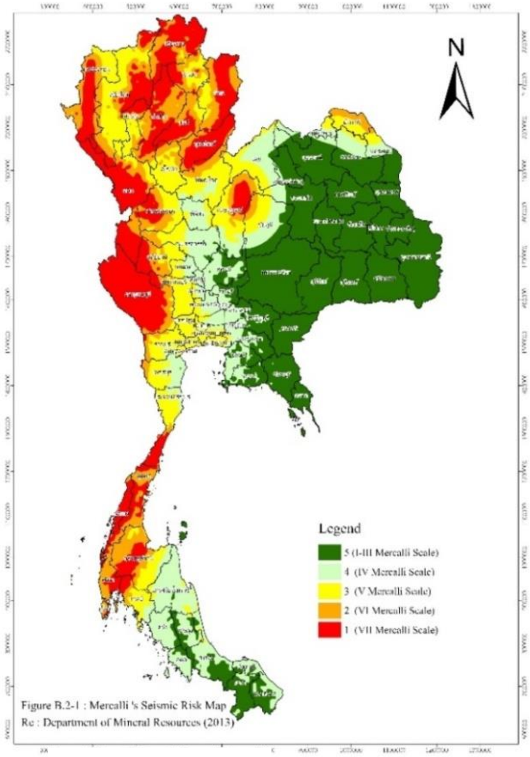

Figure 3 Mercalli’s seismic risk map

2. Natural resources and environment dimension

This dimension consists of four factors:

2.1 The forestry factor. It consists of four indicators.

1) The forest abundance indicator is defined by the number of large trees per area of 1 rai in various types of forests, whereas the forest abundance level is applied from the researched figures by the Department of Conservation Science, Faculty of Forestry, Kasetsart University, 2009 [13].

2) The forest bio-diversity indicator is determined by the number of tree species found in high concerned dominated forests type in the reservoir area, whereas the indicator level ranges are referenced to the announcement by the Department of National Parks, Wildlife and Plant Conservation (DNP) regarding the determination of the value of natural resources in protected areas, 2021 [14].

3) The indicator of prohibited tree species is determined based on the number of prohibited tree species found in the reservoir area. The prohibited trees species are referenced to the list in the announcement by the DNP regarding the determination of the value of natural resources in protected areas, 2021.

4) The uniqueness indicator is determined by the presence or absence of unique or outstanding characteristics in the conservation area.

2.2 The wildlife factor. It consists of 4 indicators.

1) The wildlife abundance indicator applies the ratio of number of species of wildlife with low to high population density compared to total species found in the reservoir area.

2) The wildlife bio-diversity indicator is determined by the number of wildlife species found in the reservoir area.

3) The wildlife status indicator is determined by the number of endangered wildlife species, of which status levels are listed as vulnerable (VU), endangered (EN), and critical (CR) by the IUCN Red List, 2015 [15].

4) The uniqueness indicator is determined by the presence or absence of unique national and international wildlife species that cannot be evacuated or translocated.

2.3 The water quality factor

The water quality factor has one indicator which is determined by the level of impact severity on water quality due to project development.

2.4 The ecosystem factor

This factor consists of three indicators,

1) The conservation area type indicator is determined based on the conservation area types impacted by the projects in terms of ecology abundance significance from higher to lower as follows: national park, wildlife sanctuation area, watershed classification 1A, 1B, and national reserved forest area (conservation zone or Zone C), respectively.

2) The impacted conservation area indicator which is the proportion of impacted

conservation area to the total conservation area.

3) The reservoir location indicator is determined by the location of the reservoir within the core area or rim of the conservation area.

3. The social dimension

The social dimension comprises three following factors:

3.1 The project opposition factor

This factor has one indicator which is determined from the number of households opposing the project compared to total households affected by the reservoir.

3.2 The affected stakeholders factor

This factor comprises three indicators:

1) The indicator of the number of affected households in reservoir per unit of reservoir capacity.

2) The indicator of the occupied land in the reservoir area per unit of reservoir capacity.

3) The indicator of the proportion of the benefit area to the reservoir area.

3.3 The factor of quality of life and uniqueness is assessed by the presence of archaeological preserved areas, tourism locations, significant mineral resources, geological conservation areas, and ethnic groups within the reservoir area.

4. The economic dimension

The economic dimension comprises three following factors:

4.1 The factor related to project benefits by applying the indicator of total annual cropping area per unit of reservoir capacity.

4.2 The factor related to project costs by utilizing the indicators of engineering cost, social cost, and environmental cost per unit of reservoir capacity, respectively.

