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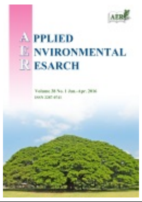

Stakeholder Involvement in Developing Environmental Indicators for the Lam Nam Yang Part 1 Watershed in the Northeastern Thailand

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Abstract

Stakeholder involvement is recognized as critical to successful long-term watershed management. Approaches to developing sustainable watershed management plans are based upon selection and weighting of a set of relevant indicators on which the watershed's sustainability and health can be measured. This study aimed to identify key environmental issues affecting the Lam Nam Yang Part 1 watershed in Thailand, and to work with stakeholders to develop a set of environmental indicators to support sustainable watershed management. The study used a community survey and key informant interviews to obtain stakeholder inputs into the process. Applying the Driver-Pressure-State-Impact-Response (DPSIR) framework, key environmental issues were identified and used to frame environmental indicators for the Lam Nam Yang Part 1 watershed. Key environmental issues identified included drought and water shortage, forest area depletion, biodiversity decline, and soil deterioration. A total of 101 candidate indicators were identified for monitoring the sustainability of the Lam Nam Yang Part 1 watershed, with 31 prioritized.

Keywords: Stakeholder involvement; Environmental indicator; Sustainable watershed management; DPSIR

Introduction

Stakeholder involvement has long been recognized as critical to successful watershed management. With this growing recognition, recent years have seen stakeholder involvement in environmental management processes shifting from a top-down approach to an increasingly bottom-up approach. Successful watershed management requires more than consensus on technological solutions. To ensure long-term sustainability, stakeholders have to work together to set criteria for sustainable management, identify priority constraints, evaluate possible solutions, recommend technologies and policies, and monitor and evaluate impacts [1].

In Thailand, participation of stakeholders in watershed management has increased in recent years. The right of local communities and citizens to participate in management of natural resources was enshrined in the 1997 Constitution. Major ministries, departments and local government agencies responsible for resources management have since adopted a range of approaches to allow communities to exercise this right. Unfortunately, implementation has led to varied results, and several watersheds in the country remain in poor condition, including the watersheds in the Chi River Basin in northeastern Thailand [2-4]. The reason for this lack of progress remains unclear, and there is inadequate information on the true level of engagement with affected local stakeholders in these watersheds. Information is lacking on the level of stakeholder support, and on monitoring processes to measure success or improvement in watershed quality.

Application of the indicator-based approach has been widely used to measure progress towards sustainable watershed management and assess environmental conditions [5-6]. In recent years, a wide range of watershed sustainability and watershed health indicators have been developed to help planners characterize the state of watershed resources and provide inputs to decision makers [7-10]. However, a process is needed to involve stakeholders in developing appropriate indicators to help monitor watershed health and measure improvements across a range of key parameters. This study aims to identify key environmental issues of the watershed and develop a set of watershed indicators specifically the environmental aspect with the involvement of stakeholders at watershed level.

The study area

The Lam Nam Yang Part 1 watershed is located in the Yang Sub-basin, forming part of the Chi River Basin in northeastern Thailand. It covers an area of 1,052.62 km^2 (657,887 rai). The watershed is used predominantly for annual crop production and other agricultural activities. Sticky rice is the main crop for consumption, while jasmine rice is cultivated for trade. Jasmine rice is popular due both to domestic and export market demand, and because of its tolerance to saline soils. After rice, cassava is the second most widely grown crop in the sub-basin despite fluctuating market prices. It is easy to grow and fast to harvest. Other major crops include sugarcane, soybeans, peanuts and green beans, as well as some vegetable crops. Tree fruits such as mango, papaya, sweet tamarind, banana and others are also cultivated in this area. Animal husbandry is also widespread, with cattle, buffaloes, pigs, ducks and hens as well as rice-fish culture considered as supplementary agricultural production [11]. The main river is the Yang River, originating in Kalasin province; it carries approximately 1,336.1 km^3 of surface runoff per annum through the lower parts of the Sub-basin. The topography of the watershed is dominated by the high Phu Phan mountain ranges (about 500 m above mean sea level (MSL)), and flat to undulating hills with average altitude of 200 m MSL. The most important forest conservation areas of the watershed are Phu Phan National Park, Phu Si Tan Wild life Sanctuary, and National Reserve forests. The total population of the region is estimated at approximately 240,000. With an average population density of 134 individuals per km^2. Situated entirely within Kalasin procince, the watershed is divided into six administrative districts (Nakhu, Kuchi Narai, Namon, Somdet, Huay Phung, and Khao Wong) [2]. The Lam Nam Yang Part 1 watershed is shown in Figure 1.

