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Sustainability Assessment of Humid Tropical Watershed: A Case of Batang Merao Watershed, Indonesia

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Abstract

Tropical watershed faces many problems that hamper its sustainability, such as land degradation, water pollution, water scarcity and several socio-economic pressures. Batang Merao watershed was selected as it is a buffer zone of a UNESCO tropical rainforest heritage site in Kerinci Seblat National Park, Indonesia. This study aimed to assess the sustainability of Batang Merao Watershed for the period of 2006-2011 using HELP (Hydrology, Environment, Life and Policy) indicators. The results showed, the watershed was at an intermediate level of watershed sustainability (overall WSI score = 0.59) and was still in high pressure due to its pressure parameter score (0.78), which was higher than both state and the response parameters (0.50). Therefore, it is urgent to improve the integrated watershed management programs for achieving the sustainability of this watershed.

Keywords: HELP indicators; integrated watershed management; land use land cover; sustainability index

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1. Introduction

Degradation of forest, land and water resources and population pressures have brought long-term reduction of watershed sustainability that can be the greatest constraints to sustainable watershed management in most developing countries in humid tropics [1]. Humid tropical Asia presents the highest deforestation and forest degradation among other regions (Latin America and Africa) as the effect of high population pressure [2]. This sustainability issue is specifically a big challenge in Indonesia due to two facts: (a) Indonesia has been experiencing intensive land use change in the last three decades [2]; (b) deforestation, land and water degradation in most of the Indonesian watersheds are in critical point and declining quality under pressures [2-4].

The vital importance of biodiversity, water, energy, and food security in sustaining human and environmental services has been recognized in numerous national and international fora, e.g. the UN-Earth Summit 1992 in Rio, the UN-world summit on sustainable development 2002 in Johannesburg, Sustain Conference 2010-2012 in Kyoto, River symposium 1-16, World Energy Congress, etc. The importance of watershed sustainability has become more relevant because of the increasing awareness that the sustainability of watershed functions is an essential requisite for sustainable future and human security. As serious global issues, both food security and environmental issues are related to and need to be addressed within the context of watershed management [2]. Because sustainable watershed management is a central challenge in the context of sustainable development [5], its management has to ensure food and human security and protect environment from negative consequences, such as ecosystem degradation, pollution, and climate change. Unfortunately, for most countries, especially those in humid tropical region, watershed management is still viewed from the narrow perspective of benefits to water projects alone while it should be in holistic perspective and should be considered essential for soil and water conservation, which, in the long run, will enhance the prospect of self-reliance of nations in terms of food and energy [6]. In addressing the sustainable future relating to food and water security, this research highlights issues that require integrated indicators in assessing the level of security or sustainability associated with watershed management.

Watershed Sustainability Index (WSI) is an integrated indicator based on basin Hydrology, Environment, Life and Policy (HELP) condition which includes describing and assessing relevant socio-economic data [7]. HELP is creating a new approach to integrated watershed management through the creation of a framework for watershed management under three indicators: Pressure, State and Response (PSR) approach. The structure of PSR approach incorporates cause-effect relationships and, thus, provides a more comprehensive understanding of the watershed than an index which only examines the State. The HELP index was established by UNESCO in 1999 and has been applied in more than 91 river basins in 67 countries, such as the Murrumbidgee catchment in Australia [8], Verdadeiro river basin in Brazil [9], and the Elqui river basin in Chile [10]. However, assessment for watershed sustainability in Indonesia, especially in Sumatera Island, is still in its infancy. For this reason, this study aimed to assess the sustainability of Batang Merao Watershed for the period of 2006-2011 using HELP (Hydrology, Environment, Life and Policy) indicators.

2. Tools and Methods

2.1. Study Area

The landscape selected for this research was the watershed of Batang Merao, which covers approximately 67,874.48 ha and is an upstream of the Batang Hari river basin. Located in northwest of Jambi Province, Indonesia, it lies between 01°42’19” - 02°08’14” South, 101°13’11”- 101°32’20” East. The elevation ranges from 767 to 3,266 m above sea level (Fig. 1). It is situated in a humid tropical zone with 2,495 mm.yr^{-1} of its annual mean precipitation over the last 20 years; meanwhile, the annual mean temperature over the last 10 years was 23.1^{0}C.

