A Combined DPSIR Framework and Logical Framework Approach for Sustainable Water Resources Management in the Lagoon Floodplain

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ABSTRACT

This article describes a combination of the driver-pressure-state-impact-response (DPSIR) framework and the logical framework approach (LFA) to develop water management strategies for a lagoon floodplain in Thailand. The DPSIR framework identified the cause-effect relationship between water and anthropogenic activities. LFA developed management strategies based on a systematic and logical approach. DPSIR analysis for the issue of water shortages for irrigated areas revealed the need for income from agriculture is a major driver, as indicated by agricultural development policy. The driver exerted pressure on increasing irrigation water demand, which increased the risk of a water shortage. The impact of water shortage was indicated by loss of farmer income. Existing responses led to inadequate problem-solving, for example, the promotion of mixed farming. Using data captured from DPSIR analysis for LFA analysis, proposed strategies to address the root causes of "ineffective irrigation water allocation" focused on improving (1) the performance of rotating irrigation systems; (2) monitoring water allocation; and (3) water use efficiency. The strategies developed using the combined DPSIR framework and LFA are effective because: (1) this method provides insight into complex water systems; (2) the strategies are developed logically to solve the problem at its root cause; and (3) there is intensive stakeholder participation and in-depth study of the area. This method is a helpful tool for developing a management strategy for a complex water system and is suitable for application by decision-makers. Stakeholder verification is required for future research to ensure that the strategies are appropriate and capable of being implemented.

1. INTRODUCTION

Water-related issues are often complex and challenging to address. Understanding the entire system associated with water management is required to manage water effectively (Enteshari and Safavi, 2021). Therefore, tools that can be used to structure problems and help policymakers address complex water issues are required. Previous studies have shown that the DPSIR framework is an analytical framework essential in promoting policy and regulation design to manage ecosystems effectively (Gari et al., 2015; Roy et al., 2017; Chen et al., 2022). DPSIR was developed in the late 1990s by the Organisation of Economic Cooperation and Development and the European Environment Agency to help decision-makers structure and organise cause-effect relationships between environmental and human systems (OECD, 1993; EEA, 1999; Tscherning et al., 2012). It identifies the cause-effect relationships in five economic and social development categories: driving forces (D) that exert pressure (P) on the environment; changes in the state of the environment (S) and impacts (I) on the ecosystem, human health, and other materials; and society's preventive, adaptive, or curative solution responses (R) to the driving forces, pressures, states, or impacts (Jago-on et al., 2009). DPSIR has been wildly used for analysing environmental problems emanating from human

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activities in policy-making and research (Gari et al., 2018; Lu et al., 2022; Agramont et al., 2022), including water issues (Kagalou et al., 2012; Hashemi et al., 2014; Gari et al., 2018; Ashfaq et al., 2018; Lu et al., 2022). Hashemi et al. (2014) found the framework useful for analysing the changing state of floods, structuring data, and examining leverage points at which appropriate responses can be exerted.

Although DPSIR was widely applied, oversimplifying the complex reality of socio-ecological systems was criticised (Wang et al., 2018; Agramont et al., 2022). As the complexity of the socio-environmental systems relies on several layers of social, political, and economic institutions and the environmental consequences behind their interactions (Teodosiu et al., 2009), the simplicity of DPSIR can be misguiding, ignoring the possible synergistic relations existing between DPSIR categories (Maxim et al., 2009). Thus, the responses defined by DPSIR analysis governed by a standardised framework may disregard such aspects. In addition, DPSIR does not explicitly prioritise responses and cannot individually determine the effectiveness of each response when working with complex systems (Gari et al., 2015; Malmir et al., 2021). To define responses that consider relevant layers under D-P-S-I-R categories and determine the effectiveness of DPSIR responses, there is a need to use other tools with this framework.

The logical framework approach (LFA) is a strategic planning and project management methodology that guides the systematic and logical analysis of key interrelated elements that constitute well-designed management interventions (The World Bank, 2000). LFA was developed in the 1960s to assist the US Agency of International Development (USAID) in improving project planning and evaluation systems (Republic of Serbia Government European Integration Office, 2011). LFA has been used in many development projects (Musiyarira et al., 2019). The problem tree, objective tree, and analysis of strategies is an LFA methodology for identifying main problems and their causes and effects, helping project planners formulate clear and manageable objectives and strategies for achieving them. The problem tree can identify the underlying causes of D-P-S-I-R categories, that is, the layers that cannot be identified using DPSIR. The underlying causes will be translated into solutions and formulated logically to formulate management interventions.