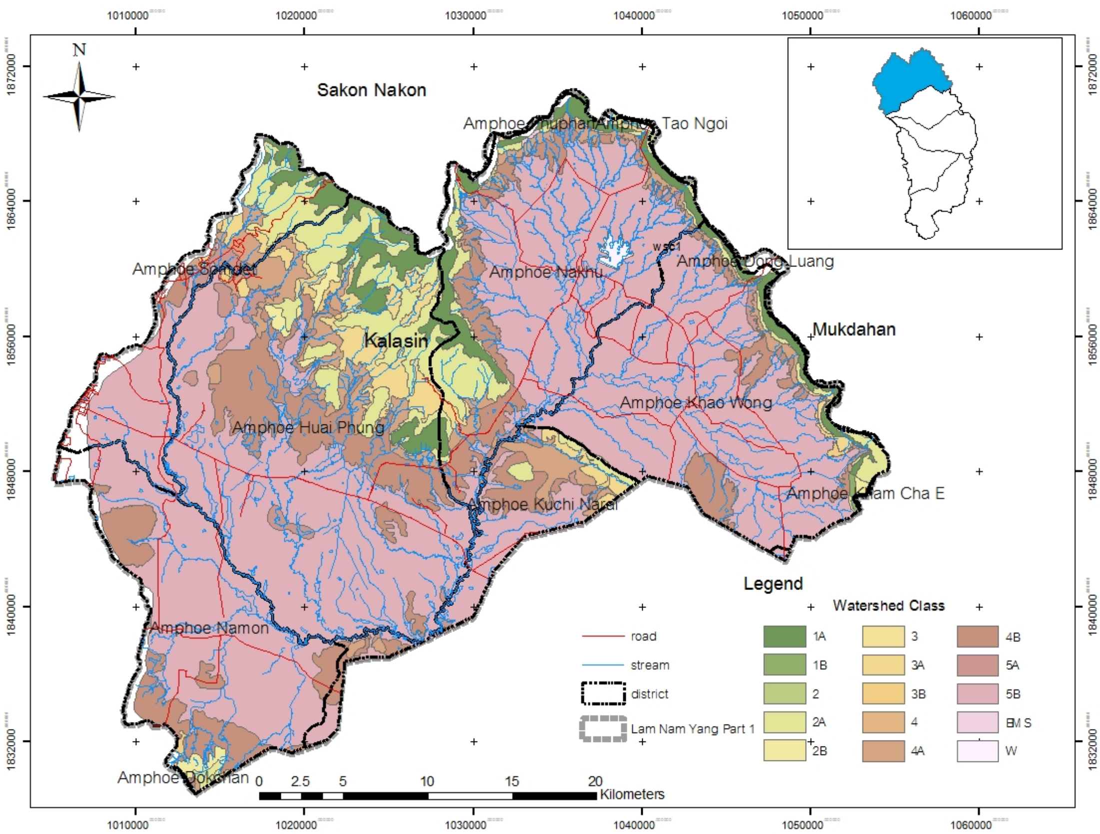

Figure 1 The Lam Nam Yang Part 1 Watershed.

Methodology

The research was carried out using both quantitative and qualitative research methods to develop the indicators with the help of stake-holders. The development of environmental indicators for sustainable watershed management of the Lam Nam Yang Part 1 Watershed consisted of several steps, including analysis of the key environment issues using the DPSIR framework as a determinant for selecting indicators, expert interviews for indicator development and selection criteria, and weighting of selected indicators. Data collection techniques are summarized as follows;

1) Literature review

A literature review was carried out to gather related information, concepts of watershed sustainability, environmental indicators, methods and approaches used in developing indicators, participation of stakeholders, as well as existing indicators used in local, national and international contexts.

2) Questionnaire survey

The questionnaire was designed to elicit the views of respondents on the condition of natural resources and environment in the watershed. A multi-stage sampling method including clustering was used to determine the group of samples in the study, in which 385 interview samples were collected. The questionnaire included both multiple-choice questions (closed-ended), and open-ended questions to which respondents could express their views and opinions freely. The questionnaire covered respondent information and demographics- their economic and social status, health and environmental hygiene, their perceptions on natural resources and environment in the watershed, and perceptions on how natural resources should be best managed to ensure watershed sustainability in the long term. The results were used to prepare baseline information for the study area, which was then used as the data for DPSIR of key environmental issues and the indicator development process.

3) Key informant interviews

The key informant interview aimed to obtain an overview of the background and status of the local environmental situation. Purposive and snowball sampling methods were applied to select a total of 25 key informants from government agencies, local organizations, private sectors, and the general public. Key informant interviews were carried out using semi-structured interviews with open-ended questions. The interview responses were used to evaluate the current state of natural resources and environmental issues in the watershed.

4) Expert consultation

An expert consultation with 9 experts was conducted to collect opinions and suggestions for the indicator development process to be applied in the study, and to select the set of indicators. The experts were selected by purposive sampling, based on their experience and understanding of the indicator development process. From the total nine experts, 2 were chosen from academic institutions, and 1 each from the Office of Natural Resources and Environmental Policy and Planning, Office of the National Economic and Social Development Board, Department of Water Resources, Department of National Parks, Wildlife and Plant Conservation, Regional Environment Office 10, the Land Development Department, and a non-governmental organization. To acquire a primary list of indicators, a scoping exercise was conducted, starting from those indicators already identified, analyzed, and described in the literature. Candidate indicators were then selected based on their relevance to the issues identified in the earlier analysis of the state of the watershed environment. Subsequently, experts assisted in selecting indicators using the DPSIR framework as outlined by UNEP [12]. The framework was used as an outline for experts to help in developing indicators to match the local environmental issues identified.

The DPSIR framework organizes indicators into five categories: Driving force, Pressure, State, Impact and Response indicators, where Driving force (D) refers to human activities and natural factors that may have an environmental effect on the watershed; Pressure (P) is the direct effect of the driving force; State (S) is the condition of the watershed resulting from both natural and human factors; Impact (I) means the environmental effect of a human or ecological pressure; and Response (R) refers to the human response (e.g. habitat restoration, pollution reduction) usually to a pressure or state categories as shown in Figure 2.

