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**THE STUDY ON WATERSHED SUSTAINABILITY INDEX
DEVELOPMENT. A PILOT STUDY OF CAU WATERSHED**

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**SUMMARY OF ENVIRONMENTAL CONTROL AND
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INTRODUCTION

1. Rationale

In recent decades, sustainable development has been receiving a great deal of attention around the world, and it has eventually become a global indispensable need due to its three-dimensional harmony orienting economic growth, social security, and environmental protection.

At the Mekong River Delta Conference on Sustainable Development in Can Tho (September 2017), scientists claimed the main causes adversely affecting the watershed (river basin) sustainable development are internal conflicts within the river basin, extreme deforestation in the upstream, and the impacts of climate change. The first and foremost cause, as it was stated in this dissertation, is the internal conflicts in watershed level. Meanwhile, under the pressure of population growth, the need for socio-economic development, environmental pollution, etc., it is the prospects of economic growth and social stability, which are both considered to lay a strong foundation to the mutual agreement among different relevant sectoral water-users from the perspective of interests in the river basin area, being greatly affected.

Presently, watersheds (river basins) are believed to encounter various challenges including water and food security, socio-economic development, and climate change. As a result, it is a must to conduct a study on watershed sustainability indices development as it will be crucial in order for policy makers, water resources managers, scientists, and stakeholders to be kept informed about the status of river basin, facilitating to integrated watershed managing solutions in

general and heading to sustainable development in particular.

Cau river basin plays an important in-stream role to Thai Binh river network, and it is taking a huge environmental stress. Therefore, the PhD candidate has decided to pick the river basin (Cau river basin) as the study area.

There are three (03) specific objectives as follows:

- To determine the scientific background of method selection on sustainability index development for watershed in Vietnam
- To select proper sets of parameters to be used in sustainability index development for watershed in Vietnam
- To carry out a pilot study on sustainability index development for Cau river basin

2. Study area and scope of the study

The sole object of the dissertation is the Watershed Sustainability Index (WSI), including the drivers (parameters) of the river basin sustainability. The parameters cover areas of Water Resources, Environment, Livelihoods, and Policies.

The general scope of the study is river basins in Vietnam, while the specific one is Cau river basin

3. Original contributions of the study

- The development of scientific basis for the determination of the sustainability index for river basins in Vietnam based on a set of indicators and parameters involving four areas: Water Resources, Environment, Livelihoods, and Policies.
- The proposed methodology for the calculation of WSI being successfully piloted for Cau river basin.

4. Protection points

1st thesis statement: The sustainable development of the river basin

is an integrated reflection of the drivers including exploitation, use and protection of existing natural resources and must be assessed through a quantitative indicator called the Watershed Sustainability Index from the major impactful factors;

2nd thesis statement: The Watershed Sustainability Index is a composite index of indicators covering water resources, environment, Livelihoods, and policies sectors, through Pressure-Status-Response parameters and is calculated based on the level of impact of the factors in each river basin.

5. The scientific and practical significance of the thesis

5.1. Scientific significance

The scientific significance of the dissertation is to provide a scientific basis for assessing the sustainability of river basins, based on the sustainability index with a set of parameters reflecting the four main aspects of the river basin: Water Resources, Environment, Livelihoods, Policies and contribute to addressing a scientific problem of integrated river basin management. This is a new and complex problem in the world in general and in our country in particular.

5.2. Practical significance

The results of the River Sustainability Assessment are supposed to help managers, scientists and people keep updated with the status and the level of sustainability of relevant river basins. From that, the measures to improve the sustainability of the river basin will be used to exploit and use rationally, economically and environmentally, especially against water resources, for sustainable socio-economic development in the river basin onwards.

5. Structure of the thesis

The dissertation consists of Introduction, Conclusion, References, Annexes, and three (03) chapters: (1) Literature reviews on WSI; (2) Scientific bases and methodology; (3) Results and Discussions.

CHAPTER 1: LITERATURE REVIEWS ON WATERSHED SUSTAINABILITY INDICES

1.1. Definition of watershed sustainability index

According to UNESCO (2006), the Watershed Sustainability Index is a quantitative measure of the sustainability of river basins, reflecting in particular the status and sustainability of each river basin, ranging from [0-1].