The Batang Merao watershed, which lies within 10 sub regencies and 124 villages, plays an important role in serving regional economic development of Kerinci Regency and Jambi Province. Most of the agricultural lands in these regions depend on this watershed for water supply. As it is a buffer zone of a UNESCO tropical rainforest heritage site in Kerinci Seblat National Park, maintenance of the protected area around the watershed is also an essential requirement for regional development. The issues of regional economic development and environmental degradation in the watershed are of great concern to the government. However, there is a clear general lack of sustainability information of this tropical watershed, making it essential to carry out more comprehensive sustainability studies. A comprehensive research is necessary to look at the integrated indicators of watershed management for ecosystem degradation, socio-economic problems and policy.

2.2. HELP Indicators Data

The primary data for Hydrological indicator were collected by primary field survey on September 20, 2011 while the secondary data were obtained from the Environmental Management Agency of Jambi Province (September 15, 2011). Water samples were collected from 15 stations of selected catchments within Batang Merao Watershed. Most of these stations were located in the upper-middle-downstream areas of Batang Merao Watershed. For the Environment indicator, especially land cover data, Landsat image TM data (path 126/row 61; year of 2006 and 2011) were used in this study. For supporting image analysis, some ancillary data were used including ground truth data (83 points) acquired through the field survey (September 10-15, 2011). Regarding the Life indicator, the HDI components (expenditure, health and education) as a secondary data were obtained from regional development planning (Jambi Province and Kerinci Regency) from 2006 to 2011. Finally, the Policy indicator data were retrieved from Center for Batanghari Watershed Management, Forestry Office of Jambi Province.

