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Sustainability assessment of community-based water resource management of irrigation systems for agriculture

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Abstract:

To study community-based water resource management (CbWRM) of irrigation for agriculture, the participation of the community in the management of the irrigation system must be considered. CbWRM is the cooperation between a farming organization (the water-using cooperative group) and state-related organizations (such as the Department of Water Resources Management and commune-level authorities) in the process of the operation and management of water. In the CbWRM model, the community participates in the selection and election of the management board, meetings to collect ideas to build a CbWRM model, and financial contributions to water use fees. The community also participates in the annual operational planning of water use. Therefore, this study aimed to develop indicators to assess the sustainability of the CbWRM model of irrigation for agriculture in the Hau Giang province, Vietnam. With an assessment result of 0.54 (relatively sustainable), this study shows a picture of water resource management in general and community participation in particular. These research results can help managers and policymakers promote community participation to achieve high-efficiency water resource management in the agriculture of the Hau Giang province.

Keywords: **agriculture, community-based, irrigation system, water resource management.**

Classification number: **5.2**

Introduction

The ever increasing water demand of communities has caused serious problems in water resource management. Because there are many methods of water resource management, assessments of the sustainability of a particular scheme of water resource management are of great importance. A meaningful assessment can help a policymaker select the most suitable method to apply to water resource management.

A large number of rural areas around the world, mainly in developing countries, have applied various models of CbWM. Nevertheless, retaining CbWM sustainability has faced difficulties due to lack of the continuous provision of the necessary technical, financial, and social resources from the responsible stakeholders. In several circumstances, the development of a number of community organizations has contributed to CbWM sustainability, which is the key role of community in the process of policy-making [1].

Community participation in the process of water resource management is considered as an inevitable rule. According to F. Molle (2005), CbWRM is a participatory process in which the community is the centre of an effective water management system. From planning to operating to maintaining the water supply system, the community is responsible for the resource from which they benefit. This engagement can be both considered as a tool for better management or as a process for community empowerment [2] as it can be established under a consumer association, by community action groups in urban areas, or by water-user groups and irrigation cooperatives in rural areas [3]. The capacity of the community in CbWRM is strongly emphasized in Madeleen (1998) [4]. This study addressed the potential for technical, labour, and financial contributions, as well as community support in the planning process, implementation, and sustainable maintenance of a water supply system. The work also demonstrated that the community has a decisive role in resolving contradiction and

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conflicts in the use, exploitation, and sustainability of water resource management [4].

In Vietnam, according to Viet Dung Nguyen, et al. (2006) [5], community participation in water resource management has a long history, especially around the northern and southern deltas. There are two basic approaches of water resource management. The first considers water as a common property. This approach is common in the upland and mountainous areas and in some lowlands of Vietnam. The second approach considers water as a commodity. Such an approach pays attention to the multiple purposes of water such as for agriculture, domestic use, aquaculture, industry, and services. This approach was taken by the Participatory Irrigation Management (PIM), which was applied in Vietnam in the early 1990s after the government officially decided to transfer agricultural land use rights to households. This is seen as an effective method for CbWRM because the communities are involved as water users, managers, and protectors of water resources, especially for small-scale irrigation systems. The PIM has been experimentally applied in many provinces such as Tuyen Quang, Bac Kan, Thanh Hoa, Nghe An, Quang Tri, Quang Ngai, Binh Dinh, and Hau Giang.

According to I. Juwana, et al. (2010) [6], a great number of indicators of water resource sustainability have been deployed in numerous countries such as the Canadian Water Sustainability Index (CWSI), Water Poverty Index, Watershed Sustainability Index (WSI), and West Java Water Sustainability Index (WJWSI). All of these indicators aim to provide the current condition of a water resource and generate inputs for policymakers to prioritize water issues.

I. Juwana, et al. (2012) [7] has proposed a list of six sub-component indicators for accessing water resource sustainability. Based on the literature review of indicator-based water sustainability in this study, water stakeholders can apply and customize existing indicators and/or develop new indicators. From these indicators, the community can learn about their current water resource situation and which element can improve its condition. In addition, the water sustainability indicators can support policymakers during the process of prioritization of problems, challenges, and water resource programs.

In a study by P. Kamalesh, et al. [8], a framework based on technical, environmental, financial and institutional criteria was developed. Similar to the above study [7], Tier I indicators were described through several component indicators. The author also provides weights for each Tier I indicator and the lower tier indicators, which make the water sustainability assessment process more accurate and reasonable. The weights were determined based on interviews and consultations with experts in sustainable water resource development. The information obtained was integrated into the scoring system to help evaluate whether the project under consideration was sustainable. The score was divided into 3 types: sustainable, partly sustainable, and unsustainable.