The combination of DPSIR and LFA will form water management tools for comprehensively analysing the water resources system and formulating logical and effective management interventions. This article demonstrates a combination of the driver-pressure-state-impact-response (DPSIR) framework and the logical framework approach (LFA) to develop water management strategies for the Sathing Phra peninsula lagoon floodplain.

2. METHODOLOGY

2.1 Study area

Floodplains are defined as areas periodically inundated by the lateral overflow of rivers and lakes. Floodplains support diverse ecosystems which provide critical benefits to people, especially in agricultural development (Binh et al., 2022). Floodplains are among the most threatened ecosystems in which the annual flood cycle critically impacts productivity (Islam and Braden, 2006). Threats are severe in lagoon floodplains because the hydrological regime is highly dynamic and impacted by salt water (López-Juambeltz et al., 2020).

The Sathing Phra peninsula, a lagoon floodplain in Thailand was selected as a study area. It is an important rice production area, holding approximately 31% of the rice field area in Southern Thailand. Water shortages occasionally occur during the dry season. Floods occur in the wet season. In 2013, severe floods caused damage to 10,654 households, affecting 36,725 people (Songkhla Provincial Disaster Prevention and Mitigation Office, 2017). Ban Khao Sub-District was selected to demonstrate a combined DPSIR and LFA (Figure 1).

2.2 Method

2.2.1 Historical water resource development and management

Participatory Rapid Appraisal (PRA) (Chambers, 1994) was applied to study the history of water resource development and management. PRA tools, including secondary data reviews, semi-structured interviews, and focus group discussions, were conducted during 2012-2019. Sixty-nine people from government organisations, local administrative organisations, communities, academics, private sectors, and NGOs participated.

The communities and community leaders provided information and jointly surveyed the area to understand its context and suggested management guidelines. Relevant government agencies share information about water management, analyse problems, and discuss appropriate management. The qualitative data was validated by triangulation.



Figure 1. Sathing Phra peninsula floodplain

2.2.2 DPSIR framework

DPSIR was used to describe water resource problems using data from the PRA step. The cause-effect relationship between the water resources systems and anthropogenic activities was identified in terms of the following elements:

- Drivers (D) are the driving forces acting on water resources systems comprising human needs.

- Pressures (P) include all human activities undertaken due to increased needs, which apply pressure on the stage.

- Stage (S) is the current status of water resources.

- Impacts (I) are categorised as loss of functions or services of water resources to humans.

- Response (R) included management practices for managing water resources in the area (Ashfaq et al., 2018).

This study first identified water resources problems (S) and their impacts (I). Next, pressures (P) and drivers (D) were analysed. Finally, existing responses (R) were analysed. The link between categories is shown in the diagram. Statistics for analysing water resource status are descriptive statistics data such as mean, percentage, etc.

DPSIR indicators for agriculture's water shortage are shown in Table 1.

2.2.3 LFA

LFA was applied to analyse the underlying layers/causes of D-P-S-I-R categories and formulate water management strategies and measures. The indicators in Table 1 were also used. Data captured from DPSIR analysis were transferred into a problem tree and disaggregated into causes, root causes, and consequences. State (S) was placed as a problem at the centre of the problem tree diagram. Major causes and root causes that contribute to the problem were replaced with drivers (D), pressures (P), and causes of ineffective responses (R). The effects were replaced with Impacts (I). Negative situations were converted into objectives in the objective tree diagram. The means to achieve the objectives of the root causes were determined as management strategies.