4.3 The factor of project feasibility includes the economic internal rate of return (EIRR) indicator and the environmental economic internal rate of return (EEIRR) indicator.

5. Factors and indicators of water scarcity level

According to related agencies' practices, there are 5 factors consisting of (1) geography, (2) level of development, (3) hydrology, (4) water demand, and (5) society.

5.1 Geography factor

There are 2 indicators including (1) drought risk area, and (2) flood risk area.

5.2 Existence of development factor

The existence of development factor or indicator which is determined the existence of development of water resources and irrigation systems overlapping project area.

5.3 Hydrology factor

There are 2 indicators comprising (1) hydrological variation, and (2) potential of groundwater supply.

5.4 Water demand factor

Water demand factor has one indicator which is determined by cropping types in the benefiting area.

5.5 Social factor

Social factor has one indicator which is determined by the level of poverty.

Weighting factors of sustainability indicators

The results from the Del Phi's 20 specified experts regarding the selected key dimensions, factors, indicators, and their weighting factor values can be summarized as follows:

1. Dimensions

The dimension's weighting factor values among engineering dimension, natural resources and environment dimension, social dimension, and economic dimension are 20 : 35 : 25 : 20, respectively.

2. Factors

1) The physical and engineering dimension. The factors' weighting values among geography, hydrology, geology, and engineering are 25 : 25 : 30 : 20, respectively.

2) The natural resources and environmental dimension. The factors' weighting values among factors of forestry, wildlife, water quality, and ecology are 25 : 30 : 20 : 25, respectively.

3) The social dimension. The factors' weighting values among project opposition, the number of affected households, and the impact on quality of life are 30 : 35 : 35, respectively.

4) The economic dimension. The factors' weighting values among project benefit, project costs, and project feasibility are 30 : 30 : 40, respectively.

3. Indicators

3.1 Indicators of the physical and engineering dimension.

1) The geographical factor includes two indicators: the corresponding weighting values between the dam's cross-section area per unit of reservoir capacity and the reservoir area per unit of reservoir capacity are 45 : 55.

2) The hydrological factor comprises one indicator: that is the design flood peak discharge per unit of reservoir capacity, resulting the weighting value of 100.

3) The geological factor includes two indicators: the weighting values between seismic risk and permeability are 50 : 50.

4) The engineering factor includes only one indicator: it is the irrigation area per unit of reservoir capacity, resulting the weighting value of 100.

3.2 Indicators of the natural resources and environmental dimension

1) The forest factor includes four indicators: the weighting values among abundance, biological diversity, prohibited trees, and uniqueness are 25 : 25 : 20 : 30, respectively.

2) The wildlife factor includes four indicators: the weighting values among abundance, biological diversity, wildlife endanger status, and uniqueness are 30 : 20 : 30 : 20, respectively.

3) The water quality factor includes one indicator: which is the impact on water quality, resulting weighting value of 100.

4) The ecology system factor includes three indicators: the weighting values among the conservation area type indicator, the proportion of impacted area and the conservation area indicator, and the reservoir location indicator are 40 : 35 : 25, respectively.

3.3 Indicators of the social dimension

1) The factor related to project opposition comprises only one indicator which is the proportion of the number of opposition to the total impacted households, resulting the weighting value of 100.

2) The factor related to the impacted sufferers and beneficiaries includes three indicators: the weighting values among the impacted households per unit of reservoir capacity, the encroached area per unit of reservoir capacity, and the proportion of irrigation area and the reservoir area, are 40 : 30 : 30, respectively.

3) The factor related to quality of life concerns one indicator which is the existence of distinctiveness value across either different aspects (archaeologic sites, tourism site, significant minerals resources, geologic conservative site, ethnic groups) resulting the weighting value of 100.

3.4 Indicators of economic dimension

1) The factor related to project benefit includes only one indicator which is the year-round cultivated area per unit of reservoir capacity, resulting the weighting value of 100.

2) The factor related to project costs includes three indicators: the weighting values among engineering costs per unit of reservoir capacity, social replacement costs per unit of reservoir capacity indicator, and environmental mitigation costs per unit of reservoir capacity indicator are 30 : 35 : 35, respectively.

3) The factor related to project feasibility includes two indicators: the weighting values of economic internal rate of return indicator, and environmental economic internal rate of return indicator are 45 : 55.

Consideration of sustainable water resources development project

Any proposed project that be developed should provide overall sustainable point in good level (66-75) or better whereas each dimension point be in moderate level (56-65) or better.

