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Fluctuations in agriculture and sediment in the Mekong delta of Vietnam due to increased upstream water use

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Abstract:

The Mekong delta (MD) of Vietnam rests at the end of the lower Mekong basin (LMB) where it is met with serious adverse effects from all upstream activities with severe consequences like landslides and complicated subsidence phenomena. Researchers agree that the main reason for these consequences are the lack of sediment deposited in MD due to the absence of floods and upstream hydropower development. To better understand the causes of the above phenomena, research on the transboundary impact between Vietnam and Cambodia in the MD was carried out [1]**. This article develops more reliable scientific evidence of the impacts of upstream water use on the economic, social, and environmental factors of its four national members. It also scientifically demonstrates the transboundary impacts of upstream hydropower and irrigation developments in LMB such as the decline of sediment and the extreme decline of the quantity/yield from natural fisheries under all development scenarios.**

Keywords: **hydropower plant, irrigation, lower Mekong basin, transboundary impacts, water resource, water use.**

Classification number: **5.1**

Introduction

Because the Vietnamese MD is a wetland, it carries many advantages such as an abundant water resource in both quality and quantity, large soil resource area, diversity in bioecology, and harmonious climate (large rainfall, warm), all of which expand the production, ecology, and environmental sectors. Now, these advantages coincide with many adverse impacts from upstream the Mekong river basin. With this comes many opinions from inside and outside stakeholders, researchers, and experts presented with this situation in the MD.

The external causes of impacts on the MD are the hydropower projects, irrigation systems, and industrial zones along upstream countries that make hydrological flow and drought more serious during the dry season [1]. The internal causes of impacts on the MD is the quality of surface water that is too polluted, which leads to the critical problem of water security [2]. With the current economic development of both upstream and downstream countries, especially those in energy development, the adverse effects are focused on mainstream hydropower plants and irrigation in the Mekong river basin [3].

To provide foundational scientific knowledge to this discussion, in 2011, the Mekong River Commission (MRC) implemented a Council Study Program (CSP), namely "Study on the sustainable management and development of the Mekong river, including impacts of mainstream hydropower projects", which was completed in 2018. The main objective of the CSP is to enhance the scientific knowledge of the potential impacts of economic development on the water, people, as well as the natural environment of the Mekong river basin [4]. Transboundary impacts have been an issue of interest to Vietnam because the MD in Vietnam is the most vulnerable region in the whole basin [3]. The results of the consultant group's assessment of

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Vietnam, which contributed to the CSP's results, presented the transboundary impacts between Vietnam (downstream) and the upstream region on agriculture production and sediment condition.

While the transboundary impacts studied in the CSP included agriculture, aquaculture, water quality, and labour, in this research the sections are the environmental (water quality, sediments), economic (production rice fluctuations), and social sectors (labour force).

Materials and methods

The CSP is a complicated body of research with many kinds of data and information with different steps, activities, and subjects in its process. The general approach of the research is summarised by the following steps:

The CSP is implemented via 2 pathways. These pathways are (1) impacts of water resource development via both positive and negative changes to the hydrological regime (i.e., hydropower or irrigation projects changing timing, quantity, quality, etc.) and (2) positive and negative impacts not transmitted via the hydrological regime. The CSP's assessment approach is illustrated in Fig. 1.

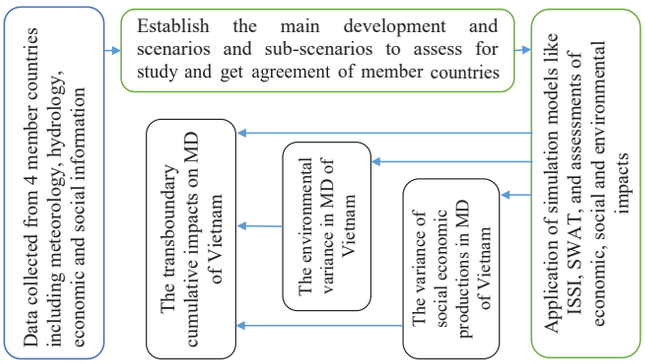

Fig. 1. CSP's integrated assessment approach [4].

The CSP divided the region of interest in the LMB into 6 subzones. Zone 6, including zone 6A - freshwater MD of Vietnam and zone 6B - saline MD of Vietnam, is the study region in Vietnam (Fig. 2). So, the area researched in zone 6 is the whole region of the MD in Vietnam. The transboundary cumulative impact assessment caused by the identified upstream development activities for zone 6 is the most comprehensive compared with those of the upper zones in the LMB [4].