Table 1. The DPSIR indicators for agriculture's water shortage

DPSIR framework	DPSIR component	Indicators	Unit
Drivers	Need of income from agriculture (rice)	Existence of policies that support agricultural development	Yes/no
Pressures	Intensive irrigation water demand	Irrigated area (off-season rice farming)	km^2
	Climate variation	Annual rainfall	mm/year
State	Water shortage for irrigated area	Number of years in which salt water intrudes during off-season rice cultivation	Year
		Uncultivated irrigated paddy field	km^2
Impacts	Loss of income	Income from the sale of off-season rice products	baht/year
	Conflict on irrigation water use	Level of conflict	Level (low, medium, violence)
Responses	Activities to prevent water shortage for irrigated area		
	- Promotion of mixed agriculture/ oil palm	- Rice field area promoted to mixed agriculture/ oil palm	km^2
	- Promotion of less water rice farming	- Rice field area promoted to less water farming	km^2
	- Improving irrigation canals	- The distance of irrigation canals has been improved	km/year
	- Establishing water user groups for managing irrigation water	- The existence of water user groups	Yes/no
	Activities to reduced impact from water shortage		
	- Compensation for rice farming damage	Amount of compensation	baht/rai (equivalent to 0.0016 km^2)
	- Conflict mediation	The existence of a conflict mediator	Yes/no

3. RESULTS

3.1 Historical water resources management in the Sathing Phra peninsula

Timelines of Ban Kao Sub-District water resources management are shown in Figure 2.

Pre-irrigation development, the main activity was rainfed rice farming. Water shortages were common in the dry season. In the second phase, irrigation systems were developed to address the water shortage. The Thung Ranod Irrigation Project supported 136 km^2 of rice fields (RID, 2012). Farmers conduct rice farming twice a year, with some increasing to five times in two years. The off-season rice fields in Ranod district increased steadily from 29.2 km^2 in 1988 to 182.7 km^2 in 2004.

The third phase involved community adaptation. In 2005, a severe flood destroyed much of the in-season rice, after which most farmers shifted the in-season rice farming period to after the rainy season and postponed their off-season rice farming. The adaptation increased the dependence on irrigation water, resulting in more severe water shortages.

3.2 DPSIR water resources system analysis

The water resources system of the Sathing Phra peninsula is depicted in Figure 3, which shows two linked causal loops: (a) water shortage for the irrigated area; and (b) flooding. This study only describes causal loop (a) (Table 2).