1.2. Literature reviews on WSI

1.2.1. Literature on WSI in the world

Studies conducted on WSI in the world are divided into two specific groups

1. Studies on WSI

The studies include: research of Chaves and Alipaz (2006) "An integrated indicators hydrology, environment, life and policy: Indicators of sustainable river basin" (An Integrated Indicator based on Basin Hydrology, Environment, Life and Policy: The Watershed Sustainability Index ; study of Dr. Rahmah Elfithri (2013): "Applying sustainability indicators Basin Langat River Basin, Malaysia" (Watershed Sustainability Index For Langat River Basin Study, Malaysia); " Applying the River Basin Sustainability Index for the Elqui Basin, Northern Chile" (Application of the Watershed Sustainability Index to the Elqui River Basin, North-Central Chile).

The advantage studies on this group is that it provides a clear and

simple way of doing things that are widely applied to different river basins. However, there are also some disadvantages such as: The same parameters do not represent the different characteristics of the river basin, or some of the parameters are simple and do not reflect the problems of the indicator. This group considers the number of component parameters and indicators to be equal, which does not reflect the level of impact of different parameters upon indicators.

2. *Studies on watershed sustainability sets of indicators*

The water sustainability sets of indicators contains the parameters related to the sustainability of water resources in these studies. An indicator set consists of several separate instructions which are not supposed to integrate regardless. The areas considered in the studies in this group are: water quantity, quality, ability to meet water resources, services and ecosystems with effective water management at community level. Some typical examples of this group are: Canada Sustainability Indicators Report: "The Canadian Water Sustainability Index "; Iwan Juwana study (2012): "Building sustainability indicators Water West Java, Indonesia" (Development of a Water Sustainability Index for West Java, Indonesia); A study by Juwana, N. Muttill, and BJC Perera (2012): " Indicator-based Water Sustainability Assessment (A Review) ...".

In general, the advantage of this group is that the indicator sets cover all issues that exist in the river basin. However, the studies also show limitations that this research focus only on the sustainability of water resources, while the sustainability of water resources is only one aspect of sustainable river basin. Not to mention robust systems of calculation are required to meet the demand of large amounts of data

in forms of parameters, which leads to higher cost of implementation. To conclude, the studies conducted by fellows in the world show that the sustainable development Basin have been receiving considerable attention that is valuable document for study and build sustainability indicators Basin for Vietnam.

1.2.2. Overview of research related watershed sustainability index in Vietnam.

There are some typical studies in Vietnam to be shown as follows: Water Sector Review (2008); Planning for the Huong-Thinh Binh River Basin Management Plan (2013); Project "Support to improve institutional capacity to monitor poverty alleviation - environment - livelihoods ... These papers generalize the water resources characteristics of the main river basins in Vietnam. These documents are also a valuable reference for the author to study issues affecting the sustainability of water resources and other areas in the river basin. In addition to the studies, the following articles are found to be related: Journal of Science and Technology Development, Volume 9, Environment and Resources, 2006, "Environmental indicators and indicators for evaluation and comparison of the state of the environment among the cities in the river basin" Che Dinh Ly; "Methodology of water quality assessment with weight and standard of one parameter" by Pham Ngoc Ho, published in VNU Journal of Science, Natural Science and Technology 27, No. 55 (2011). .v..v.

1.3. Conclusions

In chapter 1 of the dissertation, major findings of WSI in some countries such as IHP- UNESCO and Chaves & Alipaz (Brazil, Malawi, Malaysia...), the water sustainability index (Canada, France, Indonesia, India, Scotland ...). The results of research and practical

experience in establishing sustainable indicators for river basins around the world are very helpful. Usefulness can be used when building sustainable river basin indicators in our country. In the above methods, Chaves' and Alipaz's CSBVLVS methodology is a method that can be applied and improved in accordance with Vietnamese conditions. Some parameters such as surface water change during study period, water per capita, HDI parameters, improvement of water use efficiency...in existing studies will be considered to be included in the sets of parameters of WSI that will be presented in detail in the next chapter.

Also, the chapter synthesizes research results in Vietnam, which prevails the good points over the drawbacks creating the basis for initial development of WSI in Vietnam.

Based on analytical reviews of domestic and international studies, it was found that there still have been gaps among the study of the river basin sustainability index.

The results of the study of Chapter 1 will be the basis for studying the scientific basis and methodology for WSI in the context of Vietnam.

