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Indicator of Sustainable Water Resources Use in the Transboundary Basins

Due to the complex situation of integrated water resources management in transboundary river basins, this research built a set of indicators for sustainable use of water resources by the Delphi method and developed a specific calculation method for 22 indicators of 5 groups. The integrated indicator has 5 assessment levels to demonstrate the magnitude of water use and the renewability of water resources. Using these indicators to evaluate the sustainability of three border provinces in the Mekong transboundary basin which are Kontum, Attapue, and Ratanakiri, this research came to the conclusions that 9/24 districts in three provinces have moderate water use and renewable water resources level; the remaining districts are also using water at a moderate level but with low renewable water resources. Furthermore, research results showed that different governmental policies generated varying impacts on the sustainable use of water resources in three provinces. Hence, this research is an important scientific foundation for the authorities to build cooperative water resource management programs in transboundary river basins. In future research, the availability of a more detailed dataset will enable the construction of a more comprehensive water resource management plan for different phases.

Keywords: *Sustainable water resources use, transboundary basin, district and indicator.*

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Індикатор сталого використання водних ресурсів у транскордонних басейнах

Через складну ситуацію з інтегрованим управлінням водними ресурсами в басейнах транскордонних річок, у цьому дослідженні було побудовано набір індикаторів сталого використання водних ресурсів методом Дельфі та розроблено спеціальний метод розрахунку для 22 індикаторів 5 груп. Інтегрований показник має 5 рівнів оцінки для демонстрації масштабів використання води та відновлюваності водних ресурсів. Використовуючи ці показники для оцінки сталості трьох прикордонних провінцій у транскордонному басейні Меконгу, а саме Контум, Аттапуе та Ратанакірі, це дослідження дійшло висновку, що 9/24 районів у трьох провінціях мають помірне використання води та рівень відновлюваних водних ресурсів; решта районів також використовують воду на помірному рівні, але з низькими відновлюваними водними ресурсами. Крім того, результати дослідження показали, що різні урядові політики по-різному впливають на стале використання водних ресурсів у трьох провінціях. Отже, це дослідження є важливою науковою основою для органів влади для розробки програм спільного управління водними ресурсами в транскордонних річкових басейнах. У майбутніх дослідженнях наявність більш детального набору даних дозволить побудувати більш комплексний план управління водними ресурсами для різних етапів.

Ключові слова: *стале використання водних ресурсів, транскордонний басейн, район та індикатор.*

Introduction

Covering nearly half of the Earth's land surface, international river basins, which are also known as transboundary river basins, are home to about 40% of the world's population and provide more than 60% of global freshwater. The Mekong River basin is a transboundary river basin and has a total area of 795,000 km^2, making it the twenty-first largest river basin in the world. It is distributed between China (21%), Myanmar (3%), Laos (25%), Thailand (23%), Cambodia (20%), and Viet Nam (8%). In 1999, to enhance regional collaboration and solidarity, Cambodia's Prime Minister Hun Sen proposed to establish Vietnam–Laos–Cambodia Development Triangle Area at first Cambodia–Laos–Vietnamese Prime Ministers Summit held in Vientiane, Laos. The Vietnam–Laos–Cambodia Development Triangle Area contains 5 provinces of Vietnam (Kon Tum, Gia Lai, Dak Lak, Dak Nong, and Binh Phuoc), 4 provinces of Laos (Sekong, Attapeu, Saravan, and Champasak) and 4 provinces of Cambodia (Stung Treng, Ratanakiri, Mondulkiri, and Kratie).

In fact, each governing body of countries in the basin has its own opinions, philosophies, and interests, leading to complex hydro-politics. This resulted in unbalanced water allocation, impacts on water quality, and social as well as environmental conflicts in the basin ***[1]***. The challenge in the integrated management of transboundary river basins is under increasing pressure as the policies have not kept pace with the influence of climate change, and the politics of reconciling political borders as well as boundaries issues ***[2]***. The issues of equitable water allocation and distribution of social-ecological costs and benefits are important for fostering cooperation and managing conflicts in transboundary water management ***[3]***. Therefore, ensuring sustainable water resources use in transboundary basins becomes undeniably important. Not only should water resources be exploited rationally to meet the needs of economic development but water quantity, as well as quality, should also be well preserved for future generations.