With the above assessment and geographical scopes, the CSP created some scenarios to specifically research and assess as well as to form the scientific basis for the analysis of causal impacts. There are 3 kinds of development scenarios including the M1 scenario, which represents the baseline condition of research and the referential conditions for comparisons with others. The development scenarios are (i) the early development scenario (M2); (ii) the definite future scenario (M3) and with climate change (M3CC); and (iii) planned development scenarios with 12 sub-scenarios, namely, C2, C3, A1, A2, F1, F2, F3, H1a, H1b, H3, I1, and I2 with focus on irrigation, hydropower, and flood conditions (Table 1).

The transboundary impact assessment is a part of the Integrated Multi-Sector Cumulative Impact Assessment. The transboundary impact assessment between Vietnam and Cambodia is one part of this sector.

The assessment of the transboundary impacts on the MD of Vietnam caused by the construction of hydropower plants and extended irrigation areas included the upstream countries of China, Laos, Thailand, and Cambodia along with their cumulative characteristics of potential impacts [3, 4].

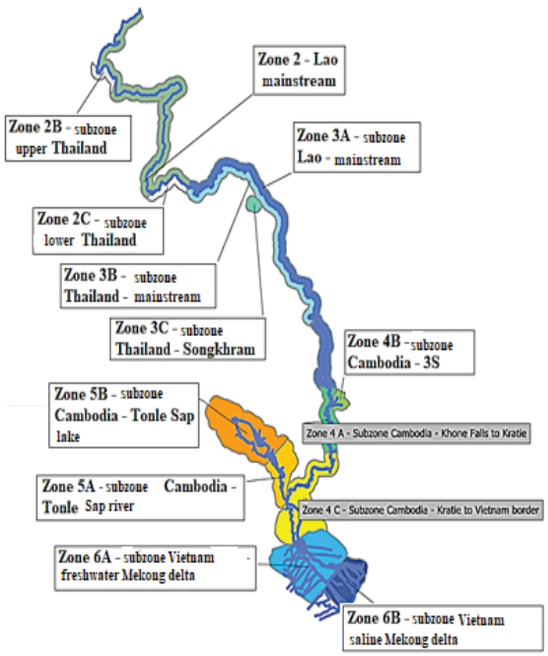

Fig. 2. Map sub-zones used for the assessment of impacts in Council Study [4].

For more detail of the transboundary impacts as well as their effectiveness, the approach from transboundary impact assessment was used, which is implemented using the following indicators as seen in Table 1. The 6 sub-scenarios in Table 2 (F2, F3, I1, A1, A2, and A3) were used to estimate the consequences of transboundary socio-economic assessment. The matrix of scenario comparisons for the transboundary socio-economic assessment is considered in Table 3.

Table 1. Composite indicators for use in the transboundary Cumulative Impact Assessment (CIA).

Approach	Dimensions	Indicators for transboundary CIA
Qualitative and Quantitative synthesis	Social - Economic	Income (fish and rice surplus) (USD) Production (fish and rice values) (USD)
	Environmental	Water quality and sediment conditions in mainstream of Mekong river
	Integrated	Resilience, vulnerability

Table 2. Main development scenarios.

Sc.	Describes	Sc.	Describes
M1	Early development scenario 2007	C2	Planned development 2040+wetter CC
M2	Definite future scenario 2020	C3	Planned development 2040+drier CC
M3	Planned development scenario 2040	F1	Planned development 2040 without FPF
M3CC	Planned development scenario 2040 with CC	F2	Planned development 2040 with FPF2
A1	Planned development 2040 without ALU	F3	Planned development 2040 with FPF3
A2	High level ALU implementation	H1a	Planned development 2040 without HPP
I1	Planned development 2040 without IRR	H1b	Planned development 2040 (Chinese, tributary and mainstream dam)
I2	Planned development 2040 with IRR HIGH	H3	Planned development 2040 with HPS3

Table 3. Scenario and sub-scenario comparisons for the socio-economic assessment.

Effects tested	Scenario comparisons	Socio-economic
Surplus of fish and rice production	(All)	X
Climate change	M3CC vs C2, C3	X
Irrigation development	M3CC vs I1, I2	X
Hydropower development	M3CC vs H1a, H1b, H3	X
Agriculture and land-use development	M3CC vs A1, A2	X
Flood protection infrastructure development	M3CC vs F1, F2, F3	X

Notes: A: agriculture; C: climate change; I: irrigation development; H: hydropower; F: flood protection.