CHAPTER 2. SCIENTIFIC BASES AND METHODOLOGY

2.1. Scientific background on selecting, proposing sets of indicators and parameters

2.1.1. The scientific bases for frame of indicators and parameters suggestion

The basis for the selection of a set of sustainable river basin indicators is followed as: (1) considering factors affecting river basin sustainability; (2) referring to domestic and international studies for a set of indicators and parameters that affect river basin sustainability.

Indicators of sustainability of a system in general must ensure that sustainability is considered in all areas of the Environment, Economy, and Society. Based on the set of guidelines according to UNESCO (2010), the dissertation considered the areas that affect the protection and protection of natural resources including: Natural resources (mainly water resources), Environment (soil, forest, livelihood, policy in river basin, while human activities in the river basin (including activities of exploitation, utilization, protection in both positive and negative aspects) are reflected in all four above-mentioned areas.

On the other hand, referring to studies have shown that the Hydrographic, Environmental, Livelihoods, and Policy indicators, mentioned in the Chaves and Alipaz studies, basically cover areas in the basin with an improvement in the parameters to meet the conditions of Vietnam.

Thus, the set of WSI indicators used in this dissertation includes four directives: Water Resources, Environment, Livelihood, and Policies

1.1.2. Scientific bases for the set of parameters selection

The parameters need to ensure accordingly: (1) being a representative

and significant parameter for water resources, environment, livelihoods, and policies; (2) laying a clear scientific basis, i.e. the parameters can be quantified and verified by actual data; (3) being widely accepted (prior consultation of experts to exclude non-representative parameters and add parameters appropriate to the practice); (4) being easy to understand, reliable, highly sensitive, independent and non-overlapping.

The sets of parameters need to ensure accordingly: (1): being a parameter gives an overview about the stress and status to the indicators of water resources, environment, livelihood and policies. (2) having adequate numbers: the less the number of parameters, the higher chance policymakers consider them economically.

2.1.3. Scientific bases for sets of indicators and parameters proposal

For river basins in Vietnam, the factors affecting sustainability are complex, including many natural and man-made causes (human impact). However, it is necessary to select the simple calculation methods as the data availability is limited, given suitable the indicators and parameters for a specific condition of basin rivers in Vietnam.

$$WSI = (aWR + bE + cL + dP) \quad (1)$$

In which:

WSI: Watershed Sustainability Indicator;

WR, E, L, and P: Water resources, Environment, Livelihood, and Policies of river basin, respectively;

a, b, c, d: Weighted factors for Water Resources, Environment, Livelihood and Policies. The sustainability hierarchy according to Chaves and Alipaz methods is as follows:

$$0 \leq WSI < 0.25 \quad \text{Highly unsustainable}$$

- $0.25 \leq \text{WSI} < 0.5$ Unstable
- $0.5 \leq \text{WSI} < 0.75$ Sustainability
- $0.75 \leq \text{WSI} \leq 1$ Highly sustainable

2.2. Drivers of the sustainability of river basins in Vietnam

Therefore, it is the factors influencing the indicators being considered such as Water resources; Environment (environmental components such as soil, ecology, minerals, energy). The Livelihood (economy, society) and human policies (exploitation, use, protection) in the river. Factors affecting water resources are irrigation, irrigation, water pollution, affecting the ability to provide for water use in the dry season, the whole year. the Factors affecting the environment are pollution, overexploitation leading to ecological imbalance. Factors that directly affect people's lives are the average per capita income in the river basin, the average life expectancy of people, the human development index. Factors affecting the policies are the legal systems, organization and capacity of water resources management in river basins.

2.3. Selection of parameters sets of WSI

Based on the above mentioned scientific and theoretical bases, the PhD candidate proposes 25 parameters divided into three groups (stress, status, response) of four sectors (water resources, environment, livelihood, policies). The selected parameters and data sources for calculating the parameters are shown in Tables 2.1; 2.2; 2.3.