5) Local expert consultation

Through in-depth interviews, local experts were engaged in the indicator development process to help in selecting and weighting of candidate indicators. Local experts were selected by purposive sampling of representatives involved and experienced in managing or applying the indicators in the watershed. A total of 12 representatives were interviewed, comprising 7 from government agencies, 3 from local organizations and 2 representatives from the Yang sub-basin committee. The local experts were interviewed in two rounds:

Round 1: each local expert was asked to choose the indicators from a list, based on a set of criteria provided. These criteria were processed and adapted from information collected by Dawson [13] and Von Schirnding [14] together with the recommendations of experts to create a set of selection criteria for indicator development. To define appropriate scores pertaining to each criteria, the methods of

Doungsuwan, the Fraser Basin Counsil, and Foushee were adapted and applied [9, 15-16]. All local experts scored each of the criteria from 1 (low/least significant) to 4 (high/most significant), then the total scores of 3 criteria together was used to find the average. Any indicator receiving an average score of 3 or above was considered as passed for selection. The rationale for weighting the indicators is shown in Table 1.

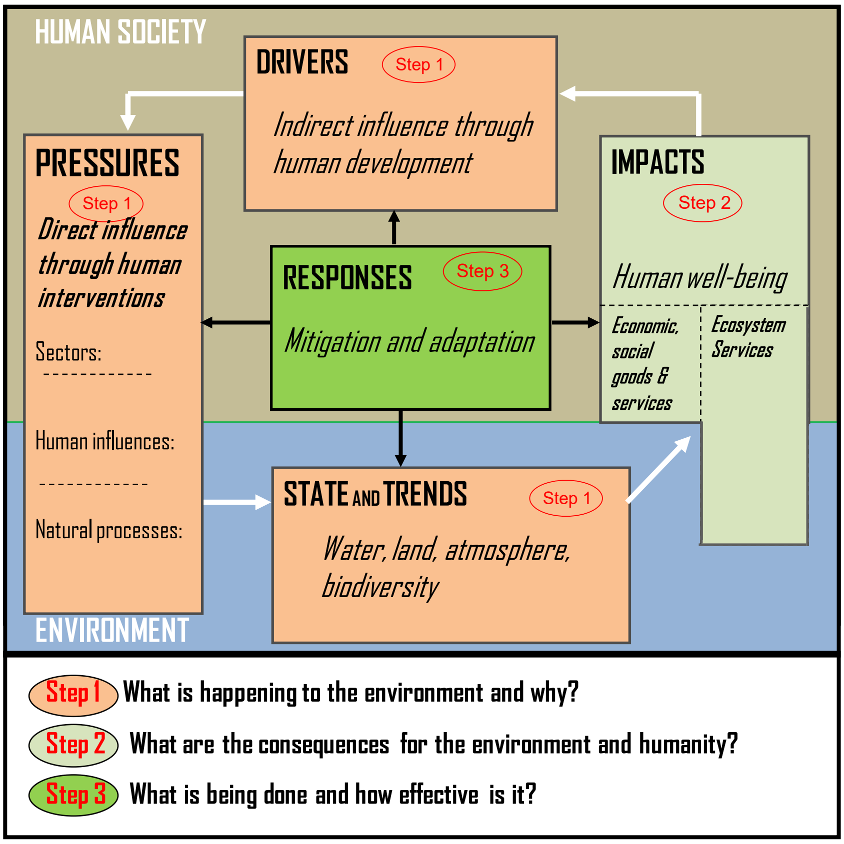

Figure 2 The DPSIR Framework for developing environmental indicators [12].

Table 1 Scores of each criteria in the selection of potential environmental indicators

Score	**Criteria**		
	Relevance to Sustainable of Yang watershed	**Relevance to stakeholders**	**Measurability and understandable by locals**
1	Minimum relevance to sustainability of watershed.	Stakeholders paid less attentions and less utilization.	It should be measurable and understandable in minimum levels.
2	Moderate relevance to sustainability of watershed.	Stakeholders paid moderate attentions and moderate utilization.	It should be measurable and understandable in moderate levels.
3	High relevance to sustainability of watershed.	Stakeholders paid high attentions and high utilization.	It should be measurable and understandable in high levels.
4	Maximum relevance to sustainability of watershed.	Stakeholders paid highest attentions and highest utilization.	It should be measurable and understandable in highest levels.

Round 2: each local expert was asked to weight the potential indicator in order of significance using the Multi Criteria Analysis (MCA) as the rating method to determine weighting and the priority of indicators [17-19]. The steps for weighting indicators were as follows:

- Stakeholders were assigned a ratio scale for each indicator from 0-100, where 0 means the factor is least important, and 100 means the factor is most important. After respondents had scored all the candidate indicators, the data was calculated using a spreadsheet.
- Original weight = Ratio scale/minimum Ratio scale
- Normalized weight = Original weight/Sum (original weight)

Result and discussion

1) Key environmental issues in the watershed

1.1) Drought and water shortage

Drought and water shortage in the Lam Nam Yang Part 1 Watershed was the most serious issues identified in both the survey and interviews. Droughts triggered by climate change were increasingly frequent and prolonged, and the watershed ecosystem was assessed to be changing as a result of community expansion, economic activity, including expansion of agricultural areas, both irrigated and rainfed. Dry season water shortages were frequent, while the potential for local water storage was limited. Reservoirs, natural wetlands and available ponds were still unable to store sufficient water for the area's total needs for agriculture, consumption and industry [20]. Over the last 10 years from 2000 to 2010 in the watershed areas, average rainfall was 1,494.4 mm with an average of 109.1 rainy days. However, in 2002, 2003 and 2005, the volume of rainfall in the watershed was unusual. It was found that the El Niño phenolmenon had drastically reduced the number of rainy days in 2003. That year saw average annual rainfall of 1,218.5 mm, with a total of 95 rainy days. The El Niño phenomenon is believed to be the cause of the severe drought in the watershed during that year [21].