Nevertheless, the current management of transboundary river basins is facing many challenges, two of which are water pollution and water resource degradation. These two challenges occur with increasing intensity and greatly affect the existence as well as reproduction process of humans and organisms, posing a threat to the sustainable development of countries. Furthermore, water resources management and environmental protection in transboundary rivers are, most of the time, burdensome and controversial due to national interests as well as security across borders ***[4]***. Since transboundary river basins are experiencing rapid changes through both physical and economic pathways around the world, the field of water conflict and cooperation deserves a re-examination based on these new realities ***[5]***. More severely, the development and consequences of hydropower in the upper Mekong Basin have led to conflicts between Thailand, Laos, Cambodia, and Vietnam for agricultural and domestic water demand, which were also the reasons for civil unrest and violence in the region ***[1]***. As a result, the need to build a set of water use indicators for transboundary river basin management has been addressed and carried out in several studies ***[6, 7, 8, 9]***.

One of the earliest studies to develop sustainability indicators for transboundary river basins and to examine their potential to apply for integrated river basin management was conducted in 2001 ***[10]***. This study confirmed that indicators, measured at the river basin scale, not only satisfy the needs of stakeholders but also provide useful integrated information for different management levels, positively paving the way for later studies in the 2000s. In later research that was conducted in 2007, an index, namely the Canada Water Sustainability Index (CWSI), was calculated by the Policy Research Initiative based on the survey results of 6 communities at the district level in Canada. As a composite index that consists of five theme-based components which are Resource, Ecosystem Health, Infrastructure, Human Health, and Capacity with 15 indicators ***[11, 12]***, the CWSI was well acknowledged as a useful tool by the community. Another research by Yoffe in 2007 determined historical indicators of international conflicts as well as cooperations for freshwater to generate a framework that can provide an outlook for potential risks in the future for international river basins. In this research, international relations over freshwater resources are highly associated with the institutional development of the regions ***[13]***. A more recent study which is the Transboundary Waters Assessment Program (TWAP), has presented the assessment results and findings of calculated indicators for projected scenarios of 286 transboundary river basins. The calculated results at a more global level were considered to be more appropriate than previous studies, even though the results for a large number of smaller basins are only indicative and cannot be assigned a credible level of scientific confidence ***[14, 15, 16, 17, 18]***.

Even though the issues of conflicts, cooperative relationships between countries in the transboundary river basin as well as the development of indicators to evaluate sustainable water resource use have been discussed in previous studies, integrated water resources management has never been implemented at the basin or national level. Thus, the selected research area in this research which are Kon Tum (Vietnam), Attapeu (Laos), and Ratanakiri (Cambodia) satisfies two conditions of being in the transboundary river basin and being in the border provinces. These three provinces form the Indochina T-junction—the "core zone" of Vietnam, Laos, and Cambodia with a total area of 32,515 km^2, playing an important role not only in the Development Triangle Area but also in the lower Mekong basin.

Using Delphi method, this research builds the Sustainable Water Resources Use Indicator (SWRUI) with 22 indicators of 5 groups which are Water Quantity, Water Quality, Ecosystem, Governance and Socio-economics. 22 individual indicators, group indicator as well as the SWRUI were calculated at the district level for each of the 24 districts in Kontum, Attapue and Ratanakiri provinces. The calculated results of sustainability indicators identify policies to preserve water resources as well as to improve the desired water management characteristics of the basin in the future.

Methodology

This research applies the Delphi technique to determine the set of indicators for the sustainable use of water resources. The objective of this technique is to organize effective communication processes that enable a group of people to solve a complex problem ***[19]***. Being developed for military forecasts by RAND company in the United States in 1944 ***[20]***, the Delphi technique has gradually become a universal approach that is customizable for a variety of purposes ***[21]*** such as to carry out a survey questionnaire to gain consensus from an expert panel ***[22, 23]***, which is also the main approach of this research.