Table 2.1. Indicator and parameters of stress of WSI

Indicators		Parameters	Symbol	Unit
Water Resources	Quantity	1. Water variation in dry seasons/entire year	S_{LN1}	%
		2. Surface water	S_{LN2}	%

Indicators		Parameters	Symbol	Unit
		variation in dry seasons/entire year		
		3. Extractable groundwater variation in dry seasons/entire year	S_{LN3}	%
	<i>Quality</i>	4. Rain water quality variation in dry seasons/entire year	S_{CLN1}	%
		5. Surface quality variation in dry seasons/entire year	S_{CLN2}	%
		6. Groundwater quality variation in dry seasons/entire year	S_{CLN3}	%
<i>Environment</i>		7. Forest area variation	S_{MT1}	%
<i>Life</i>		8. Per capita income variation	S_{DS1}	%
<i>Policy</i>		9. Literacy HDI variation	S_{CI}	%

Table 2.2. Indicator and parameters of status of WSI

Indicator		Parameters	Symbol	Unit
<i>Water Resources</i>	<i>Quantity</i>	1. Amount of surface water per capita in the catchment	H_{LN1}	m^3 / year
		2. Utilizing water ration (rain-, surface-, ground-)	H_{LN2}	%
		3. Ratio of diverted water	H_{LN3}	%
	<i>Quality</i>	4. Average value of rainwater quality	H_{CLN1}	Unitless
		5. Average value of surface water quality	H_{CLN2}	Unitless

Indicator		Parameters	Symbol	Unit
		6. Average value of ground water quality	$H_{CLN\ 3}$	Unitless
<i>Environment</i>		7. Forest area ratio	$H_{MT\ 1}$	%
<i>Life</i>		8. Human development index (HDI)	H_{DS1}	Unitless
<i>Policy</i>		9. Literacy human development index	H_{C1}	Unitless
		10. Status of integrated water resources of river basins	H_{C2}	Unitless

Table 2.3. *Indicator and parameters of response of WSI*

Indicator		Parameters	Symbol	Unit
<i>Water Resources</i>	<i>Quantity</i>	1. Water utilization efficiency in the study period	U_{LN1}	Unitless
	<i>Quality</i>	2. Improvement of wastewater treatment and water quality	U_{LN2}	Unitless
<i>Environment</i>		3. Increase of forest area in the study area	U_{MT1}	Unitless
		4. Treated hazardous waste ratio	U_{MT2}	Unitless
<i>Life</i>		5. Water and sanitation ratio	U_{DS1}	%
<i>Policy</i>		6. Improvement of integrated water resources of river basins	U_{C1}	Unitless

2.4. Selection sustainability hierarchy of the parameters

The hierarchy must come from the concept of sustainability of the river basin. The parameter affecting river basin sustainability are hierarchized in such manner as follows: the parameters already in the previous studies, if appropriate, will be kept as the parameters of the index sustainable river basin; In the contrary, those newly proposed will be evaluated based on the nature and the variability of the parameters to proceed to construct the hierarchy basis accordingly.

The results of hierarchy of the parameters of the Water Resources, Environment, Livelihood and Policies indicators are presented in final report of the dissertation.

2.5. Methodology of weighting parameters of WSI

Currently, there have been several studies in the world that refer to the method of weighting the parameters, highlighting the method of hierarchical analysis of AHP. This method was proposed by Thomas L. Saty, based on a sociological survey of the information received through the questionnaires according to the criteria collected by direct inquires (field, record). The results of the sociological survey are used directly to assess the importance and comparability of the components and parameters to each other in the river basin. The final report of the dissertation presented this method thoroughly.

2.6. Calculation process

The procedure of calculating the LVS is as follows:

- **Step 1:** Develop the indicator frame;
- **Step 2:** Selection of parameter sets for indicators for the calculation of river basin sustainability in Vietnam;
- **Step 3:** Data collection, calculation of parameters;
- **Step 4:** Standardization and decomposition of parameters;

- **Step 5:** Determining the weights of parameters / indicators;
- **Step 6:** Calculating the river basin sustainability;
- **Step 7:** Assess sustainability and propose measures to improve river basin sustainability.

2.7. Conclusions

Based on the analysis of the scientific bases and the application of improved WSI calculation methods by Chaves and Alipaz, the dissertation proposed the clustering of river basin indicators including Water Resources; Environment; Livelihood, and Policies indicators.

Based on the calculation method of Chaves and Alipaz, the PhD candidate proposed some additional parameters. Calculation method is proposed according to formula (1).

The sustainability hierarchy of Chaves and Alipaz is the same as Step 7 of the WSI. The larger the WSI, the more sustainable the basin; In contrast, the smaller the WSI basin, the less sustainable.