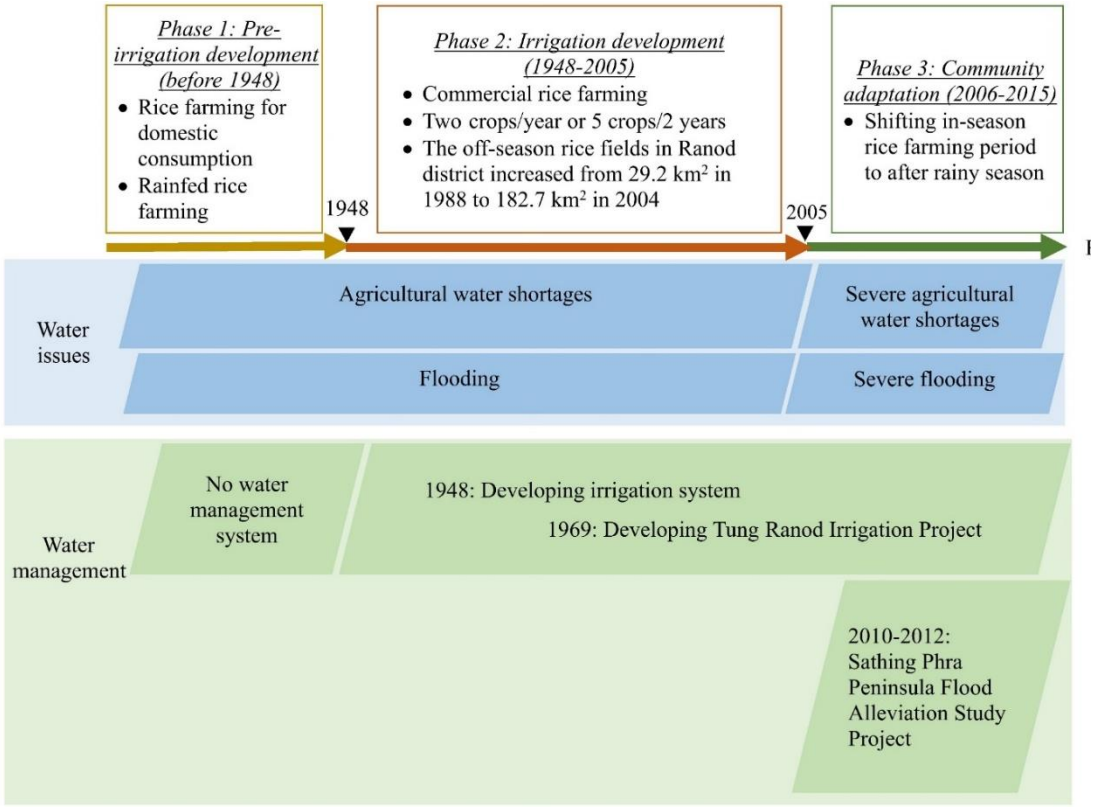


Figure 2. Timelines of water resources development and management in the Ban Kao Sub-District