From the results of the survey, most people (61.3 %) believed that the shortage of water for agriculture was caused by the deterioration of natural storage, followed by insufficient storage (53.3 % of respondents); climate change (shifting in rainfall patterns) (45.5 %, of respondents); insufficient irrigated areas (32.2 %); increasing agricultural areas (21.8 %); increased water demand development (21.0 %), prevailing sandy soils with low water retention capacity (17.4 %); and others (0.5 % of respondents).

This water shortage problem resulted in an average 68.1 % reduction in crop yields followed by drought. Over 50.6 % of these drought-affected land could not be fully utilized. There was a 47 % shortfall in water for cropping, resulting in widespread socio-economic damage (e.g. household's distress, financial difficulties, unemployment for the people who earned a living from water-dependent activities, failed or poor crops) by 36.6 %, water use conflicts by 23.6 %, and others by 1.3 %.

1.2) Forest area depletion

Forest in the Lam Nam Yang Part 1 watershed are under increasing threat from human activities and natural disasters. The current forest area is about 226.70 km^2, representing an estimated 21% of the watershed area. However, the actual forest area remaining is only 57.24 % of the area designated as National Reserve forest. It was found that these areas suffered extensively from encroachment and forest converted to agriculture, with crops such as paddy rice, corn, cassava, sugarcane, papaya, rubber and others widely grown. The encroachment was even incentivized by the government's promotion of monoculture cash crop cultivation including hemp, cassava and sugarcane 10 years ago [11].

Wildfire is one of the most serious challenges in the watershed, with wildfires breaking out every year in Phu Phan National Park and other areas of dry dipterocarp forests, mixed deciduous forests and dry evergreens. The statistics indicate 358 incidents, with 4.56 km^2 of forest destroyed from 2005 to 2013 [22].

The survey indicated that deforestation in conservation areas was caused primarily by (a) illegal logging (46.5 %); (b) overexploitation of forest products (46 %); (c) forest fires (40 %); (d) agricultural expansion into forest land (20 %); (e) development projects (11.4 %); (f) human settlement in forest areas (9.9 %); (g unclear forest boundaries (6.5 %); and (h) others (e.g. poverty, population change) (2.1 %).

The survey of views on the drivers of deforestation revealed that 67.3 % of respondents believed that deforestation was caused mainly by (a) drought and lack of moisture (67.3 %); (b) surface soil erosion (41.3 %); (c) damage to habitats and biodiversity (32.7 %); (d) water runoff and severe soil erosion (24.2 %); (e) lack of resources for carbon dioxide capture (17.7 %); and (f) other causes (1 %).

1.3) Declining biodiversity

The major habitats for animal and plant species in the Lam Nam Yang Part 1 Watershed are the Phu Phan National Park and the Phu Si than Wildlife Sanctuary [23-24]. The abundance of plants and wildlife in these areas was reported by Misit et al. [25]; however, many species have been reported to be in continuous decline over the past 30 years [25]. Key informants commented that forest destruction in the watershed caused inclement weather, higher temperatures and arid weather. Moreover, it affected the amount of surface and groundwater. Due to habitat degradation, the abundance of wild animals and aquatic animals is seriously diminished. In the past, the villagers could readily collect wild products and herbs for traditional medicine; these products are now rarely seen. This information is supported by the study of Naeem et al. that biodiversity loss could alter both the magnitude and the stability of ecosystem processes [26]. A less diverse ecosystem may be less effective in regulating environmental perturbations such as drought, and may also deliver fewer ecosystem services such as maintaining soil fertility and soil moisture, regulating water flow and quality, and, boosting crop productivity. Pest and disease cycles may also become more unpredictable as biodiversity declines [26].

The survey results indicate respondents' views on the causes of biodiversity loss, both terrestrial and aquatic. About 57.9 % of respondents believed biodiversity loss was caused by habitat destruction, 41.3 % by climate change, 36.1 % by overexploitation of the forest, 23.4 % by wildlife hunting, 19.5 % by illegal trading of forest products and wildlife, 10.1 % by invasive species, with 2.1 % advancing other reasons (e.g. market demand, or lack of awareness) as the main driver of biodiversity loss.

The decline in plant and animal species affected the species are at risk of extinction the most (61.4 %), caused ecological imbalance and instability (37.9 %), affected the livelihood of people in local communities (34.8 %), resulted in food security (23.9 %), reduced the ecosystem productivity (21.3 %), and caused other difficulties (1 %).

1.4) Soil deterioration

Over time, soil deterioration has resulted in much reduced agricultural productivity. Key informants emphasized that the causes included inadequate knowledge of farmers, who damaged oil health through excessive chemical use and poor land husbandry. Soil erosion was one of the most significant problems, including soil surface erosion, loss of soil nutrients, reduction in soil abundance, reduced crop yields per unit area, and lack of water. The soil erosion rate in the Lam Nam Yang Part 1 watershed ranged from mild (covering 965.40 km^2, or 89.5 % of the watershed area; moderate (covering 103.89 km^2 or 9.63 % of the total area); severe (covering 8.36 km^2 or 0.77 %), or highly severe (covering 0.76 km^2 or 0.07 % of the total area) [11].