Results and discussion

Based on the results of all the scenarios (i.e., main and sub-development scenarios), the changes in social, economic, and environmental dimensions in zone 6 (MD of Vietnam) due to the transboundary impacts caused by upstream development activities along upstream countries are identified and summarised below.

The variance of social economic productions in MD of Vietnam

The transboundary social economic assessment was implemented by identifying food security from surplus of fish and rice production. In fact, there are many other factors related to the food security, but, at this time, they are out of the scope of this research. The surpluses of rice and fish production in the sub-scenarios are presented with the variances of transboundary impacts caused by the upstream development activities on MD of Vietnam in Figs. 3, 4.

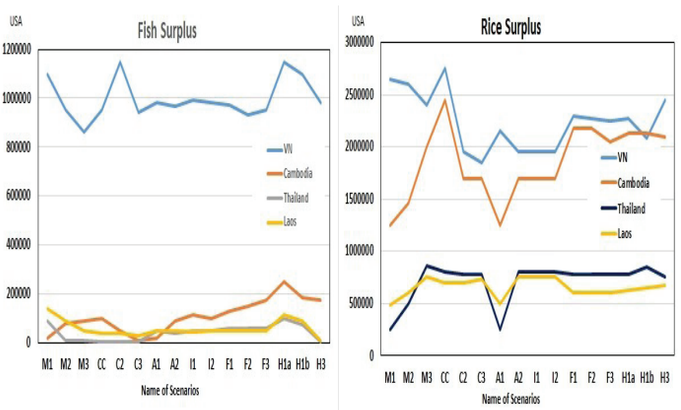

Fig. 3. National fish and rice surplus for all scenarios [4].

Figure 3 indicates that Vietnam's fish and rice production are influenced by all of the upstream water development activities described in the sub-scenarios. However, the variance of fish and rice surplus is not large and could be explained by the dependence of fish and rice surplus on the export market.

With changes in rice and fish production, poor households become more vulnerable in sub-scenarios C3 and F2, which cause major dips in fish surplus, as well as C2, C3, A1, A2, IRR2, IRR3, and H1b, which all reduce rice surplus. When considering climate change conditions, Vietnam could help the conditions of increasingly poor households and would likely to see a substantial reduction in vulnerability if less dams or no dams were built (H1a or H1b) (Fig. 4).

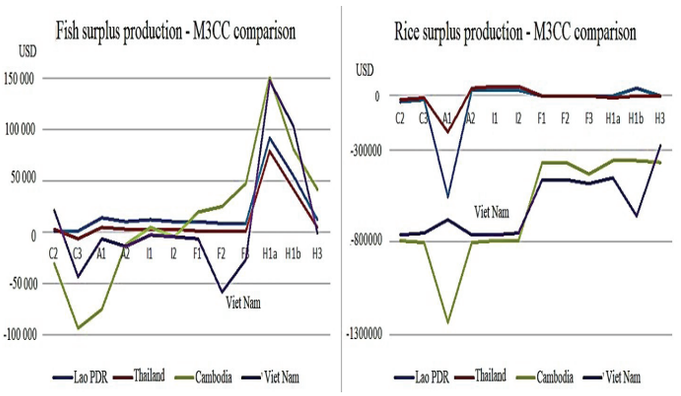

Fig. 4. Fish and rice surplus for sub-scenarios if compared with M3CC [4].

The rice production in zone 6 (MD of Vietnam) estimated over a 24-year period under the main development scenarios is illustrated in Fig. 5. The rice production's variance over the 24-year development scenario is not much because the local water infrastructure has been nearly completely constructed, which protects the rice land and local residences.

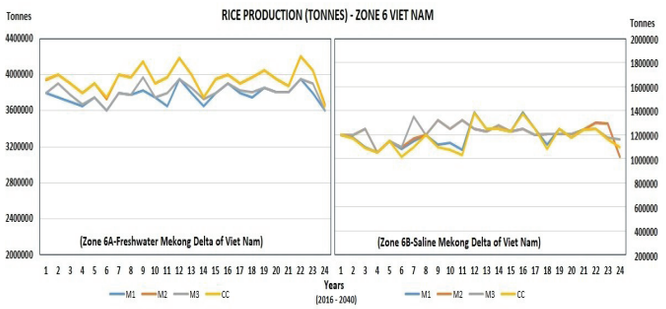

Fig. 5. Rice production (tons) over the 24 year by main development scenarios [4].