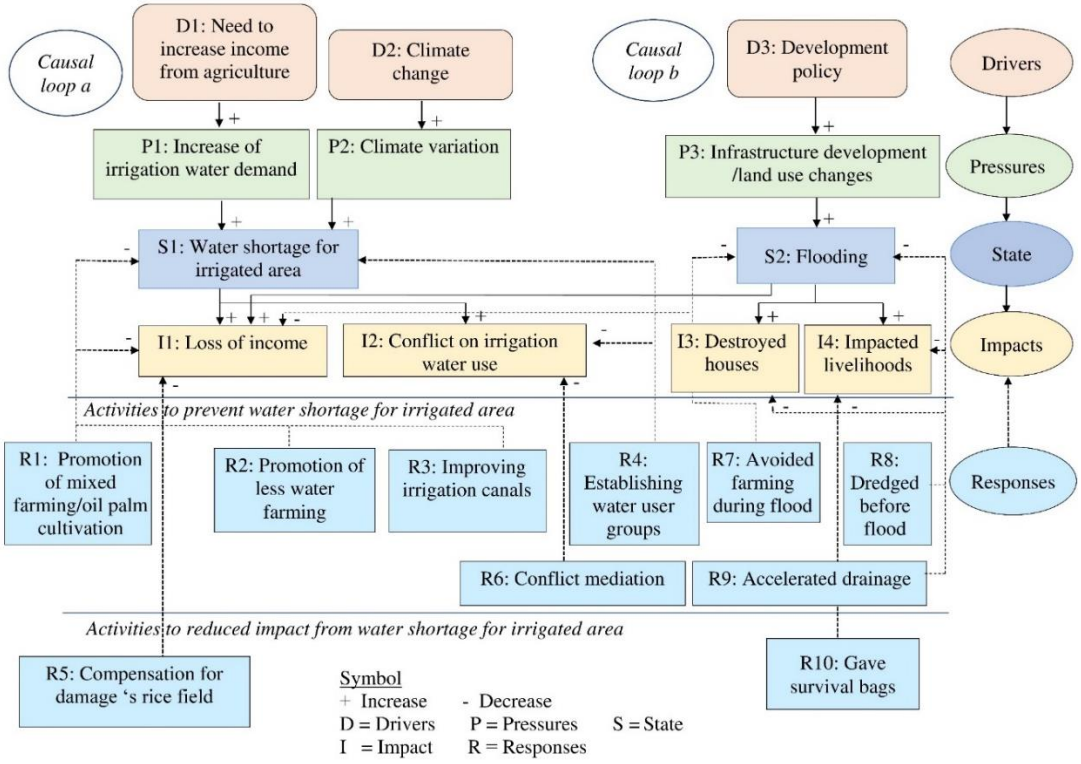


Figure 3. DPSIR analysis for the Sathing Phra peninsula

Table 2. DPSIR for causal loop (a) water shortage for the irrigated area

			Phase		
DPSIR framework	DPSIR component	Indicators	Phase 1: pre-irrigation development (before 1948)	Phase 2: Irrigation development (1948-2005)	Phase 3: Community adaptation to water shortage (2005-2015)
Drivers	Need to increase income from agriculture (D1)	Existence of policy that supports agricultural development	Most rice farming was rainfed	Policy to increase agricultural productivity through irrigation development	Policy to promote mixed agriculture/oil palm and less water farming
Pressures	Increasing of irrigation water demand (P1)	Irrigated rice farming area (Off-season rice farming)	0 rai	Increase of 100% from phase 1	Increase of 100% from phase 1
	Climate variation (P2)	Annual rainfall	n/a	During 1974-2005, annual rainfall below 1,500 mm/year for 3 years	During 2006-2011, no annual rainfall below 1,500 mm/year
State	Water shortage for irrigated area (S1)	Number of years in which salt water intrudes during off-season rice cultivation	n/a	4 years during 1992-2005	1 year during 2006-2010
		Uncultivated irrigated paddy field	None	20.64 km^2 for 4 years (1992-2005)	20.64 km^2 for 1 year (2006-2010)
Impacts	Loss of income (I1)	Income from the sale of off-season rice products	-	23.5 million baht (0.71 million USD)/year (for 4 years)	45.9 million baht (1.39 million USD)/ year (for 1 year)
	Conflict on irrigation water use (I2)	Level of conflict	None	Low	Low
Responses	Activities to prevent water shortage for irrigated area				
	- Promotion of mixed farming/oil palm cultivation (R1)	- Rice field area promoted to mixed agriculture/oil palm	None	n/a	1% of the total area of irrigated rice farming
	- Promotion of less water rice farming (R2)	- Rice field area promoted to less water farming	None	None	None
	- Improving irrigation canals (R3)	- The distance of irrigation canals has been improved	n/a	n/a	n/a
	- Establishing water user groups (R4)	- The existence of water user groups	No	Yes	Yes
	Activities to reduce impact from water shortage				
	- Compensation for rice farming damage cause by water shortage (R5)	Amount of compensation	No	Insufficient	Insufficient
	- Conflict mediation (R6)	The existence of conflict mediator	No (no conflict)	Yes	Yes

n/a=not available

From Figure 3 and Table 2, in developing the area from phase 1 to phase 2, farmers' poverty led to needing to increase income from agriculture which is described as a first driver (D1). This driver was investigated based on the existence of policies to support agricultural development. In phase 2, under

the 2nd National Economic and Social Development Plan, the important policy regarding agricultural development focused on increasing productivity via developing irrigation systems (National Economic and Social Development Board, 1967). Therefore, the Thung Ranod irrigation project was developed.

The pressure reflected by the driver is increasing irrigation water demand (P1) which is considered based on irrigated rice farming area. In the second phase, the irrigated rice farming area increased 100% from the first phase, increasing irrigation water demand (RID, 2012). The change in the state due to pressures is water shortage for the irrigated area (S1) which one indicator is the number of years that saltwater intrusion caused uncultivated rice farming, which occurred in 1991, 1992, 1993, 2005, and 2010. The other indicator is the uncultivated irrigated rice farming area, which indicated 20.64 km^2 in the four years that the aforementioned saltwater intrusion occurred (Regional Irrigation Office 16, 2011).

The impacts of water shortage caused loss of income (I1) and conflict in irrigation water use (I2), which is quantified by indicators including income from the sale of irrigated rice products and level of conflict between water users. Inability to do irrigated rice farming in 1991, 1992, 1993, 2005, and 2010, caused the area a loss of income of approximately 23.5 million baht (0.71 million USD)/year (Songkhla Provincial Agriculture and Cooperatives Office, 2022). In addition, because irrigation water supply is limited, conflicts between farmers occurred almost every year.

In the second phase, the results from the study indicated that the existence of the water user group (R4) helped prevent water shortages as the water user group set rules for equitable allocation of limiting irrigation water among users, while other responses did not show clear results due to lack of information. The compensation for rice field damage from water shortage (R5) is insufficient as the cost of compensation was only 28% of the actual cost (actual cost 2,700 baht (81 USD)/rai (Regional Irrigation Office 16, 2011) and compensation 1,113 baht (34 USD)/rai (Songkhla Provincial Agriculture and Cooperatives Office, 2020).

For the third phase, policy regarding agricultural development changed to promoting mixed agriculture/oil palm and less water rice farming. However, the off-season rice farming area is similar to the second phase. This indicated that the new policies have little impact on the water resource system. The reason is that new policies have implementation limitations, for example, inappropriate area, farmer budget, and land tenure problems.