In this chapter, it is finally presented the scientific bases for selecting 25 representative and significant parameters for water resources, environment, livelihoods and policies and the selection issues that affect the sustainability of the river basin, which are all scientific based, using well-defined and verifiable data; consulting experts to exclude non-representative parameters and add parameters that are appropriate to the situation; measured by a precise method and cost within the allowable limits; parameters are all easy to understand, reliable, highly sensitive, independent and non-overlapping.

CHAPTER 3. RESULTS AND DISCUSSION

3.1. The scope of Cau river

The basin of the Cau River basin includes cities, districts, and towns in 6 provinces as shown in the following table:

Table 3.1. Cau River Basin

TT	Name of province	Cities, districts, towns
1	Bac Kan	Bac Kan town and 3 districts: Bach Thong, Cho Don and Cho Moi.
2	Thai Nguyen	Thai Nguyen city and 8 districts and towns: Dai Tu, Dong Hy, Dinh Hoa, Pho Yen, Phu Binh, Phu Luong, Song Cong town and Vo Nhai district.
3	Vinh Phuc	Vinh Yen, Phuc Yen and in 6 districts: Binh Xuyen, Me Linh, Tam Dao, Tam Duong, Vinh Tuong and Yen Lac.
4	Bac Giang	3 districts: Hiep Hoa, Viet Yen and Yen Dung
5	Bac Ninh	Bac Ninh city and 4 districts: Que Vo, Tien Du, Tu Son and Yen Phong
6	Hanoi	Soc Son and Dong Anh

3.2. Basin delineation for calculation in the Cau river basin

The Cau River Basin is subdivided into five sub-basins: Upper, Middle, Cong, Ca Lo and Lower, based on four principles: (1) ensuring the sub basins are closed and, the outlets to the Cau rive; (2) natural and socio-economic conditions in the sub-basin are quite similar; (3) irrigation system is relatively independent in operation and management; (4) sub-basins with an area of no more than 2500 km².

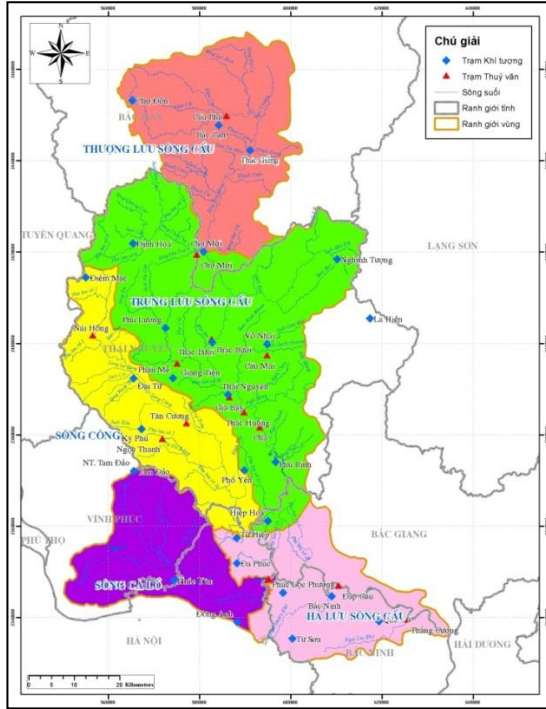


Figure 3.1. Map of Cau River basin

3.3. Selection of sets of parameters of WSI of Cau river basin

Sets of parameters calculation WSI consists of 25 parameters, when applied specifically for Cau river basin, are proposed to exclude "Diverted surface water ratio" as it does not exactly reflect the non-diverting characteristics of Cau river basin. For the others, only part of the water from the river basin of the Cong river (Nui Coc Lake) leads through the canal to the Cau river to supply to Thuy Nguyen and irrigate downstream through the Thac Huong dam. Data for calculation was proposed to be 24 parameters. (Table 3.2)

Table 3. 2. Selection of parameters to calculate the sustainability of
Cau river basin