Richter, et al. (2018) [9] developed a set of indicators for assessing the sustainability of urban water supply systems including: (1) governance of water resource and its role; (2) preparedness for droughts and other capabilities for emergency response; (3) monitoring of water resources; (4) capacity to pay for water resources and social justice; (5) efficiency and conservation in water usage and water quality; and (6) protection of the watershed. The indicators presented in this work supports cities with improving the sustainability of their water supply systems. While it is straightforward to quantify and evaluate the subcomponents of these indicators, in some cases subjective judgement and ultimate weighting are needed. In order to enhance the service reliability, financial viability, customer satisfaction, and environmental health, these indicators can be evaluated and tracked by utilities over time.

Popawala and Shah (2011) [10] provided a set of indicators to evaluate the sustainability of an urban water management system, including primary, secondary, and first-level indicators that encompass social, economic, environmental, and technical aspects [10]. The second-level indicators include, for example, population with access to water supply, sewage, rainwater, investment capital, maintenance costs and repair, daily water supply per person, per capita water production waste per day, covered pipe area, and energy consumption. In addition, the authors also weighted the indicators for levels 1 and 2 based on expert opinions combined with findings from field surveys.

In Vietnam, a variety sustainable assessment methods have been proposed and applied. In the study of [11], the authors analysed the social elements of model management in terms of community participation. The authors used six key indicators: (1) water sustainability; (2) sustainability of the project; (3) community participation; (4) technology sustainability; (5) sustainable financial economy; and (6) organizational sustainability.

Thi Lan Huong Nguyen (2010) [12] defined seven requirements for assessing the sustainability and effectiveness of a water supply system as follows: (1) adequate water supply for at least 70% of the households in the community; (2) the quality of water supply services meets the needs of the community; (3) technical problems are promptly solved and water supply interruptions should not exceed 1 day per year and the leakage rate is below 20%; (4) transparency in finance; (5) no negative social impacts on the community; (6) having technical support and access to financial resources for maintenance and repairs; and (7) the functional lifetime of the system is not less than 30 years.

Viet Dung Nguyen, et al. (2006) [5] explained the concept of a sustainable water resource management model. It has been said that community participation is very diverse both in form and level, so it is difficult to say which model is the best overall because each one corresponds to a community with specific populational, geographical, institutional, and cultural characteristics. Therefore, in order to consider the success of a sustainable CbWRM model, specific criteria and indicators are needed.

Within the framework of this study, the authors aim to develop a set of indicators to evaluate the sustainability of CbWRM models at the local level. The results of the evaluation will help managers identify priority issues and devise strategies, plans, and action programs to balance factors in the process of developing a specific model of CbWRM.

The Hau Giang province was selected for study. A survey of irrigation in Hau Giang showed that there is a community-based model in their agriculture known as "water use cooperatives", which is a form of PIM. This approach to CbWRM of irrigation for agriculture in Hau Giang can be described as follows:

First, the Government invests in an electric pumping station. Through the Provincial Department of Irrigation and the commune authorities, the government assigns a water cooperative group (WCG) to manage and operate the system. The WCG develops the plans to pump water and collect fees from the households. All villagers participated in the selection of a management board and meetings to collect ideas to develop the system. The villagers also paid water use fees and participated in the meetings for annual operational planning.

According to the survey, the model in place at Hau Giang has significant economic benefits such as reduced investment costs, increased productivity, and profits. The second-most significant benefit is social benefits such as to stabilize people's lives and increase their connectivity in the community. However, most of models only work for a short time (2 years), so it will take time for people to get used to using and managing the system. The model is based on an existing irrigation infrastructure that did not involve the community from the beginning and thus they did not participate in the planning, designing, and construction stages. The community was only involved in the management.

Methodology and data

Methodology

To assess the sustainability of CbWRM of irrigation for agriculture in Hau Giang, the research team used several methods: (1) data collection and social surveys; (2) expert consultation; and (3) a set of indicators to evaluate the sustainability.

Data collection, social surveys

The data included information related to community participation in irrigation works; ability and willingness to pay for irrigation services of community; information related to economic, technical, and environmental factors, and benefits of water supply services. A questionnaire was used and applied to the communities (people living in the area) and managers. The details of the application of this method are described below.

Expert consultation:

Experts were consulted to determine the weights of the Tier I and Tier II indicators to serve the assessment of the sustainability CbWRM in the study area.