In this research, the Delphi technique is implemented through two rounds. In the first round, a number of experts in the field of water resources are interviewed and consulted to gather in-depth opinions and identify criteria groups to build closed questions for the second round. In the second round, a closed questionnaire is sent to the experts who participated in the first round to calculate mean scores, and standard deviations so as to reach a consensus. Reliability on the level of agreement is assessed using Kendall's coefficient (W). The Kendall coefficient ranges from 0 to 1 to measure the degree of consensus and the degree of trust ***[24]***.

According to previous research ***[25]***, this research targets a sample of experts from 15 to 35 people to collect objective data. The group of experts participating in the first round of interviews consists of 20 Vietnamese experts, 11 Laos experts, and 15 Cambodian experts. After sending the questionnaire to each of the experts, 35 replies were received and five groups of criteria are selected for creating the closed questionnaire including Water Quantity, Water Quality, Ecosystems, Governance, and Socioeconomics. The closed questionnaire of the second round were sent to the experts who participated in the first round with a summary of the first round's results. The response rate was 100%. The second round is meant to collect scores from experts for each criteria, according to which this research can calculate mean scores as well as standard deviations and assess consensus. Kendall's W value at 0.503 in the second round satisfies the necessary and sufficient conditions at the beginning with a high degree of consensus and trust. Thus, the interview ended after the second round. The results from the second round are then ran with SPSS20 software ***[26]*** to find out the indexes of each variable in five groups. After processing the data through two rounds, 5 indicator groups with 22 indicators were identified from 40 proposed indicators.

Results and discussions

With 22 indicators identified above, this research develops a calculation method for each indicator as presented in ***Table 1.*** After that, this research calculates each indicator, group indicator as well as the SWRUI based on collected data from 2019 ***[27]*** for 22 indicators of 5 groups including Water Quantity, Water Quality, Ecosystem, Governance, and Socioeconomics in 24 districts of 3 provinces.

Two first indicators of Water volume (total surface runoff) and Dry season water volume in group 1 are calculated from the runoff map of the area. The third indicator, the scarcity of water resources indicator, is calculated by the available of renewable freshwater per capital in a year ***[12]***. In addition, the last three indicators of group 1 are calculated by taking the ratio of water demand for domestic use ***[28]***, for agriculture ***[29]***, and for industry ***[28]*** over the total water volume, consecutively.

In order to assess the level of nutrient contamination in the seventh indicator of group 2), water samples are collected and analyzed in the laboratory. Classification of levels of nutrient pollution is referenced according to the National Technical Regulation on Surface Water Quality ***[30]*** of Vietnam. The source of water pollution in the eighth indicator is determined by the results of the field survey. Finally, the data for indicators in Group 3, group 4, and group 5 are collected and calculated from the field survey.

Each indicator was assigned to one of the five categories with scores (Very low = 1, Low = 2, Moderate = 3, High = 4, and Very high = 5) to assess the risks related to water resources use. The higher the score of the indicator, the more this activity will adversely affect the sustainability of water resources in the basin. The integrated indicator of each group is calculated by taking the average of the component indicators and was also assessed according to the above 5 levels. After calculating the indicator of each group, the SWRUI is calculated and assessed by summing up all calculation results and taking the average of 5 group indicators. The SWRUI is assessed according to the following principle. A higher value of the calculated result represents a higher level of risk in current water use activities, implying that water resources are being used unreasonably and disrupting the renewability as well as the sustainability of water resources. The detailed hierarchy of calculation results for the SWRUI and the degree of impact on the sustainability of water resources are listed in ***Table 2.***

The calculated results for 24 districts of 3 provinces are illustrated in ***Figure 1*** and ***Table 3.*** The results show that less than half of the districts (9/24) have sustainable water resources use at level 3; the remaining districts are at level 4.