The variance in fish production in zone 6 over the 24-year development scenarios are shown in Fig. 6. The fish sector (including the native fish catch and aquaculture) changed because it depends on a lot on the flow of both quality and quantity, which is significantly impacted by the development activities of upstream countries.

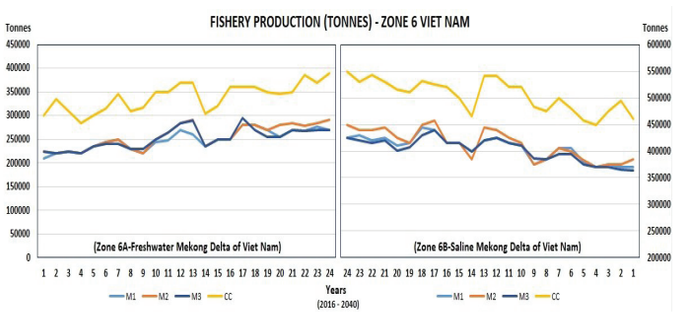

Fig. 6. The native fish catch and aquaculture production estimated in zone 6 (6A, 6B) [4].

The CSP's sector approach has shown that even until 2040, significant impacts from climate change are likely and could be caused by transboundary impacts of water resource development coupled with the changing climate. When considering climate change, one striking finding is the significant reduction of future GDP for all climate scenarios. The change of GDP in zone 6 is listed in Table 4. The reducing rates in the climate change scenarios clearly showed that climate change will directly affect the LMB including zone 6 - MD of Vietnam.

Besides the transboundary impacts of Cambodia caused by its economic decline of rice and fish production, MD of Vietnam has to face the adverse variance of water resource due to the rise in sea level, which makes salinity intrusion penetrate deeply into the area.

Table 4. The GDP projection (average) and its (%) reduction for 2040 due to climate change [4].

Scenarios	GDP (billion USD)	Rate (%)
M1 trend	82.3	
M2	82.7	-0.6%
M3 (No CC)	82.5	-0.2%
M3CC	81.3	1%
C2 (Wet)	78.9	4%
C3 (Dry)	78.7	5%

The environmental variance in MD of Vietnam

The modelling study of CSP considered the effects from different scenarios on a variance/change of issues such as flow, sediment, and nutrient regimes due to the cumulative effects of upstream development activities including climate change. The natural phenomena regime is changed significantly due to the impacts of upstream reservoirs and dams. The variance of flow regime is different between the time scenarios, which means the seasonal or annual average or tidal flows.

Seasonal flow changes: with the development of hydropower projects in the basin, there is a change in flow regime between the wet season with lower flows and the dry season with increased flows in MD. A potential benefit may appear when the dry seasonal flow increases, and oppositely, when flood areas and the reversal of the Tonle Sap lake to the MD are reduced, which impacts flood pulse-dependent ecosystems. The reversal in flow will be 8% lower for (M2), 5% (M3), and 9% (M3CC). In a different way, a dry year would have a reversal of 58% (M2), 60% (M3), or 55% (M3CC) of the baseline average.

Annual average flow change: the change in annual average mainstream flow did not increase or reduce by much. The variance was between -3.4 and 2.4% when the authors compared the main development scenarios to the baseline scenario M1 (Fig. 7).

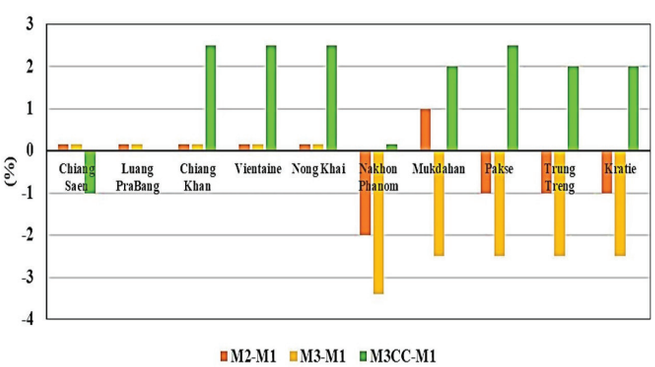

Fig. 7. The percent different annual average flow at key stations along river [4].