According to the survey, the majority of respondents (62.3 %) believed that the lack of fertile soil was due to excessive use of chemical fertilizers, followed by the wide-spread practice of burning of rice stalks and crop wastes (47.0 %); lack of soil conservation measures and poor land husbandry (45.2 %); consecutive monocropping for a long time (32.5 %); naturally occurring poor soil structure (31.7 %); bare soil, where fertile topsoil has been washed away by the rain (27.5 %); and other reasons (1.0 %).

The survey findings also revealed that most respondents (64.7 %) believed that soil deterioration reduced crop yields; whilst 48.8 % believed that more expenditures were needed for land and soil improvement. 46.8 % of respondents believed in the continuing need for chemical fertilizers and pesticides.

2) DPSIR of key environmental issues

The survey of the environment situation in the watershed revealed many environmental problems, including forest encroachment, biodiversity loss, and loss in soil and water resources. These issues affect the long-term sustainability and ecosystem services delivered by the watershed, and the impacts were well described by local residents and key informants. Important catalysts identified as drivers of this broad-based erosion of the integrity of the watershed included climate variability (shifts in rainfall patterns and increasing rainfall intensity), land use changes due to expansion of agriculture in the exploitation of finite natural resources, intensive farming and overuse of chemicals and changes in land use all resulted in a deteriorating natural resource base and environmental quality, as well as far-reaching consequences for human health and quality of life for local residents.

Identification of these key drivers of watershed deterioration and their relationships was accomplished via the DPSIR framework, as shown in Figure 3.

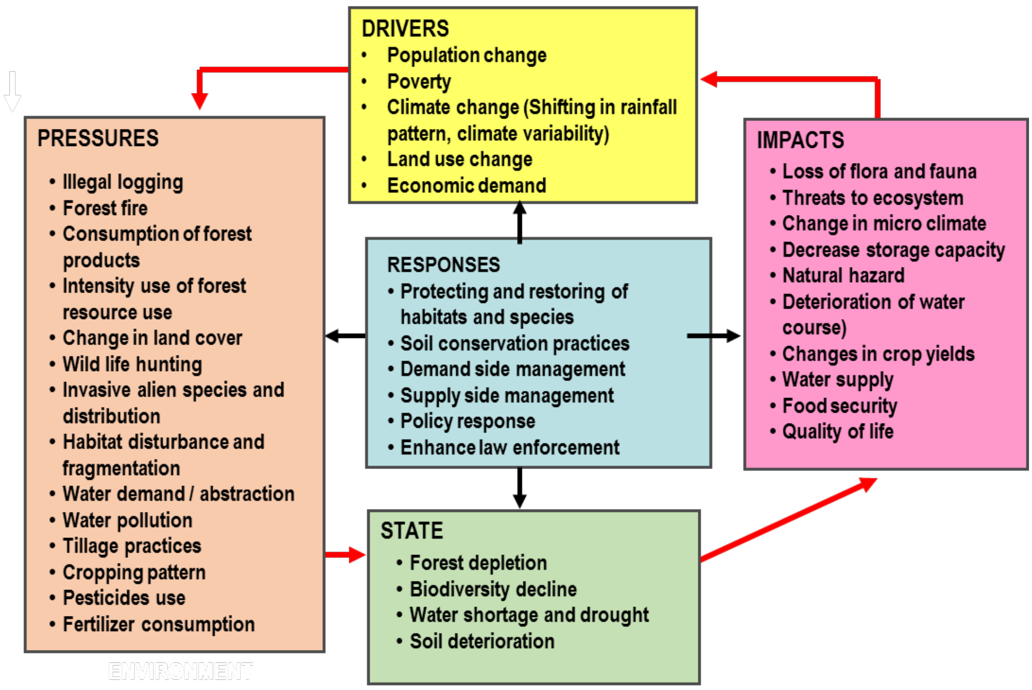

Figure 3 DPSIR for key environmental issues of the Lam Nam Yang Watershed Part 1.

3) Environmental indicators of the Lam Nam Yang Part 1 Watershed

3.1) Expert selection

An initial list of candidate environmental indicators was derived from the literature review by selecting the most relevant within the DPSIR framework, and presenting in the form of an "indicator sheet". Experts assisted in selection of 101 candidate indicators for each framework component. The selected indicators comprise 13 indicators associated with issues including population change, poverty, climate change, land use change, and economic demand. The selected 24 pressure indicators covered illegal logging, forest fires, consumption of forest products, change in land cover, wildlife hunting, invasive alien species and distribution, habitat disturbance and fragmentation, water demand, water pollution, tillage practices, pesticide use and fertilizer concentration. The selected 24 state indicators portrayed key issues of watershed condition, including forest resources, biodiversity, water resources, and soil resources. The selected 21 impact indicators reflected changes in the environment that have impacts on the functioning of watershed, human health and socio-economic performance namely loss of flora and fauna, threats to ecosystem, change in micro climate, decrease storage capacity, natural hazard, deterioration of water courses, changes in crop yields, water supply, food security, and quality of life. The selected 19 response indicators referred to the responses by individuals and groups, and government attempts to prevent, protect, conserve, or adapt to changes of undesired impact at any point along the chain between drivers and impacts. They outline the issues of protecting and restoring habitats and species, soil conservation practices, supply-side and demand-side management, policy responses, and enhanced law enforcement.