Development of the set of indicators:

A set of indicators was developed based on the following criteria:

- Comprehensive: the indicators should provide an overview and capture the multidimensional nature of sustainable state management community models. Sustainability aspects need to be assessed for each type of model.

- Simplicity: the indicators must be simple enough to facilitate data collection, analysis, and evaluation.

- Clarity: the indicators must be clearly defined and given specific calculation instructions.

- Availability: the given indicators should be consistent with the data available to collect and assess. This will contribute to time and cost saving during the evaluation. However, it should be noted that when data collection and evaluation are not available, it is necessary to ensure reasonable data collection time and cost.

- Relevance: the indicators will be compatible with the objectives of the national and local strategies and master plans.

To develop the set of indicators, five steps were followed:

Step 1: develop the frame of indicators

The objective of this step is to clearly identify the area being assessed and the scope of the evaluation indicators including Tier I and Tier II indicators. To develop the frame of indicators, this study was based on an evaluation of indicators developed by previous research including the study by I. Juwana, et al. (2012) [7]; P. Kamalesh and B. Shashi (2008) [8]; Popawala and Shah (2011) [10]; Hoang, et al. (2007) [11], and Thi Lan Huong Nguyen (2010) [12]. Then, the results from these evaluations will be combined with the local survey to develop a set of indicators.

Step 2: selection of Tier I and Tier II indicators

The selection of Tier I and II indicators needs to follow certain criteria: (1) feasibility of the data; (2) simplicity of data; and (3) validity of the data. From the frame of indicators developed in Step 1, the research team set up a common set of indicators (level 1) for irrigation water supply in agriculture (Table 1).

Table 1. Set of indicators to assess the sustainability of CbWRM.

Tier I indicators	Tier II indicators	Sources of data
Social indicator	Conflict possibility in using water resources	From survey data
	The level of community participation in developing model	From survey data
	The level of community involvement in operating the model	From survey data
	The level of community participation in maintenance / repairing model	From survey data
	The level of community participation compared to the model design	From survey data
	The level of community participation in the financial decisions of the model	From survey data
	Service complaints regarding the model	From survey data
	Qualifications of managers and operators of model	From survey data
	Percentage of model managers and operators who participate in technical training and operational management	From survey data
	The percentage of people participating in technical training on how to operate and use the model	From survey data
	Executive board of the model	From survey data
Technical indicator	Degree of meeting the demand of using water in agricultural production	From survey data
	Access ability to water resources	From hydro-meteorological data
	Water quality	From environmental data
	Frequency of malfunctioning of models	Survey data from the irrigation company
	The frequency of periodic maintenance of the model	Survey data from the irrigation company
	The rate of water loss	Survey data from the irrigation company
Environmental indicator	Possibility of the influence of the natural environment on the model	From environmental data
	Risk of natural environmental pollution from the model	From environmental data
Economic indicator	Capital for developing models	Survey data from the irrigation company
	Capital for operating the model	Survey data from the irrigation company
	Capital for model maintenance/repair.	Survey data from the irrigation company

Step 3: collecting data

After setting up the indicators, the data is collected. This data is very important and helpful for the calculation.

Step 4: calculating the sustainable index

The sustainability index (SI) of the CbWRM is calculated directly through the values of the four Tier I indicators: economic, social, environmental, and technical by Eq. (1):

$$\text{Sustainable Index (S.I)} = \sum_{i=1}^{m} Mi * Wi \quad (1)$$

where Mi is the normalized value of a Tier I indicator number i; W_i is the weight of Tier I indicator number i; and m is number of Tier I indicators.

The value Mi of a Tier I indicator number i is calculated based on the Tier II indicators by Eq. (2):

$$Mi = \sum_{j=1}^{n} \frac{Xij}{n} \quad (2)$$

where X_{ij} is the normalized value of a Tier II indicator number j and N is the number of the Tier II indicator i that belongs to the Tier I indicator.

As each Tier II indicator is calculated in different units, it is necessary to calibrate each of these indicators to the same standard system [13].

(+) If the value of a Tier II indicator is proportional to vulnerability, then Eq. (3) will be applied to normalize its value:

$$Xij = \frac{S - S_{min}}{S_{max} - S_{min}} \quad (3)$$

where s is a Tier II indicator; s_{min} is the minimum value of a Tier II indicator, and s_{max} is the maximum value of a Tier II indicator.

(+) On the other hand, if the value of a Tier II indicator is inversely proportional to vulnerability, then the value will be normalized by Eq. (4):

$$Xij = \frac{S_{max} - S}{S_{max} - S_{min}} \quad (4)$$

where s is a Tier II indicator; s_{min} is the minimum value of a Tier II indicator; and s_{max} is the maximum value of a Tier II indicator.