Sediment flux: the change in volume of sediment flux is the most striking finding from the modelling so far. The retaining of sediment passage by the cumulative effect of reservoirs in the upstream river basin's region, in tributaries, and as proposed in the mainstream all but take out the sediment from the river when it reaches to downstream region. At Kratie, there was only 3% sediment flux continuing to the delta as highlighted in red in Fig. 8. The figure also shows the adverse effect of trapped sediment on hydropower reservoirs along the mainstream is significant. For example, the volume of sediment from MRB through Kratie toward the delta was simulated to be about 143 Mt/y (M1). It was reduced in 2020 (M2) to only 47.4% of the natural value and for M3 and M3CC to less than 4% for the 2040 scenarios that have full hydropower development.

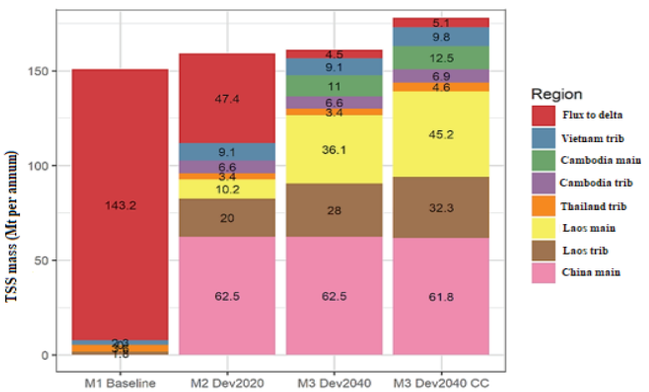

Fig. 8. Reservoir sediment trapping by region main scenarios [4].

The transboundary cumulative impacts on MD of Vietnam

The authors integrated all figures of the positive and negative impacts of all upstream development activities in upstream countries through the main and sub-development scenarios. The assessment of the transboundary effects/ adverse impacts on the MD of Vietnam can be considered as connections between benefit and cost-sharing mechanisms, which require the consideration of very complex socio-economic interactions. This assessment focused on the most critical trade-off between hydropower and fisheries. The integration echoed many of the themes raised by other assessments. The transboundary assessment impacts are only focused on a few themes like:

- The emerging trade-offs between hydropower and fisheries are substantial and suggest a project-by-project assessment to identify the most harmful and the most efficient investment projects.

- Transboundary effects were significant and include positive effects for Thailand and Vietnam as a consequence of their investments in hydropower. While Cambodia had negative effects due to losses in fisheries and sediment.

The approach for addressing benefit sharing is to compare sector impacts (hydropower and fisheries) in key sub-scenarios. Sub-scenario H1a quantifies the negative external impacts the combined bundle of hydropower project is likely to have on fisheries. Sub-scenario H1b limits the effects on mainstream hydropower.

Table 5. Comparison of hydropower benefits and fisheries cost for H1a and H1b [4].

Scenario	Country	Hydropower benefits ($)	Fisheries costs ($)	National cost-benefit ratio	Possible benefit transfer levy
H1a	Cambodia	11.1	6.5	58%	Mainstream HPP: 18.9%
	Lao PDR	36.3	4.0	11%	
	Thailand	82.9	6.5	8%	
	Vietnam	26.7	2.5	9%	
H1b	Cambodia	3.7	2.3	61%	On tributary HPP: 8.6%
	Lao PDR	17.3	2.1	12%	
	Thailand	63.7	3.1	5%	
	Vietnam	15.2	1.2	8%	

Table 5 compares country-specific hydropower benefits with the costs of fisheries, which results in a side-effect of hydropower investments. Critical to this comparison is that hydropower benefits do not remain in the countries where dams are or would be located. However, it should be noted that the fisheries sectors are likely to experience substantial losses when there is increasing investment on hydropower development. The economic losses of the fisheries sector are not only about the price and fishing catch, but also the reduction of both nutrient, sediment, and the variance of flow due to the impacts of upstream hydropower development. So, Table 5 is a clear demonstration of a synthesis of the combined impacts of upstream development activities on the MD of Vietnam.

Conclusions

The transboundary cumulative impact assessment helps us understand the relationships between upstream water development activities and the adverse variations occurring in the MD. Additionally, we found significant cause for all impact factors. The significant trade-off in hydropower development in the lower basin may cause damage to the MD of Vietnam specifically to the fisheries sector and by significantly reducing the sediments deposited in reservoirs (by about 4%) and decreasing the amount of sediment and nutrients moving downstream compared to 2007. Besides, the results of this research also showed the inter-dependence of LMB countries in the economic-social development of each country.

Although the scope of our study is focused on the transboundary cumulative impacts of upstream water development activities, especially upstream hydropower development impacts on the mainstream, the research results are still logically useful scientific bases and a methodical investment compared with many related studies in the Mekong region so far.

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COMPETING INTERESTS

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

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