3.2) Local expert selection

Following the expert process, local experts selected potential indicators using three criteria for selection described in the methodology section above. The results of selection based on scores received as shown in Supplementary Material 1. In all, 31 indicators were found with an average score over 3, based on the views of local experts. The selected key indicators for the watershed are highlighted in red in the list of 101 indicator (Figure 4).

After scoring the potential indicators, local experts gave the weight of every indicator using Multi Criteria Analysis (Ratio estimation). The results of scoring and weighting of 31 potential environmental indicators are shown in Supplementary Material 2. The ranking of indicators by local experts showed that indicators related to water resources received a high weighting, including overall reservoir stocks, water levels, frequency, duration and extent of water shortages, water use by sector, changes in crop yields, and decreased storage capacity. These indicators corresponded to the concerns of local people expressed in the survey results and the stakeholders' views on the water status of the watershed. "Shifting rainfall patterns" was allocated the highest weight among the driver indicators. This is not surprising, considering the outcomes of a study conducted by the Secretariat of the Chi River Basin Committee [27], which noted observations by residents in the watershed of variations in monsoonal weather patterns in recent years, that have led to increased uncertainty for farmers in their rice growing calendar.

The pressure indicators such as "Application rates of different pesticide categories" gained interest because it reflected the threat impact of agricultural pesticide usage to human health and the environment. Ruangchai and Inmuong [28] investigated farmers' health impact on pesticide use (organophosphates and carbamates) in Lamhuay Lua Sub-district in the watershed, and pointed out that improper pesticide use carried serious human health impacts.

The indicators of "Distribution of land-cover types across the total watershed area", "Area damaged by fire", and "Forest area damaged by illegal logging" assess the extent and nature of land cover and land use within the watershed. These indicators also reflect the extent of degradation of forest resources in the watershed, clearly evident in the conversion of forest to other categories of land use [11].

The indicators "Improve water storage capacity", "Protected area as a percent of total watershed area", "Area of forest plantation", "Forest fire monitoring and controlling mechanism", "% of farmers practicing soil and water conservation technologies", and "Planting cover crops" help identify actions needed at individual, community group and government agency levels to remedy problems caused by declining watershed health. Some actions can be taken at farm level, such as conservation of soil and water, for example by strip cropping, micro- or drip irrigation, ditches, and soil sediment traps along watercourses. At higher levels, local governments or central regulatory bodies could take enforcement measures.

The selection process reduced the 101 candidate indicators to a final set of 31 final indicators. Comparing with previous research into sustainability indicators development for catchments, it is apparent that each indicator set is unique, depending on diverse factors [7-10, 15, 29-31]. The differences might be from scale of the indicator applied, goal or purpose of the indicator used, indicator frameworks, criteria selections, weighting of indicator, and participation of stakeholders. Different types of indicators; e.g. descriptive, showing trends, communication, assessment, and predicting future; serve different purposes [13].

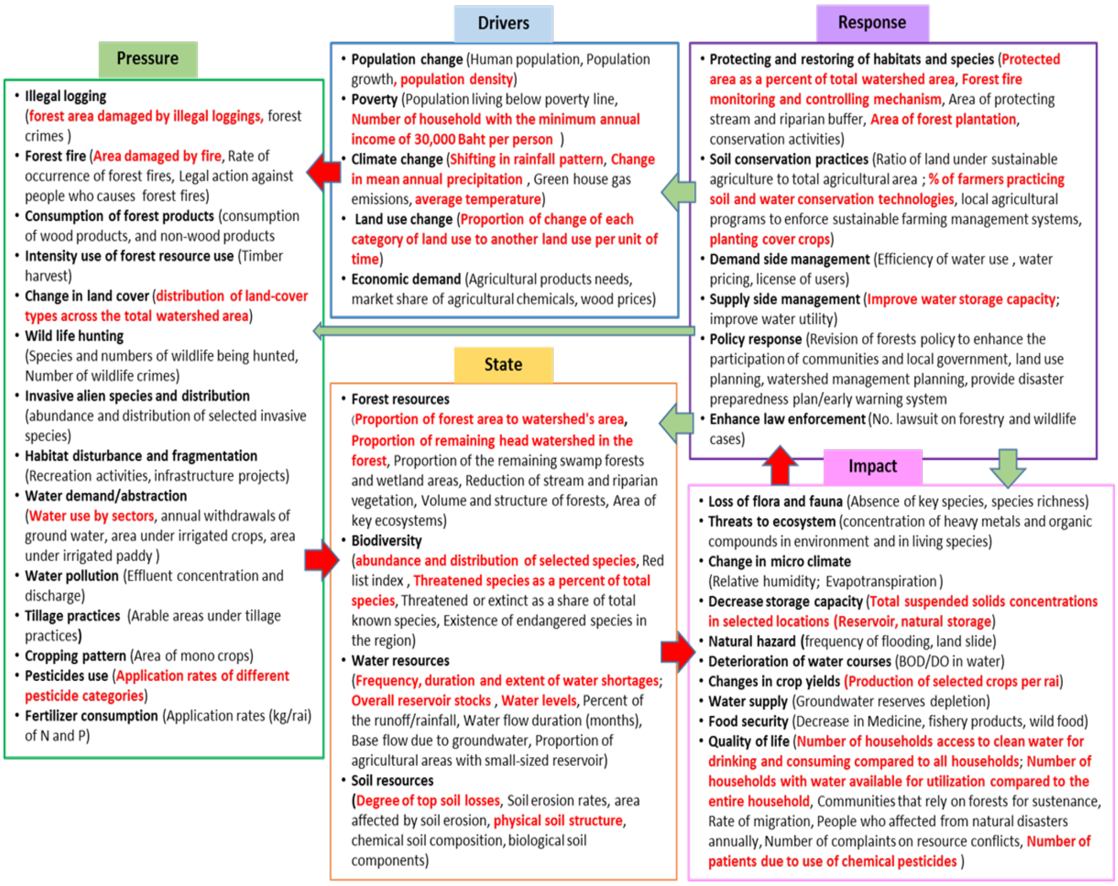

Figure 4 Candidate environmental indicators as part of the experts' indicator list.