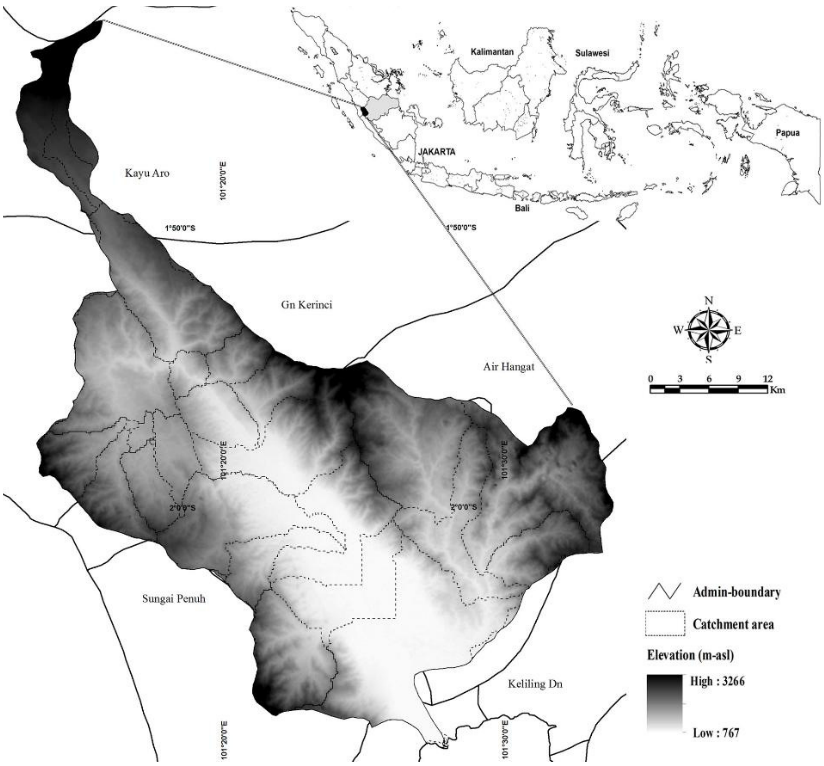

Fig. 1 Location of Batang Merao Watershed, Indonesia

2.3. Analysis

The Hydrology indicator contains two sets of sub-indicators: water quantity and water quality. In order to analyze water quality, the collected data of physical, chemical, and biological parameters (Temp, TDS, TSS, pH, BOD_5, COD, DO, P, NO_3 and Coliform) were analyzed by using the Water Pollution Index (WPI) and STORET method. The laboratory analyses of those parameters were determined according to the national standard of water quality status in Indonesia [11]. The Environmental indicator was determined by Environmental Pressure Index (EPI) [9,12] which was derived from land change data. In order to analyze land change, several technical methods, such as supervised classification, an accuracy assessment, and the Kappa coefficient method, were implemented. LULC classification was modified from the LULC categories of the Indonesian National Standard no. 7645:2010 specified by the National Standard Agency of Indonesia which refers to the FAO's land cover classification system and ISO 19144-1 [13]. The life indicator is related to the HDI, which gives information on the evolution of the minimum life quality in the watershed. The Policy indicator evaluates the levels of HDI-education, institutional performance/legality, and integrated budgeting for watershed management.

Table 1. A summary of HELP indicators and parameters of watershed sustainability index

Indicators		Parameters		
		Pressure	State	Response
H (Hydrology)	Quantity (Δ1)	variation per capita water availability (m^3.$person^{-1}$.$year^{-1}$)	water availability per capita (m^3.$person^{-1}$.$year^{-1}$)	water-use efficiency
	Quality (Δ2)	variation BOD_5	average long term BOD_5	sewage/disposal treatment
E (Environment)		environment pressure index (forest and population)	percent of area under vegetation/forest	evolution conservation areas
L (Life)		variation HDI expenditure	Human Development Index	evolution in the HDI
P (Policy)		variation HDI-Education	institutional/management	expenditure for watershed

Table 2. Description of the ***WSI Pressure*** indicators, level and scores

Indicators	Pressure parameters	Level	Score
Hydrology	Δ1- variation in the watershed per capita water availability in the period studied, relative to the long –term average (m^3.person-$^{1.}$ $year^{-1}$)	Δ1 < -20%	0.00
		-20% < Δ1 < -10%	0.25
		-10% < Δ1 < 0%	0.50
		0% < Δ1 < +10%	0.75
		Δ1 > +10%	1.00
	Δ2-variation in the watershed BOD_5 in the period studied, relative to the long-term average	Δ2 > +20%	0.00
		+10% < Δ2 < +20%	0.25
		0% < Δ2 < +10%	0.50
		-10% < Δ2 < 0%	0.75
		Δ2 < -10%	1.00
Environment	Environment pressure index (EPI) in the period studied	EPI > +20%	0.00
		+10% < EPI <+ 20%	0.25
		+5% < EPI < +10%	0.50
		+0% < EPI < +5%	0.75
		EPI < 0%	1.00
Life	Variation in the watershed per capita Human Development Index (HDI)-Income* in the period studied, relative to the previous period (*:this study used HDI-expenditure data instead of HDI income data)	Δ < -20%	0.00
		-20% < Δ < -10%	0.25
		-10% < Δ < 0%	0.50
		0% < Δ < +10%	0.75
		Δ1 > +10%	1.00
Policy	Variation in the watershed HDI-Education in the period studied, relative to the previous period	Δ < -20%	0.00
		-20% < Δ < -10%	0.25
		-10% < Δ < 0%	0.50
		0% < Δ < +10%	0.75
		Δ > +10%	1.00

As summarized in Table 1, the HELP, a UNESCO integrated watershed sustainability index, was employed to assess the sustainability level of the watershed. The WSI was computed as all indicators have a certain range of value index (0 – 1). As the result, the watershed sustainability can be computed in the following equation:

$$WSI = (\mathrm{H} + \mathrm{E} + \mathrm{L} + \mathrm{P})/4 \qquad (1)$$

where WSI is the watershed sustainability index, H is the hydrologic indicator, E is the environmental indicator, L is the life indicator, and P is the policy indicator. All indicators have the same weight and value index (0 – 1).