According to the calculation results for the 3 provinces, it can be concluded that there exist heterogeneities between the 3 provinces in the research area. Most of the districts in the research area had a very low risk of water quantity but almost all districts faced a high risk of water pollution. Kon Tum city even reached a very high risk of water quality. The current conditions of the ecosystem had high risk and will surely be negatively affected because of water pollution. As a result, even though water resources governance in all districts had low or moderate risk, the preservation of the ecosystem requires the water resources governance to act in a more timely and serious manner. Furthermore, current social-economic conditions pose a moderate risk in some districts and a high risk in others. The integrated calculation results suggested that Kon Tum city, which was the only urban district in the research area, will soon suffer from the consequences of unsustainable water use (as shown in ***Figure 1*** and ***Table 3***). Additionally, all districts of Attapue and Ratanakiri provinces which are identified as the downstream areas of the river basins were more affected than the districts in Kon Tum province (except for Kon Tum city) in the upstream areas.

All in all, in this research, the results of the assessment of sustainable use of water resources at the district level were obtained, which has never been done in previous studies. Despite the extensive application of TWAP model ***[31]***, calculations performed at a basin level cannot detect variation in different areas within the basin and prevent the development of management strategies for the basin, especially for complex transboundary basins such as the Mekong River basin where the integrated water resources management is more difficult to implement. On the other hand, the calculation results of the CWSI index ***[11, 12]*** for only some domestic regions in Canada benefitted the assessment process but the institutional policy in the country's water resources sector was not considered. This research, however, fulfills the literature gap by developing a set of sustainability indicators at the district level, including institutional considerations. The results of this research, thus, provided insightful and meaningful implications for the complicated water resource use in transboundary basins.

Conclusion

This research builds a set of indicators for sustainable use of water resources with 22 indicators of 5 groups by the Delphi method. From the complex situation of integrated water resources management

Table 1. **Hierarchy of risks related to group indicator**

Indicator	1. Very low	2. Low	3. Moderate	4. High	5. Very High
Group 1.	**Hierarchy of risks related to water quantity**				
1) Water volume (total surface runoff), mm/year	≥ 2000	1600 ÷ 2000	1200 ÷ 1600	1000 ÷ 1200	< 1000
2) Dry season water volume, mm	≥ 1000	800 ÷ 1000	600 ÷ 800	400 ÷ 600	< 400
3) Scarcity of water resources, m^3/cap/year	≥ 1700	1300 ÷ 1700	1000 ÷ 1300	500 ÷ 1000	< 500
4) Water demand for domestic use, % water volume	< 1	< 2	< 3	< 4	≥ 4
5) Water demand for agriculture, % water volume	< 10	< 20	< 30	< 40	≥ 40
6) Water demand for industrial production, % water volume	< 1	< 2	< 3	< 4	≥ 4
Group 2.	**Hierarchy of risks related to water quality**				
7) Nutrient pollution, mg/l — $NH_4^+(N)$ $NO_2^-(N)$ $NO_3^-(N)$ $PO_4^{3-}(P)$	< 0.3 < 0.05 < 2 < 0.1	≤ 0.3 ≤ 0.05 ≤ 5 ≤ 0.2	≤ 0.9 ≤ 0.05 ≤ 10 ≤ 0.3	≤ 0.9 ≤ 0.05 ≤ 15 ≤ 0.5	> 0.9 > 0.05 > 15 > 0.5
8) Presence of water pollution sources	Unlikely	Slightly likely	Somewhat likely	Likely	Very likely
Group 3	**Hierarchy of risks related to ecosystem**				
9) Aquatic biodiversity protection and conservation	Very low	Low	Moderate	High	Very high
10) Aquatic resources protection and conservation					
11) Depletion of fisheries resources					
12) Ecosystem degradation due to the construction and operation of hydropower plants					
13) Ecosystem degradation due to water pollution/ depletion					
Group 4	**Hierarchy of risks related to water resources governance**				
14) Planning of environmental protection program	Available and being implemented effectively	Available and being implemented	Available	Under construction	Not available
15) Planning of water resources management					
16) Water resources governance capacity	High	Moderate	Low capacity but capable of training	Low	Very low
17) Water resources — related conflict	Available and being implemented effectively	Available and being implemented	Available	Under construction	Not available
Group 5	**Hierarchy of risks related to socio-economics in water use**				
18) Living standards and well-being of communities	Very high	High	Medium	Low	Very low
19) Exploitation of hydropower resources	Did not exploit	Slightly exploited	Moderately exploited	Highly exploited	Exhaustedly exploited
20) Indicator of livelihoods and employment of communities using water resource	Very high livelihood Over 95% of working age population has jobs	High livelihood Over 85% of working age population has jobs	Moderate livelihood Over 75% of working age population has jobs	Low livelihood Over 75% of working age population has jobs	Very low livelihood Over 50% of working age population has jobs
21) Indicator of economic efficiency of water usage industries	Very high	High	Moderate	Low	Very low
22) Indicator of adaptability of the economy in the use of water resource					