Weighting factors of project's water scarcity level

There are five main factors applied for the assessment of water scarcity level or necessity level of water resource development. They are geography, the existence of water resources and irrigation development, hydrology, water demand, and poverty. The weightage of these factors is distributed as 20 : 15 : 20 : 20 : 25, respectively.

1) The geographic factor consists of two indicators: the drought risk area indicator and the flood risk area indicator. The weightage is distributed as 55 : 45, and the reference maps applied are based on the drought and flood risk level mapping by Geo-Informatics and Space Technology Development Agency (GISTDA) as shown in Fig.4 and Fig.5.

2) The existence of water resources and irrigation development factor consists of a single indicator, resulting a weightage of 100. The reference map is based on the RID's present reservoirs and irrigation areas map as presented in Fig.6.

3) The hydrologic factor includes two indicators: the weighting values of hydrological variation indicator and groundwater recharge indicator, are 65 and 35, respectively. The indicators are based on data from rain gauge stations provided by the RID and the groundwater yield map provided by the Department of Groundwater Resources (DGR) as shown in Fig.7 and Fig.8, respectively.

4) The water demand factor consists of a single indicator which is the agricultural water demand indicator, resulting the weighting value of 100. This indicator is referenced from the land use map provided by the DLD as presented in Fig.9.

5) The poverty factor consists of a single indicator which is the household poverty indicator, resulting the weighting value of 100. This indicator is established from data of the National Electronics and Computer Technology Center (NECTEC) in 2022 as shown in Fig.10.

6) The results from the Del Phi's panel are concluded that a project with a scarcity score or water resources necessity score of less than 33 is considered a low water scarcity level. For scarcity point of a project falling within the range of 34-67, it is considered a moderate level, while a project scoring 68 or higher is considered a significant high water scarcity. In cases where the project has moderate to high water scarcity level, it is advisable to undergo further development. However, if the project has sustainability scores below the moderate threshold (less than 55), it is recommended to revise project size, to alter dam location, or to improve project components to achieve a higher total sustainability rating at least within the moderate range.

Application of sustainability indicators

Tables 2 and 3 show summary of 30 reservoirs' basic data and weighting factors of the project's sustainability indicators, whereas Table 4 presents summary of weighting factors of water scarcity assessment. Results of applying indicators' weighting scores for project sustainability assessment are summarized as follows.

1) Sustainability assessment of engineering dimension, one- third or 11 projects were evaluated as low sustainable level.

2) Sustainability assessment of natural resources and environmental dimension, no projects were assessed as low sustainable level.

3) Sustainability assessment of social dimension, five projects were assessed as low level,

4) Sustainability assessment of economic dimension, eight projects were classified as low level.

5) Overall project sustainability, there were no projects defined as low sustainable level, whereas three projects were assessed as medium level and suggested to be upgraded or improved namely, Nam Yuan, Huai Phet Ja Khor, and Huai Poeng Phark.