Finally, the WSI classification follows the UNDP's HDI classification (low for WSI <0.5, intermediate for WSI between 0.5 and 0.8, and high for WSI >0.8) [9-10,12].

Table 3. Description of the *WSI State* indicators, level and scores

Indicators	State parameters	Level	Score
Hydrology	Watershed per capita water availability (m^3.person-1. year^{-1}), considering both surface and groundwater sources	Wa < +1700	0.00
		+1700 < Wa <+ 3400	0.25
		+3400 < Wa < +5100	0.50
		+5100 < Wa < +6800	0.75
		Wa > +6800	1.00
	Watershed averaged long term BOD_5 (mg.l^{-1})	BOD_5 > +10	0.00
		+10 < BOD_5 < +5	0.25
		+5 < BOD_5 < +3	0.50
		+3 < BOD_5 < +1	0.75
		BOD_5 < +1	1.00
Environment	Percent of watershed area under natural vegetation (Av)	Av < +5	0.00
		+5 < Av < +10	0.25
		+10 < Av < +25	0.50
		+25 < Av < +40	0.75
		Av > +40	1.00
Life	Watershed Human Development Index (HDI), weighed by county population	HDI < +0.50	0.00
		+0.50 < HDI < +0.60	0.25
		+0.60 < HDI <+0.75	0.50
		+0.75 < HDI < +0.90	0.75
		HDI > 0.90	1.00
Policy	Watershed institutional capacity in Integrated Water Resources Management (legal and organizational)	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00

Table 4. Description of the *WSI Response* indicators, level and scores

Indicators	Response parameters	Level	Score
Hydrology	Improvement in water-use efficiency in the watershed	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
	Improvement in adequate sewage treatment/disposal in the watershed, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
Environment	Evolution in watershed conservation areas (Protected areas and Best Management Practices), in the period studied	Δ < -10%	0.00
		-10% < Δ < 0%	0.25
		0% < Δ < +10%	0.50
		+10% < Δ < +20%	0.75
		Δ > +20%	1.00
Life	Evolution in the Human Development Index in the watershed, in the period studied	Δ < -10%	0.00
		-10% < Δ < 0%	0.25
		0% < Δ < +10%	0.50
		+10% < Δ < +20%	0.75
		Δ > +20%	1.00
Policy	Evolution in the Water Resources Management expenditures in the watershed, in the period studied	Δ < -10%	0.00
		-10% < Δ < 0%	0.25
		0% < Δ < +10%	0.50
		+10% < Δ < +20%	0.75
		Δ > +20%	1.00

Each indicator in Equation (1) is derived from the integrated analysis mentioned in Table 1 which considers important factors, such as *Pressure, State*, and *Response* (PSR) approach. The approach is often used in environmental reports as it provides a useful and simple tool to formalize environmental problems [14]. In addition, this approach lies in the fact that it takes into account cause-effect relationships, allowing different stakeholders, managers, and decision makers to recognize and understand the interconnections between the indicators [15]. The WSI indicators and parameters, including their levels and scores, are presented in Tables 2, 3, and 4. An overall WSI assessment was obtained after assigning score of PSR parameters of each indicator.

3. Results

The research findings can be divided into four broad indicators and one overall assessment as Hydrology, Environment, Life and Policy, and the overall watershed sustainability index in the last section as follows:

3.1. Hydrology Indicator

The calculated values for Hydrology quantity and quality were summarized in Table 5. In the case of the water quantity, Batang Merao watershed has a long-term (1985-2011) average flow of 190.70 $m^3 s^{-1}$ and a short-term (2006-2011) average of 202.78 $m^3 s^{-1}$. Divided by a total watershed population of 229,009 inhabitants (in 2011), the per capita water availability (Wa) is 3,481.24 $m^3.person^{-1} year^{-1}$. The score for the State quantity parameter is 0.50. The variation in Wa, with respect to the long-term average, was +0.90% with the Pressure quantity score of 0.75. In the case of quantity Response, the only regular activities for improving water use efficiency were maintenance of physical infrastructures, farm facilities, and small micro-hydro facilities, which resulted in a score of 0.5. As the result, the average score for Hydrology quantity in the watershed was (0.75+0.50+0.50)/3=0.58. Because of the lack of time series information on water quality, the long-term and short-term analyses were obtained from the secondary data (for the year of 1990, and from 2006 to 2010), and the primary data (for the year of 2011). In the case of the water quality parameters, Pressure related to the variation in the watershed BOD_5 (+8.95%) with a score of 0.75. For the State parameter, the value of 4.44 $mg.l^{-1}$ contributed a score of 0.50. The Response parameter resulted in a score of 0.50 (medium improvement in sewage treatment/disposal). The Hydrology quality indicator was, therefore, (0.50+0.50+0.50)/3=0.50. Hence, the overall Hydrology indicator value was 0.54.

Table 5. Calculated values for Hydrology indicator

	Pressure		State		Response		WSI Score
	Value	Score	Value	Score	Value	Score	
Hydro Quantity	0.90	0.75	3,481.24	0.50	medium	0.50	0.58
Hydro Quality	8.95	0.50	4.44	0.50	medium	0.50	0.50
Average		0.63		0.50		0.50	**0.54**

3.2. Environment Indicator

Table 6 summarizes the results for this indicator. In the case of Pressure, the combined watershed variation in forest area and population in the period studied were -25.09% and 20.93%, respectively, resulting in an EPI value of -23.01%. This finding corresponds to an environmental Pressure score of 1.00. In the case of environmental State, the watershed maintained 18.13% of its original vegetation coverage in the year 2011, resulting in a score of 0.50. Regarding environmental Response, there was an increasing forest rehabilitation from 980 ha (2006) to 1,050 ha (2011) respectively, resulting in a score of 0.75. Therefore, the overall score for the Environment indicator was 0.67.

Table 6. Calculated values for Environment indicator

Pressure		State		Response		WSI Score
Value	Score	Value	Score	Value	Score	
-23.01	1.00	18.13	0.50	7.14	0.50	**0.67**

3.3. Life Indicator

The summary of Life indicator was shown in Table 7. By calculating the variation in the watershed's HDI-Expenditure in the study period, Life Pressure in the watershed, a score of 0.75 was obtained. In the case of Life State parameter, the watershed HDI was 0.73, resulting in a score of 0.50. The Life Response, i.e., the evolution of the expenditures in the watershed, was +2.01%, resulting in a score of 0.50. As the result, the overall Life score for the watershed was 0.58.

Table 7. Calculated values for Life indicator

Pressure		State		Response		WSI Score
Value	Score	Value	Score	Value	Score	
2.45	0.75	0.73	0.50	2.01	0.50	**0.58**

3.4. Policy Indicator

The scores for Policy indicator were summarized in Table 8. The score of policy Pressure (variation in the HDI-Education sub-indicator) for the watershed was +1.08%, resulting in a parameter score of 0.50. The policy State score was based on watershed institutional capacity and performance with a score of 0.50. With regard to policy Response, the evolution in the watershed expenditures was +7.05%, resulting in a value of 0.50 (Fig. 2). Therefore, the overall score for Policy indicator was 0.58.