Indicators	Stress	Status	Response
Water resources– Quantity	<ul style="list-style-type: none"> - Precipitation variation in dry seasons/entire year compared to average over years (S_{LN1}). - Surface water variation in dry seasons/entire year compared to average over years (S_{LN2}). - Extractable groundwater variation in dry seasons/entire year compared to average over years (S_{LN3}). 	<ul style="list-style-type: none"> - Amount of surface water per capita in the catchment (H_{LN1}). - Utilizing water ration (rain-, surface-, ground-) (H_{LN2}). 	<ul style="list-style-type: none"> - Water utilization efficiency in the study period. (U_{LN1}).
Water resources – Quality	<ul style="list-style-type: none"> - Rainwater quality variation in dry seasons/entire year compared to average over years (S_{CLN1}). - Surface quality variation in dry seasons/entire year compared to average over years (S_{CLN2}). - Groundwater quality variation in dry seasons/entire year average over years (S_{CLN3}). 	<ul style="list-style-type: none"> - Average value of rainwater quality in the study period(H_{CLN1}). - Average value of surface water quality in the study period (H_{CLN2}). - Average value of groundwater quality in the study period (H_{CLN3}). 	<ul style="list-style-type: none"> - Improvement of wastewater treatment and water quality (U_{CLN1}).
Enviroment	<ul style="list-style-type: none"> - Forest area variation compared to average over years (S_{MT1}). 	<ul style="list-style-type: none"> - Forest area ratio (H_{MT1}). 	<ul style="list-style-type: none"> - Increase of forest area in the study area (U_{MT1}). - Treated hazardous waste ratio (U_{MT2})

Indicators	Stress	Status	Response
Life	- Per capita income variation compared to average over years (S_{DS1}).	- Human development index (HDI) (H_{DS1}).	- Water and sanitation ratio (U_{DS1}).
Policies	- Literacy HDI variation compared to average over years (S_{C1}).	- Literacy human development index (H_{C1}). - Status of integrated water resources of river basins (H_{C2}).	- Improvement of integrated water resources of river basins (U_{C1}).

3.4. Results of the WSI calculations

The calculation results of the indicators are shown in Table 3.44.

Table 3.44. The results of calculating the WSI in Cau River basin

Sub-basin	Water Resources	Environment	Life	Policy	WSI
Upstream	0.61	0.63	0.54	0.42	0.56
Middle	0.59	0.67	0.58	0.54	0.60
Cong river	0.55	0.67	0.65	0.63	0.61
Ca Lo river	0.50	0.63	0.65	0.67	0.59
Downstream	0.48	0.50	0.67	0.63	0.55
Cau River Basin	0.55	0.62	0.62	0.58	0.58

Table 3.44 shows that the sustainability of the Cau River Basin is 0.58, which is moderate. In general, the level of sustainability in the river basins varies not significantly from 0.55 to 0.61. However, the sustainability scores of the indicators show great variability, from 0.42 to 0.67. In the area of water resources, the least unsustainable level is 0.48 in the Lower Mekong Basin, the highest 0.61 in the

upstream sub-basin. Results of the WSI for the 5 Sub-basins including Upper; Middle; Cong; Ca Lo and Cau Downstream have the tendency to suffer lower sustainability compared to the remaining. This indicates that the Lower of the Cau River still has many problems affecting the sustainable development of the river basin.

3.5. Determine suitability when applying the method of calculating sustainable indexes for Vietnam (Compatibility assessment)

The dissertation has selected a suitable method that demonstrates the complexity of issues that affect river basin sustainability, while not only simplifying the calculation of different river basins, but also lowering the sophisticated procedure during use.

Based on the Chaves and Alipaz method, the PhD candidate used some indicators and parameters to calculate the WSI of river basins in Vietnam. The calculation results for the Cau River basin are perfectly adequate and reliable enough to provide managers and policy makers with measures and measures to enhance the sustainability of Cau river basin.

The method of calculation with parameter sets can be applied to different river basins in Vietnam. Each river basin has different characteristics. It will select the parameters in the parameter framework already available to suit real-life condition of that river basin.

3.6. Recommendation of measures to improve the sustainability of Cau river basin

According to the calculated results, water resources is a major factor affecting the sustainability of the river basin, the upstream sub-basin

has the highest sustainable index of 0.61, which indicates a moderate sustainability. In the lower sub-basins, Cong and Ca Lo, the average level of sustainability present decreasing scores, reaching 0.59, 0.55 and 0.50, respectively. Lower sub-basin lower suffers lowest value of 0.50. Therefore, the measures should focus on improving the sustainability of water resources, especially water resources in the Lower Mekong Sub-Basin.