Based on this study, use of the DPSIR framework might lead to ignorance in dealing with multiple attitudes and definitions of issues by local people, as noted by Svarstad et al. [32]. The process of developing environmental indicators depended heavily on the participation and perspectives of the experts selected, as well as the nature of the engagement with stakeholders. In this study, each expert was selected for his/her unique domain expertise. While expert opinion is required to develop a set of candidate indicators, the final core indicators must also satisfy the needs and requirements of local stakeholders too. An attempt should therefore be made to include the requirements of stakeholders in general [31]. Based on this study, the involvement of local people in developing indicators was quite low because the selection of stakeholders was very specific and limited to those familiar with the preparation and use of indicators.

The criteria used in the selection and weighting was important for the selection of potential environmental indicators. In this study, the main criteria for selection and weighting were from the review of documents and expert's opinions, so the criteria or weight might cause different results of indicator selection. However, in terms of indicators selected in this study, all stakeholders and local experts agreed that it could be applied to measure the sustainability of the watershed.

Conclusion

It was found that the Lam Nam Yang Part 1 watershed faces numerous and serious environmental challenges. Key environmental issues (water shortage, loss of soil fertility, forest area depletion, and decline of plant and animal species) affected the sustainability and ecosystem functions of the watershed. The impacts were observed and described by residents and key informants. The important driving forces as problems catalysts included climate variability, land use change due to agricultural area expansion, economic or market demand, poverty, and population change. Exploitation of natural resources, farming, overuse of chemicals and changes in land use were all considered as pressure indicators, driving adverse changes in natural conditions and environmental quality. Such changes would affect physical and biological conditions, as well as human health, and modified or attenuated delivery of essential ecosystem functions of the watershed. Identification of key environmental issues in the DPSIR framework could help in building of a useful and locally relevant set of indicators.

The development of environmental indicators for of the Lam Nam Yang Part 1 watershed consisted of several steps including identification of key environment issues using DPSIR as a framework for indicator selection, expert interviews to identify a set of candidate environmental indicators, and selection of final indicators by local experts. The experts selected 101 candidate indicators for monitoring watershed health; the number was reduced to a final set of 31 indicators prioritized by key stakeholders and local experts. It is expected that the indicator set may benefit stakeholders in understanding and addressing critical issues in order to achieve sustainable watershed management. Development of watershed indicators through stakeholder involvement is a complex and essential process as its goal is to use multiple criteria to measure overall watershed health.

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Supplementary Material 1 Scoring of each environmental indicators

Driver Indicator	Pressure Indicator	State Indicator	Impact Indicator	Response Indicator
Human population (2.81) Population growth (2.83) Population density (**3.36**) Population living below poverty line (2.86) Number of household with the minimum annual income of 30,000 Baht per person (**3.28**) Shifting in rainfall pattern (**3.11**) Change in mean annual precipitation (**3.22**) Greenhouse gas emissions (2.92) Average temperature (**3.25**) Proportion of change of each category of land use to another land use per unit of time (**3.11**) Agricultural product needs (2.72) Market share of agricultural chemicals (2.67) Wood products (2.78)	Volume of tree fellings (2.75) Forest area damaged by illegal logging (**3.33**) Forest crimes (2.86) Area damaged by fire (**3.39**) Rate of occurrence of forest fires (2.75) Legal action against people who causes forest fires (2.78) Consumption of wood products (2.86) Consumption of non-wood products (2.94) Timber harvest (2.81) Distribution of land-cover types across the total watershed area (**3.00**) Species and numbers of wildlife being hunted (2.83) Number of wildlife crimes (2.78) Abundance and distribution of selected invasive species (2.94) Recreation activities (2.86) Infrastructure projects (2.75) Water use by sectors (**3.03**) Annual withdrawals of ground water (2.97) Area under irrigated crops (2.94) Area under irrigated paddy (2.83) Effluent concentration and discharge (2.92) Arable areas under tillage practices (2.86) Area of mono crops (selected crops) (2.81) Application rates of different pesticide categories (**3.33**) Application rates (kg/rai) of N and P (2.78)	Proportion of forest area to watershed's area (**3.17**) Proportion of remaining head watershed in the forest (**3.22**) Proportion of the remaining swamp forests and wetland areas (2.75) Reduction of stream and riparian vegetation (2.78) Volume and structure of forests (2.86) Area of key ecosystems (2.75) Abundance and distribution of selected species (**3.33**) Red list index (2.81) Threatened species as a percent of total species (**3.42**) Threatened or extinct as a share of total known species (2.83) Existence of endangered species in the region (2.81) Frequency, duration and extent of water shortages (**3.19**) Overall reservoir stocks (**3.69**) Water levels (**3.64**) Percent of the runoff/rainfall (2.75) Water flow duration (months) (2.89) Base flow due to groundwater (2.78) Proportion of agricultural areas with small-sized reservoir (2.81) Degree of top soil losses (**3.47**) Soil erosion rates (2.94) Area affected by soil erosion (2.81) Physical soil structure (**3.44**) Chemical soil composition (2.89) Biological soil components (2.83)	Absence of key species (2.81) Species richness (2.83) Concentration of heavy metals and organic compounds in environment and in living species (2.92) Relative humidity (2.86) Evapotranspiration (2.78) Total suspended solids concentrations in selected locations (Reservoir, natural storage) (**3.33**) Frequency of flooding (2.83) Land slide (2.92) BOD/DO in water (2.78) Production of selected crops per rai (**3.28**) Groundwater reserves depletion (2.83) Decrease in Medicine (2.86) Fishery products (2.86) Wild food/products (2.92) Number of households access to clean water for drinking and consuming compared to all households (**3.58**) Number of households with water available for utilization compared to the entire household (**3.17**) Communities that rely on forests for sustenance (2.83) Rate of migration (2.83) People who affected from natural disasters annually (2.86) Number of complaints on resource conflicts (2.78) Number of patients due to use of chemical pesticides (**3.17**)	Protected area as a percent of total watershed area (**3.50**) Forest fire monitoring and controlling mechanism (**3.00**) Area of protecting stream and riparian buffer (2.89) Area of forest plantation (**3.17**) Conservation activities (2.83) Ratio of land under sustainable agriculture to total agricultural area (2.86) % of farmers practicing soil and water conservation technologies (**3.17**) Local agricultural programs to enforce sustainable farming management systems (2.92) Planting cover crops (**3.08**) Efficiency of water use (2.86) Water pricing (2.83) License of users (2.81) Improve water storage capacity (**3.17**) Improve water utility (2.75) Revision of forests policy to enhance the participation of communities and local government (2.92) Land use planning (2.78) Watershed management (2.75) Provide disaster preparedness plan/early warning system (2.81) No. lawsuit on forestry and wildlife cases (2.72)