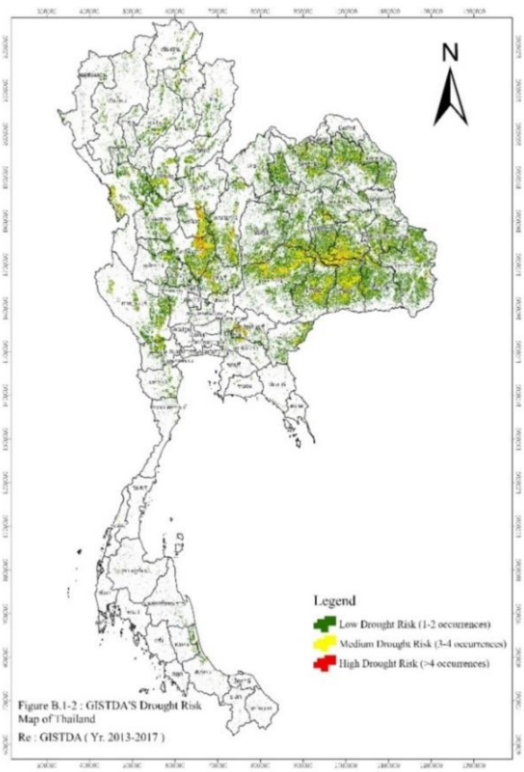

Figure 4 GISTDA’s drought risk map

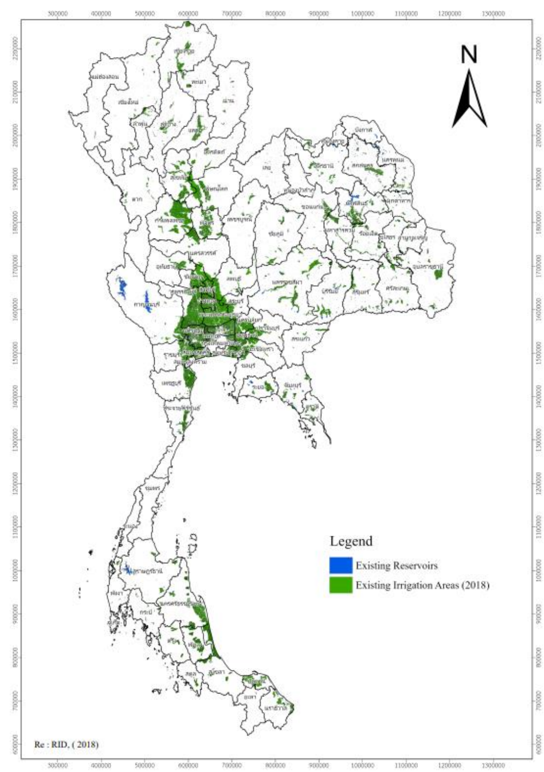

Figure 6 The location map of irrigation areas

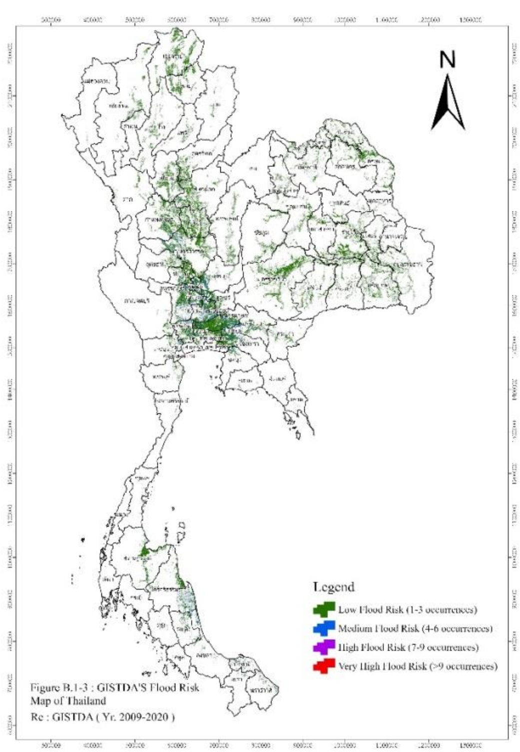

Figure 5 GISTDA's flood risk map

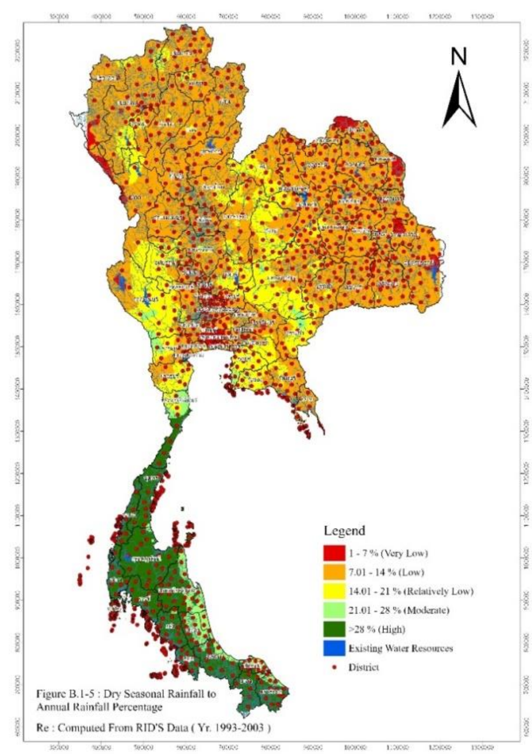

Figure 7 Dry seasonal rainfall to annual rainfall percentage map

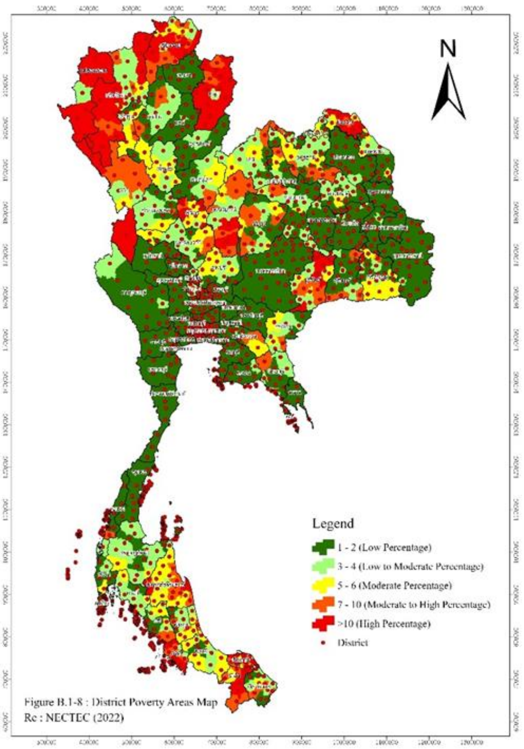

Figure 8 Groundwater potential map

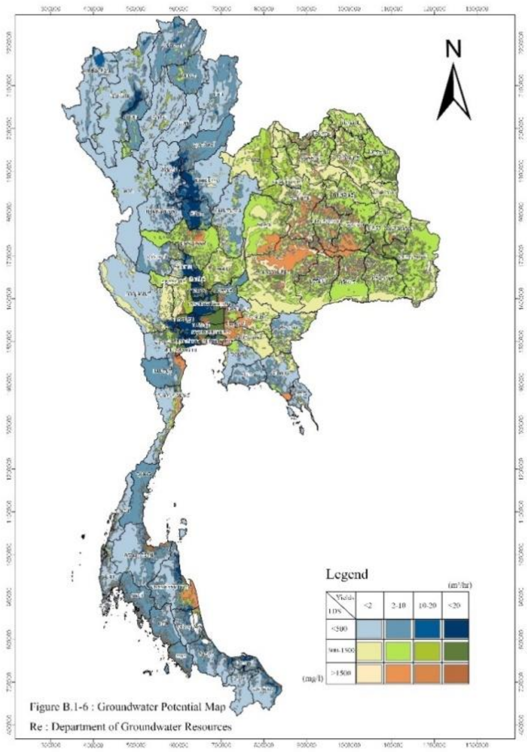

Fig 10 District poverty areas map

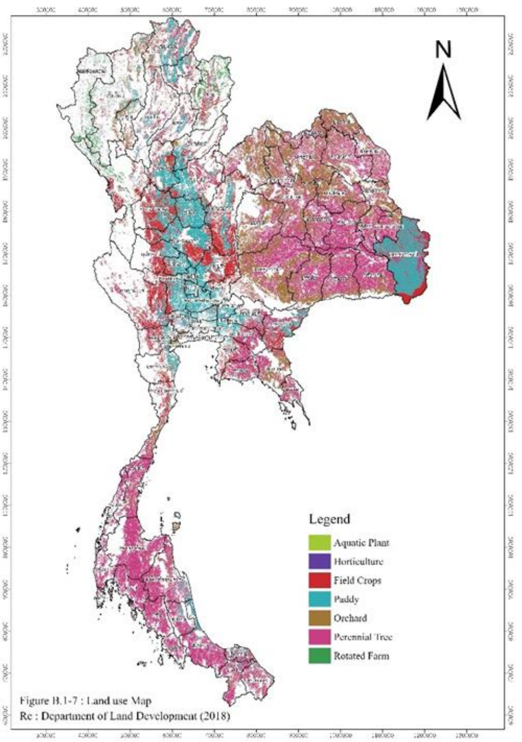

Figure 9 Land use map

6) In term of factor level concerning natural resources and ecology, There were seven projects that were determined low sustainable level namely Klong Yai, Mae Phuak, Huai Satone, Klong Ma Dua, Huai Kha Yung, Khlong Wang Tanode, and Mueng Takua.

7) For project's water scarcity level, only two projects namely Huai Pang Luang and Khlong Chom Phoo were defined as high level whereas the others were middle level.

In summary the established sustainable indicators are applicable complied with the threats and barrier as well as potential and strength of the projects.

Table 2 Summary of basic project components of 30 reservoir projects

Item	Project Features	Unit	Min	Max	Mean
1	Storage Volume	mcm	2.1	295	40.1
2	Retention Area	Rai	87	16,250	2,172
3	Irrigation Area	Rai	1,273	111,300	28,831
4	Dam Crest Length	m.	133	3,000	794
5	Dam Height	m.	11	80	40
6	Construction Cost	MB	149	5,668	1,172
7	Catchment Ares	sq.km	11	677	142
8	Mean Annual Flow	mcm/yr	2.8	266	57
9	Inflow Flood Discharge	mcm/s	35.6	1,428	387

Remark : 1 Rai = 1600 sq.m.