Table 2. **Hierarchy of Sustainable Water Resources Use Indicator**

Calculation results	Degree of impact
1 — Very low	Reasonable use and high renewable water resources
2 — Low	Reasonable use of water resources
3 — Moderate	Moderate use and renewable water resources
4 — High	Moderate use and low renewable water resources
5 — Very high	Unreasonable water resources use

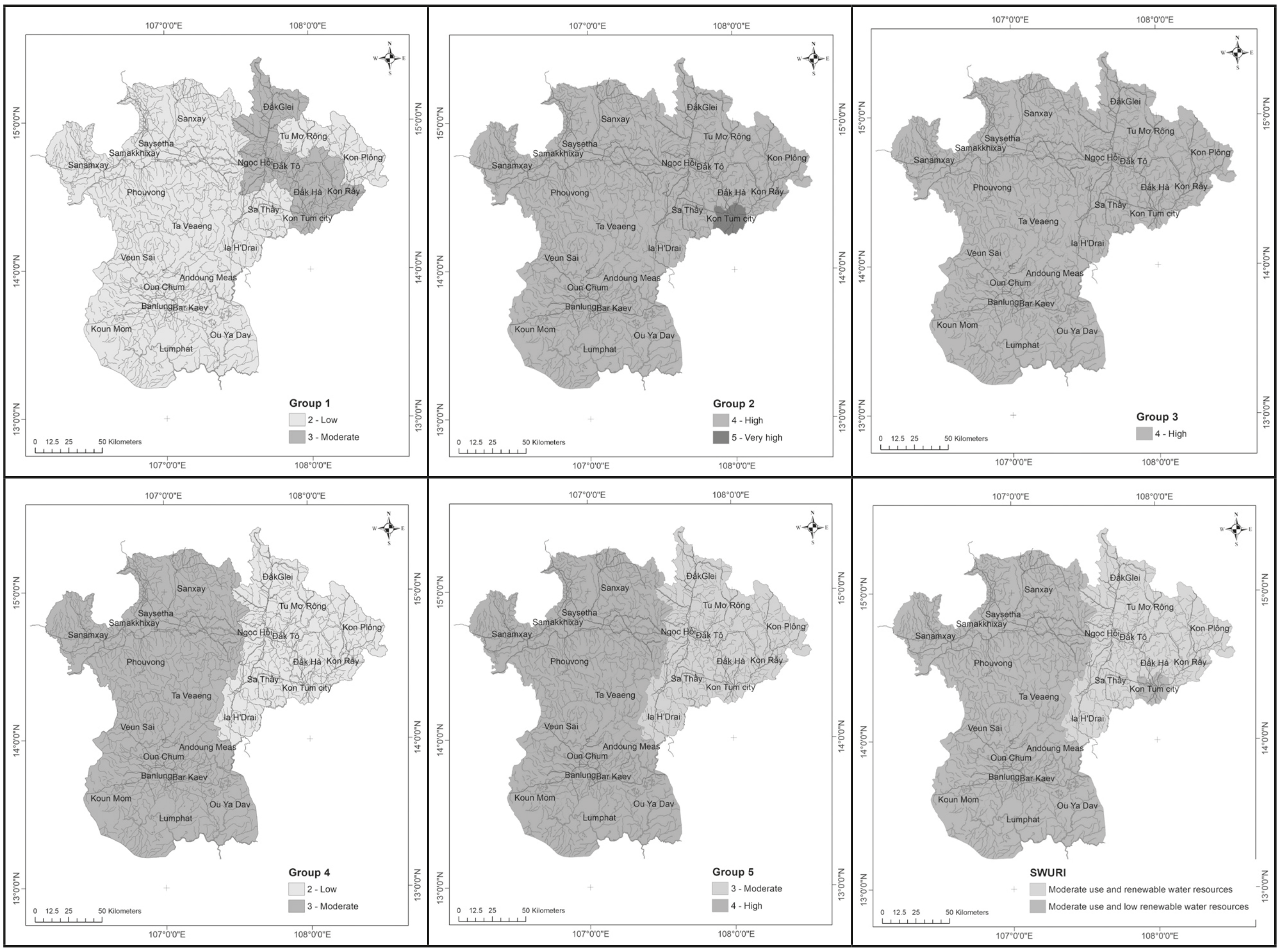

Figure 1. Results of calculation of Sustainable water resources use indicator

Table 3. **The calculated results of the SWRUI for 24 districts**

No.	Province/ District	Indicator						
		Group 1	Group 2	Group 3	Group 4	Group 5	SWRUI	Standard deviation
I. KONTUM								
1	Kon Tum city	3	5	4	2	3	4	1.140
2	DakGlei	3	4	4	2	3	3	0.837
3	Ngoc Hoi	3	4	4	2	3	3	0.837
4	Dak To	3	4	4	2	3	3	0.837
5	Kon Plong	2	4	4	2	3	3	1.000
6	Kon Ray	3	4	4	2	3	3	0.837
7	Đak Ha	3	4	4	2	3	3	0.837
8	Sa Thay	2	4	4	2	3	3	1.000
9	Tu Mo Rong	2	4	4	2	3	3	1.000
10	Ia H'Drai	2	4	4	2	3	3	1.000
II. ATTAPEU								
11	Saysetha	2	4	4	3	4	4	0.894
12	Samakkhixay	2	4	4	3	4	4	0.894
13	Sanamxay	2	4	4	3	4	4	0.894
14	Sanxay	2	4	4	3	4	4	0.894
15	Phouvong	2	4	4	3	4	4	0.894

Table 3. **The calculated results of the SWRUI for 24 districts** *(continuation)*

No.	Province/ District	Indicator						
		Group 1	Group 2	Group 3	Group 4	Group 5	SWRUI	Standard deviation
	III. RATANAKIRI							
16	Andoung Meas	2	4	4	3	4	4	0.894
17	Banlung	2	4	4	3	4	4	0.894
18	Bar Kaev	2	4	4	3	4	4	0.894
19	Koun Mom	2	4	4	3	4	4	0.894
20	Lumphat	2	4	4	3	4	4	0.894
21	Oun Chum	2	4	4	3	4	4	0.894
22	Ou Ya Dav	2	4	4	3	4	4	0.894
23	Ta Veaeng	2	4	4	3	4	4	0.894
24	Veun Sai	2	4	4	3	4	4	0.894