- Step 5: sustainability assessment

After calculating the sustainability index, it is necessary to determine the level corresponding to the values. By referring to previous studies, combined with expert advice of the actual situation, the authors divided the value in intervals to represent the levels of sustainability for the CbWRM model as follows:

SI: ≥0.7-1 : sustainable

SI: ≥0.5-0.7 : relatively sustainable

SI: <0.5 : not sustainable

Delphi method:

The Delphi method was conducted in the study to select indicators and the weights of the indicators. In the practical application of the Delphi method, the authors followed the following steps:

1. Define the purpose of selecting indicators and evaluating weights of indicators to assess the sustainability of the CbWRM in Hau Giang.

2. Select a team of 10 experts with solid knowledge and interest in the field of water resources in particular and natural resources and environment in genera.

3. Establish level I and level II indicators, assign initial values of weights to level I indicators and send to each member of the expert group.

4. The feedback results from each expert are collected, tabulated, and summarized.

5. Summary of the results sent back to experts for comments to emphasize opposing, extreme, or special opinions different from the majority.

6. Experts have the option to revise their previous estimates after reviewing information received from other (unnamed) members.

7. Repeat steps 3 through 5 until there are no longer any significant changes (i.e. the experts reach an agreement).

The results of the Tier I indicator weights identified based on the Delphi method are summarized in Table 2.

Table 2. Tier I indicator weights.

No	Weight before Delphi		Weight after Delphi	
	Tier I indicators	*Weight*	*Tier I indicators*	*Weight*
1	Social	0.25	Social	0.28
2	Economic	0.25	Economic	0.24
3	Environmental	0.25	Environmental	0.24
4	Technical	0.25	Technical	0.24

Data

To collect the data, the authors conducted a survey in the study area and had meetings with representatives from the Department of Agriculture and Rural Development as well as the Department of Natural Resources and Environment, Centre for Rural Water Supply and Sanitation in Hau Giang and interviewed people from the Hoa Luu commune, Vi Thanh city, Hau Giang province.

Information collected during the survey in Hau Giang to serve for the development and calculation of indicators includes:

- The model of CbWRM in Hau Giang in the field of irrigation in agriculture.

- Local policies and mechanisms related to the model of CbWRM in Hau Giang in the field of irrigation in agriculture.

- The technical parameters of the model of CbWRM in Hau Giang in the field of irrigation in agriculture.

- Construction investment capital and recurring expenses for the model of CbWRM in Hau Giang in the field of irrigation in agriculture.

- People's participation in the operation of the model of CbWRM in Hau Giang in the field of irrigation in agriculture.

- The operation of the model of CbWRM in the field of irrigation in Hau Giang agriculture.

- The limitations of the model of CbWRM in the field of irrigation in Hau Giang agriculture.

- Benefits that the model of CbWRM in the field of irrigation in Hau Giang agriculture.

- Assessing the effectiveness of each model of CbWRM of irrigation in Hau Giang agriculture.

- Proposing how to sustainably develop the model of CbWRM of irrigation in agriculture in Hau Giang.

The required data are described in the questionnaire of both levels (managers and communities). These data include: the specifications of the model; information related to investment capital and periodic model costs; how the model works; people's participation in the operation of the model; benefits and limitations that the model brings along with its socio-economic-environmental impacts; and the effectiveness of each model and information on the proposal to replicate an effective model. Data on policy mechanisms are directly consulted with local leaders. The survey sites were carefully considered by the method of overview and direct consultation with local leaders, from which the locations for each agriculture field in Hau Giang province was identified.

The survey took place in Hau Giang from March 3, 2017 to March 7, 2017. The authors interviewed a few organizations under DARD and DONRE in Hau Giang such as the Department of Water Resources, under Department of Natural Resources and Environment of Hau Giang province; the Department of Irrigation, under the Department of

Agriculture and Rural Development of Hau Giang province; the Center for Rural Water Supply and Sanitation in Hau Giang province; and interviewed people from the Hoa Luu commune, Vi Thanh city, Hau Giang province.

The total number of questionnaires was 200, of which 100 were for managers and 100 were for people in Hau Giang. The questionnaire was built based on the purpose of the survey, the subject matter investigated, and the scope of the survey. The questionnaire forms for managers and communities are shown in Annex 1 and Annex 2. Data collected during the survey was analysed and synthesized by simple statistical methods (e.g. aggregating data, averaging, etc.).

Results and discussion

This study developed 4 Tier I indicators (social, economic, environmental, and technical) and 22 Tier II indicators. They were applied to assess the sustainability of CbWRM for agriculture in Hau Giang. The results are summarized in Table 3.