3.2 LFA

Taking causal loop (a) as an example for the LFA analysis, the problem tree analysis showed three significant causes of water shortage for the irrigated area: (1) insufficient water in the dry season, which the indicator showed that during 1992-2005 there were four years that the area of uncultivated irrigated rice farming was 20.64 km^2/year; (2) increased water demand for rice farming which is indicated by an increase of irrigated rice farming area of 100% compare to the pre-irrigation development phase; and (3) ineffective irrigation water allocations which is indicated by the area of uncultivated irrigated rice farming mentioned above. The root causes of each major cause are also shown in Figure 4.

The major causes were then transformed into objectives which were: (1) sufficient water; (2) water demand for rice farming appropriate to the water available; and (3) effective irrigation water allocations (Figure 5).

After the desired future situation, the most feasible strategies and measures were identified. In this study, only the third chain of the objective tree in Figure 5 (effective irrigation water allocation) was selected as an example. The target of management strategies for this chain is at least 70% of farmers having enough water for off-season rice farming. This is achieved by:

1) Improving the performance of the rotating irrigation systems through developing an automatic water-level monitoring system and strengthening the water user groups.

2) Improving the monitoring and evaluation of irrigation water allocation and delivery through participatory monitoring and evaluation of irrigation water allocation and delivery.

3) Improving irrigation water use efficiency through applying economic instruments.

The details of management strategies and indicators are shown in Supplementary Table S1.

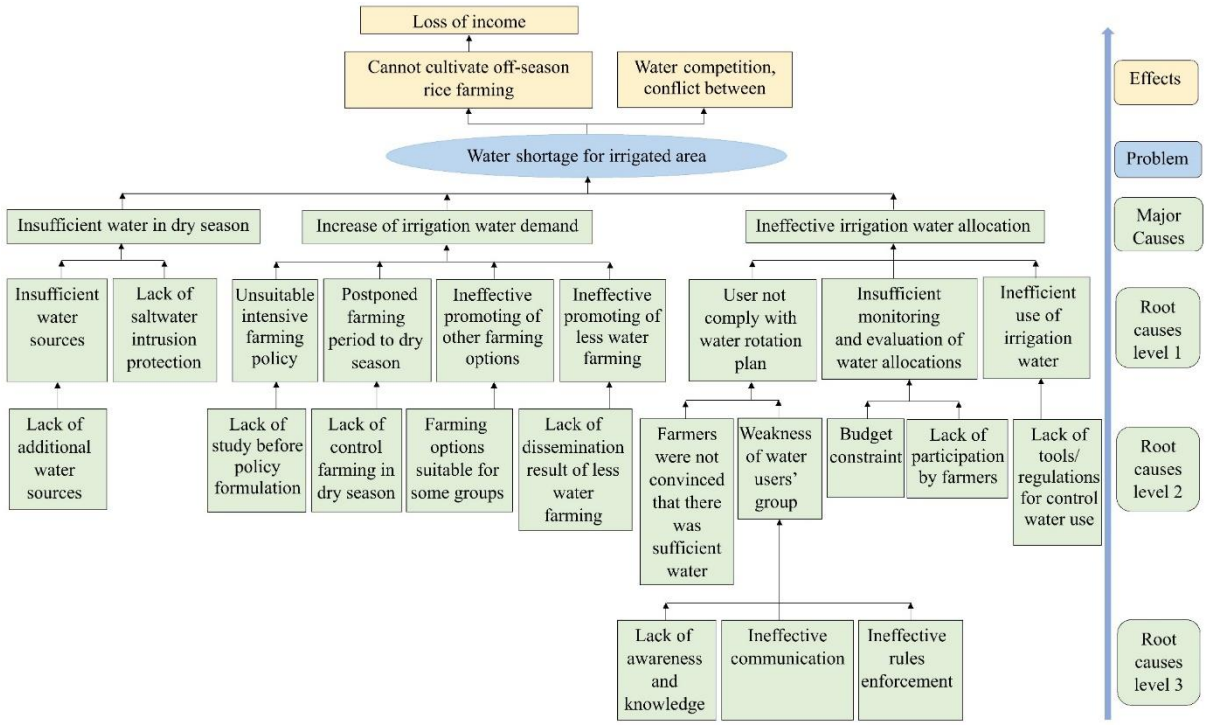


Figure 4. Problem tree analysis for causal loop (a) water shortage for the irrigated area