Major measures to water resources include: strengthening the integrated and rational exploitation, utilization and protection of water resources, especially improving the use and saving of water resources; Strengthening propaganda and dissemination of knowledge to raise the awareness of environmental protection river basin; improving water resource planning in Cau river basin so as to take initiative in water sources, ensuring water source security, ensuring equality and rationality, and increase the efficiency of water resources exploitation and use to reduce the risk of pollution, Restoring the degraded water sources, serving as a basis for socio-economic development of the sub-basins; Increase the plantation and protection of forests, especially watershed protection, to regulate the flow of water, to prevent adverse impacts caused by water (such as floods, flash floods, droughts). This will contribute to the protection of the natural environment of the river basin. This measure can enhance the sustainability of both the water resources indicator and the environmental indicator. Other indicators in regards to environmental, livelihood and policy measures are presented in the dissertation..

3.7. Conclusions

In chapter 3, the thesis computes in detail the sustainability index of

Cau river basin. The set of parameters of the initial sustainability index includes 25 parameters that apply to all river basins of Vietnam, when applied specifically for Cau river basin proposed for selection of 24 suitable parameters.

In this chapter, the thesis analyzes the natural and socio-economic characteristics of the river basin. Then calculate the parameters and indicators of the Cau River Basin Sustainability Index for the five sub-basins. The results of the LVS Sustainability Index are limited in terms of data but overall results for LVS Demand are reasonable, the Cau River sustainability level is 0.58 achieving medium sustainability. Based on the results of the proposed major solutions to overcome specific weaknesses (low parameters), to improve the sustainability of the sub-basins in particular and Cau river basin in general.

Also from the results of calculating the index in the Cau River basin, the author said that with this set of indicators and parameters can apply and assess the sustainability index for the LVS in Vietnam. However, when applying the calculation, it is possible to adjust and subtract parameter sets to suit the characteristics of each river basin in Vietnam.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

- 1) The dissertation has reviewed the current relevant situation in the world and in Vietnam, which sets out the need for a scientific basis and approach to studying and calculating sustainability indicators for river basins in Vietnam.
- 2) The dissertation has selected and proposed the method of calculating the river basin sustainability index based on the method of Chaves and Alipaz. This approach is appropriate for river basins in Vietnam due to its simple calculations procedures. Indicators in the formula adequately cover river basin issues, successfully being applied to Cau river basin.
- 3) The dissertation has proposed sets of parameters include 25 parameters in the areas of water resources, environment, livelihoods, human activities and policies. Given the specific application of the Cau River basin, due to data limitations and characteristics of the Cau River basin, the it was proposed to reduce to 24 parameters. Cau river basin performance has a sustainability index of 0.58, showing medium sustainability overallly.
- 4) The dissertation has calculated and weighted some indicators, parameters by AHP method.
- 5) The dissertation has WSI for 5 sub-basins and the entire Cau river basin.
- 6) From the results of the calculations, the thesis proposed measures to overcome the unsustainability of the specific parameters (factors) that cause unsustainability to the instructions.

The thesis has made original contributions: Developing the scientific bases for the determination of the WSI of Vietnam on the basis of a

set of indicators and parameters reflecting four areas: Water Resources, Environment , Livelihood and Policies; Suggested method for calculating river basin sustainability, being piloted on Cau river basin.

Further potential development of the dissertation

In order to bring the results of the thesis into practice as well as to application to other river basins, it is necessary to study further and expand and specifically calculate the different river basins of Vietnam, then compare and complete with the proposed calculation framework and develop a set of sustainable indicators for all different river basins in Vietnam.

Recommendations

The results of this thesis can be used to assess the sustainability of different river basins in Vietnam. When applied to specific river basins, it should be divided into small areas, with those having areas smaller than 2500 km² to reduce the errors in the calculation and comparison process.

These results can be used by managers, policy makers, state units within or without the Ministry of Natural Resources and Environment to provide measures as well as appropriate policies to improve river basin sustainability, ensuring sustainable development in all areas.

LIST OF ARTICLES BY AUTHOR RELATING TO THIS DISSERTATION

1. **Van Le Thi Mai**, Thuy Nguyen Thi, Don Than Van, Xuan Tran Thanh (2016), Determining the weights of parameters to calculate the Watershed Sustainability Index. Journal of the Ministry of Natural Resources and the Environment, 2016, No. 8 (238) ISSN: 1859-1477, pp. 14-15.
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