Discussion and Recommendations for Project Enhancement for Sustainability

1) Applying the sufficiency economic concept, comprising moderate scale development together with reasonable outcome and risk management with appropriate impact mitigation plans, would solve unbalance or conflict between economic and environments. Therefore, in case a project's environmental sustainability score is low, modification of project scale, reservoir size, dam relocation will be one of the solution to improve sustainability score level, environmental and social impact, and project feasibility.

2) Reducing the project size by decreasing the storage capacity of the reservoir and the reservoir area in cases where the topography of the reservoir is flat may not significantly affect the sustainability score in the engineering dimension. This is because the indicator value is relative to the unit capacity, and minor changes in engineering size do not have a significant impact on the range of scores in this dimension.

However, the reduction in project size, especially in terms of reservoir capacity or retention area, would result in a better positive impact on natural resources, environments, ecosystem, society, and economic aspects.

3) Nevertheless, in cases where there is no additional revised survey of natural resources due to the reduction in the reservoir area, the sustainability score in the mentioned dimension may not change significantly either, since the scoring interval range of indicators have a wider range of which results are analyzed from wider range of size and varieties of geography, natural resources types and socio-economic characteristics from all regions over the country. Consequently, further studies on scoring range of indicators especially for each region is recommended.

Conclusion

Four dimensions including engineering, natural resources and environment, social and economic are recommended as key dimensions for considering water resource development project's sustainability, whereas the natural resources and environment is the most significant dimension.

There are 14 factors concerning the project sustainability, of which 7 factors that have higher significant weight: wildlife (10.5%), forestry (8.75%), ecology (8.75%), social (8.75%), life value (8.75%), economic feasibility (8%), and opposition (7.5%), respectively.

There are 29 indicators concerning the project sustainability, of which 12 indicators having higher weight: (1) uniqueness, (2) number of opponents per impacted households, (3) water quality, (4) annual cultivated area per unit of reservoir capacity, (5) design flood rate per unit of reservoir capacity, (6) environmental economic feasibility, (7) economic feasibility, (8) proportion of beneficiaries on sufferers (9) conservation area type, (10) Number of compensated households per unit of reservoir capacity (11) endangered wildlife, and (12) biodiversity of wildlife.

There are 5 factors to assess the project's water scarcity level, including geography, existence of irrigation system, hydrology, water demand, and poverty. The poverty, land use, and existence of irrigation system play higher weights. Status of project's water scarcity issue from moderate to high level will be another factor to lessen sustainability level criteria from good to moderate level so that such project could be implemented.

Table 3 Summary of factors and indicators for water scarcity level assessment

Factors / Indicators	Unit	Water Scarcity Level			Gross Weighting Score	Net Weighting Score
		Low (No. of Proj.)	Moderate (No. of Proj.)	High (No. of Proj.)		
1. Geography factor					**100**	**20**
1.1 Drought indicator - Frequency in the past 5 years of droughts.	Years	1-2 (18)	3-4 (8)	≥5 (4)	55	11
1.2 Flooded indicator - Frequency in the past 12 years of floods.	Years	≤4 (26)	5-8 (3)	>8 (1)	45	9
2 Irrigation system existence factor					**100**	**15**
- Irrigation system existence index	-	Partial Irrigated by reservoir. (5)	Partial Irrigated without reservoir. (2)	No Irrigation system. (23)	100	15
3 Hydrology factor					**100**	**20**
3.1 Rainfall variation indicator - Proportion of dry season rainfall to annual rainfall.	%	> 30 (3)	25-30 (5)	< 25 (22)	65	13
3.2 Groundwater potentials indicator					35	7
- Yield	cu.m./hr,	>20 (5)	10-20 (2)	<10 (23)		
- Total Dissolved Solids (TDS)	mg/l	<500 (26)	-	>500 (4)		
4 Water demand factor					**100**	**20**
- Agricultural land use type indicator	Type	Perennial Tree (4)	Field Crops (12)	Orchard/Paddy (14)	100	20
5 Poverty factor					**100**	**25**
- Poverty indicator (Proportion of the poors to district's population.)	%	≤2.5 (15)	2.6-10 (14)	>10 (1)	100	25

Remark : NP = National Park; WL = Wildlife Sanctuation Area; 1A = Watershed Class. 1A; RF = Reserved Forest; 1 Rai = 1,600 sq.m.

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