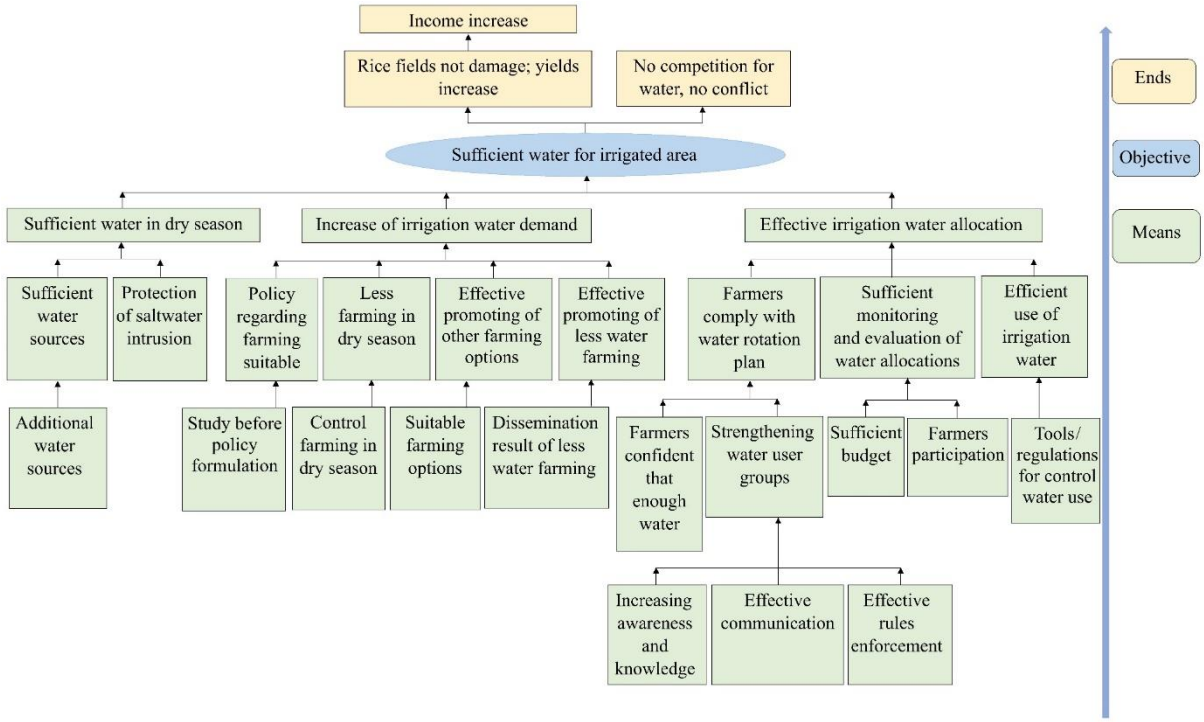


Figure 5. Objective tree analysis for causal loop (a) water shortage for the irrigated area

4. DISCUSSION

Water management strategies for the Sathing Phra peninsula were developed using the combined DPSIR framework and LFA. DPSIR analysis showed the important driver for the issue of water shortage in irrigated areas is the need for income from agriculture, which is associated with water user groups and is difficult to change. Growing demand for irrigation water, combined with natural factors, posed a risk of water shortages. Current responses, such as government policies to promote the transition from rice farming to mixed farming and the promotion of

less water rice farming, which have very little application, are ineffective and unable to mitigate water shortages and their impacts. The results illustrated that DPSIR analysis allowed understanding the variables affecting the system, the weights of the variables, the roles of stakeholders, and evaluating the effectiveness of existing responses. This study's findings are consistent with Agramont et al. (2022), who discovered that DPSIR allows understanding the sources of socio-ecological distress and reveals the ineffectiveness of policy responses in Bolivia's Katari River Basin. However, the root cause of the problem, which is useful for developing management strategies, is difficult to identify by DPSIR analysis.