Table 3. The value of Tier II indicators.

Tier I indicators	Tier II indicators	Value
Social indicator	Conflict possibility in using water resources	0.33
	The level of community participation in developing model	0.00
	The level of community involvement in operating the model	0.50
	The level of community participation in maintenance / repairing model	0.89
	The level of community participation compared to the model design	1.00
	The level of community participation in the financial decisions of the model	0.50
	Service complaints regarding the model	0.50
	Qualifications of managers and operators of model	1.00
	Percentage of model managers and operators who participate in technical training and operational management	1.00
	The percentage of people participating in technical training on how to operate and use the model	1.00
	Executive board of the model	0.10
Technical indicator	Degree of meeting the demand of using water in agricultural production	1.00
	Access ability to water resources	1.00
	Water quality	0.00
	Frequency of malfunctioning of models	1.00
	The level of periodic maintenance of the model	0.50
	The rate of water loss	0.10
Environment indicator	Possibility of the influence of the natural environment on the model	0.50
	Risk of natural environmental pollution from the model	0.50
Economic indicator	Capital for developing models	0.00
	Capital for operating the model	1.00
	Capital for model maintenance/repair.	1.00

The final result of sustainability assessment for CbWRM model of irrigation for agriculture in Hau Giang province are shown in Table 4.

Table 4. The results of sustainability assessment.

Tier I indicators	Value of Tier I indicators	Weight of Tier I indicators	Final value	Sustainable Index
Social (A)	0.58	0.28	0.16	0.54
Technical (B)	0.75	0.24	0.18	
Environment (C)	0.50	0.24	0.12	
Economy (D)	0.33	0.24	0.08	

This result shows the superiority of the closed model design, which has been implemented in many provinces and cities nationwide. The design and financial participation in the construction investment, as well as major repairs of the irrigation system, were carried out by state agencies without the participation of the community.

The overall sustainability assessment result of 0.54 is considered "relatively sustainable". This shows that the model is in the early stages of formation and many factors, especially issues related to community, need to be improved (Fig. 1).

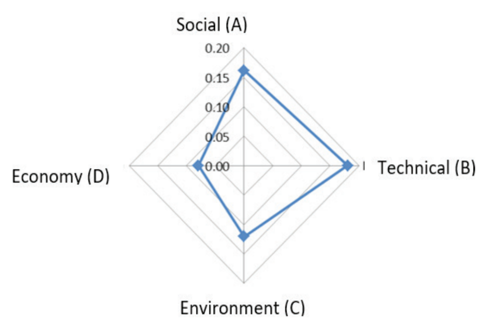

Fig. 1. Sustainability assessment.

The CbWRM model in the agricultural sector is assessed to be relatively sustainable due to the low values of the calculated indicators. These indicators relate to the disputed abilities of water use and the level of community participation in model development and management. The indicators related to the modelled capital sources with focus on the capital source of the state, private investors, and people are still limited. Therefore, for the next period, the model needs more investment from community capital for operation and maintenance. However, the cooperation model of the investment management and exploitation of irrigation works in Hau Giang and other provinces in the Mekong delta is on the right track and consistent with the policy of the Ministry of Agricultural and Rural Development. This model works by reducing the investment of the state budget, enhancing the role of the people and the private sector, improving the efficiency of the irrigation system, and increased agricultural output. Such a model should be comprehensively studied in order to apply to the entire Mekong delta and other regions across the country. However, it is necessary to solve the shortcomings arising from what is currently happening in Hau Giang. The problems identified in the sustainability assessment need to be addressed before replicating the model. There is a particular need for a gradual enhancement of community participation, not only in management, but also in investment and system design. One of the factors essential to the development and replication of the model is the issue of capital investment in infrastructure and policy institutions.

Conclusions

CbWRM of irrigation for agriculture is a typical system found in Vietnam. While it is a relatively new type of system, CbWRM has shown its role to the local community. The entire community should engage in the system by participating in the following activities: selection of management boards, community meetings to collect ideas for developing the system, paying water use fees, and participating in relevant meetings for developing an annual operation plan.

This study introduced a set of indicators to evaluate the sustainability of the CbWRM. The set of indicator includes four Tier I indicators: social, technical, environment, and economy. Each indicator had Tier II indicators to assess the sustainability of CbWRM for agriculture practice.

On the basis of the evaluation results, it was possible to identify factors affecting the sustainability of the model to support managers in making appropriate adjustments. The results of this study can be extended to other regions in the Mekong delta, and the whole country, to evaluate existing models and propose appropriate adjustments.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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