for transboundary river basins, this research selects three provinces in the Mekong transboundary basin which are also the three border provinces in the Southeast Asian region. From the set of indicators obtained after 2 rounds of Delphi interview, calculations were carried out for 24 districts in the three provinces. This is the first research to develop and calculate indicators of sustainable water resource uses at the district level instead of a general assessment for the entire basin. Based on the calculation results of present status at the district level, sustainable use of water resources for 24 districts in 3 provinces in the research area are presented as follows. Water resources use in 9 out of 24 districts are at moderate level and renewable while the remaining 15 districts are at moderate use but with low renewable water resources.

Out of 22 indicators used for calculation, some indicators are qualitative based on survey results. Hence, scoring and classification results were based on the subjective opinions of the expert panel to perform the assessment. In fact, creating a homogenous dataset for a research area that includes 3 countries with different characteristics of water resources, different institutions and policies on exploitation and use of water as well as different economic development, and political characteristics, was the biggest challenge when conducting studies for transboundary river basins. However, the results from this research are applicable to areas within transboundary river basins. In order to fulfil sustainable development goals, the sustainability of water resources management is one of the most critical issues to be addressed in a timely and serious manner. As a result, this research lays an important scientific foundation for the authorities to build cooperative programs for water resource management in transboundary river basins. In the future, the availability of a more detailed dataset will enable the construction of a more comprehensive water resource management plan for different phases.

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