Using the results from the DPSIR analysis to formulate strategies to resolve the root causes using LFA, three strategies to increase the efficiency of irrigation water allocation were proposed. First, improving the rotating irrigation systems' performance by developing an automatic water-level monitoring system and strengthening water user groups. The system provides real-time data that helps water managers and users track transmission and conveyance losses and take decisions to improve water use efficiency (Reddy et al., 2016). Strengthening the water user group will lead to continuous, more efficient, and concrete management of water resources, consistent with the study of Teamsuwan and Satoh (2009), which concluded that the Water User Organisations (WUOs) in the Chao Phraya Delta, Thailand, demonstrate successful long-term management because of the clear definition of the WUOs' common management activities and a budget to guarantee the activities. Second, improving monitoring and evaluating the irrigation system through participatory monitoring and evaluation of irrigation water allocation and delivery. The advantage of this strategy is collaborative problem-solving through the generation and use of knowledge that leads to corrective action by involving all levels of stakeholders in shared decision-making. Uprety et al. (2019) also suggested that the principles of citizen science can help improve the spatial coverage of data, aiding local decision-makers in the water resource management realm. Third, improving water use efficiency in irrigated agriculture by applying economic instruments is instrumental in achieving efficient and equitable use and encouraging conservation and protection of water resources (Rey et al., 2019).

The proposed strategies differ from strategies suggested by the Royal Irrigation Department using rational planning (RID, 2012). Regarding the IWRM component (Global Water Partnership, 2000), for the institutional roles, this study suggests strategies related to water user groups, while RID emphasises the functions of regulators. For the management instruments, this study proposed economic instruments for optimising water use, while the RID proposed guidelines on the effective use of irrigation water and public relations to educate farmers. The result indicated that strategies proposed by this study focus on improving management mechanisms of water user groups differently from those proposed by the rational planning method, which focuses on the function of regulators. The reason is that DPSIR helps structure the information on water resources issues and clearly explains the relationship between DPSIR categories. From this study, DPSIR analysis showed that the important driver is the need for income from agriculture which is associated with water user groups, as mentioned above. While the rational planning method does not analyse the system-wide problem, it is too narrow in focus due to the focus on water management by the responsible authorities and the emphasis on infrastructure development.

Our results demonstrated that the combined DPSIR and LFA enable the development of appropriate and realistic water management solutions. DPSIR provides a framework for comprehensively analysing cause-effect relationships, factors, and actors' influences in the complex water resource system. Analysing the data with stakeholders and revising the DPSIR diagram several times gives us an in-depth and comprehensive understanding of the relationships among variables affecting water systems. In addition, an intermediary study with no interest in the area resulted in facts that reflected water management problems in the area better than studies by agencies or decision-makers due to the embarrassment of the informants in providing information. From the comprehensive understanding of the water system obtained from DPSIR analysis, when further analysed using LFA, it is possible to identify root causes contributing to the problem, which enables the development of feasible solutions/ strategies to solve at the leverage point. Combined DPSIR and LFA is a modified method for analysing water resource systems, an essential step in planning. DPSIR has been used with other tools for analysing water resource systems; for example, Zare et al. (2019)

applied DPSIR as an analytical framework to support the problem scoping and structuring phase in the SD modelling process, and Apostolaki et al. (2019) combined DPSIR with the ecosystem services approach and scenario assessment for developing programs of measures and river basin management plans.

5. CONCLUSION

Applying the combined DPSIR framework and LFA effectively developed water management strategies for a complex water system, including a lagoon floodplain in Thailand. The strategies developed using this method are more effective than those developed using other tools that do not analyse the water system comprehensively and let the responsible authorities focus only on their duties. The effectiveness of the strategies is due to: (1) this method provides insight into complex water systems, stakeholder relationships, key factors influencing the system, and root causes; (2) the strategies developed systematically and logically solve the problem at its root cause, which is the real problem; and (3) intensive stakeholder participation in problem-cause analysis and in-depth study of the area. This method is appropriate for decision-makers because it provides a framework for in-depth analysis of problems and their causes and root causes, covering socioeconomic and environmental aspects. It aids in formulating logical management approaches to solving problems at their root cause. For future research, verifying strategies by stakeholders is needed to ensure the strategies are suitable and applicable.

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