Supplementary Material 2 Ranking of potential environmental indicators

No.	Type	Issue	Indicator name	Ratio Scale	Original Weight	Normalized Weight
1	State	Water resources	Overall reservoir stocks	90.83	3.40582	0.04928
2	State	Water resources	Water levels	86.67	3.24959	0.04702
3	State	Water resources	Frequency, duration and extent of water shortages	85.00	3.1871	0.04611
4	Pressure	Water demand/abstraction	Water use by sectors	80.83	3.03087	0.04385
5	Impact	Changes in crop yields	Production of selected crops per rai	72.50	2.71841	0.03933
6	Impact	Decrease storage capacity	Total suspended solids concentrations in selected locations (Reservoir, natural storage)	71.67	2.68716	0.03888
7	Driver	Climate change	Shifting in rainfall pattern	66.67	2.49969	0.03617
8	Pressure	Pesticides use	Application rates of different pesticide categories	65.83	2.46844	0.03571
9	State	Forest resources	Proportion of forest area to watershed's area	65.83	2.46844	0.03571
10	State	Soil resources	physical soil structure	65.83	2.46844	0.03571
11	Pressure	Change in land cover	distribution of land-cover types across the total watershed area	65.00	2.4372	0.03526
12	State	Forest resources	Proportion of remaining head watershed in the forest	65.00	2.4372	0.03526
13	Pressure	Forest fire	Area damaged by fire,	61.67	2.31221	0.03345
14	State	Biodiversity	abundance and distribution of selected species	61.67	2.31221	0.03345
15	Impact	Quality of life	Number of patients due to use of chemical pesticides	59.17	2.21847	0.0321
16	State	Soil resources	Degree of top soil losses	57.50	2.15598	0.03119
17	Impact	Quality of life	Number of households with water available for utilization compared to the entire household	57.50	2.15598	0.03119
18	Driver	Climate change	average temperature	55.83	2.09349	0.03029
19	Driver	Land use change	Proportion of change of each category of land use to another land use per unit of time	55.83	2.09349	0.03029
20	Driver	Population change	population density	55.42	2.07787	0.03006
21	State	Biodiversity	Threatened species as a percent of total species	55.00	2.06224	0.02984
22	Response	Supply side management	Improve water storage capacity	55.00	2.06224	0.02984
23	Response	Protecting and restoring of habitats and species	Protected area as a percent of total watershed area	52.50	1.9685	0.02848
24	Pressure	Illegal logging	Forest area damaged by illegal logging	48.33	1.81227	0.02622
25	Response	Protecting and restoring of habitats and species	Area of forest plantation	48.33	1.81227	0.02622
26	Response	Protecting and restoring of habitats and species	Forest fire monitoring and controlling mechanism	45.83	1.71854	0.02486
27	Impact	Quality of life	Number of households access to clean water for drinking and consuming compared to all households	42.50	1.59355	0.02306
28	Driver	Climate change	Change in mean annual precipitation	41.67	1.5623	0.0226
29	Response	Soil conservation practices	% of farmers practicing soil and water conservation technologies	41.67	1.5623	0.0226
30	Driver	Poverty	Number of household with the minimum annual income of 30,000 Baht per person	39.58	1.48419	0.02147
31	Response	Soil conservation practices	planting cover crops	26.67	0.99988	0.01447
				TOTAL	69.1164	1