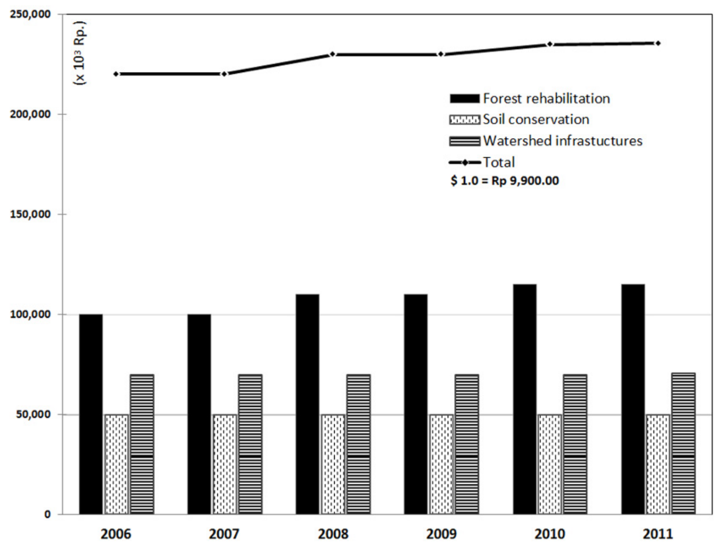

Fig. 2 Evolution of watershed management expenditure from 2006-2011

Table 8. Calculated values for Policy indicator

Pressure		State		Response		WSI
Value	Score	Value	Score	Value	Score	Score
0.04	0.75	medium	0.50	7.05	0.50	**0.58**

3.5. Overall WSI Assessment

The value index for watershed sustainability was summarized in Table 9. The overall WSI index of the Watershed was 0.59 which was classified into intermediate level of watershed sustainability. Simultaneously, the lowest score of indicators was Hydrology (0.54), whereas the highest was Environment (0.67). Concerning the Pressure, State and Response factors, the highest score was Pressure (0.78), and the lowest were both State and Response (0.50). It indicated that the watershed was still in high pressure and exceeded the management capacity in maintaining the watershed sustainability.

Table 9. A summary of the watershed sustainability index

	Pressure	State	Response	Result
Hydrology 1	0.75	0.50	0.50	
Hydrology 2	0.50	0.50	0.50	
Hydrology (average)	0.63	0.50	0.50	0.54
Environment	1.00	0.50	0.50	0.67
Life	0.75	0.50	0.50	0.58
Policy	0.75	0.50	0.50	0.58
Result	0.78	0.50	0.50	**0.59**

4. Discussion

This study successfully integrated HELP (Hydrology, Environment, Life and Policy) indicators for assessing the sustainability level of Batang Merao watershed. With the overall WSI score of 0.59, the watershed was an intermediate level of watershed sustainability. In comparison to other watersheds in the humid tropical region, Batang Merao watershed was not better than others with respect to the WSI value in San Francisco Verdadeiro, Brazil (0.65) [9], the Elqui river basin, Chile (0.61) [10] , the Reventazon River, Costa Rica (0.74) [12] and Langat river basin, Malaysia (0.65) [16].

The environmental pressure was still higher than the management's response to solve the pressure. This condition could be due to the land-use land-cover change. It was noted that the deforestation rate was 824.14 ha yr^{-1} in other sides; several areas had increased, such as agricultural land (200.75 ha yr^{-1}), mix plantation (811.36 ha yr^{-1}) and settlement (24.05 ha yr^{-1}), as described in Figure 3. This improper land-use change is a major barrier for watershed sustainability [17] and could become a serious problem in the future. Therefore, in land-use management, the result emphasized the need of protection and conservation for the forest area in much of the areas in rapidly dynamic change of the watershed. In addition, integrated watershed management programs, such as soil and water conservation as well as the wise use of land and water, need to be effectively improved.

The study also revealed that the pressure parameters of hydrological, Life, and Policy indicators were higher than the state and response parameters. To overcome HELP indicators leading to pressure parameters, especially for environmental degradation, the demands for sustainable watershed management need to be transposed into policy and practical regulation and action that allow a harmonic development in the watershed with the wise use of land and natural resources and the effective performance of watershed management. Appropriate policy responses, therefore, require a better understanding of HELP indicators values and progresses, ranging from national policy, local regulation and collective community and partnership decisions. In order to support watershed sustainability, attention should be paid to integrated watershed programs about landscape change, eco-hydrological effects and strong supports from institutional arrangements and partnership in watershed management.

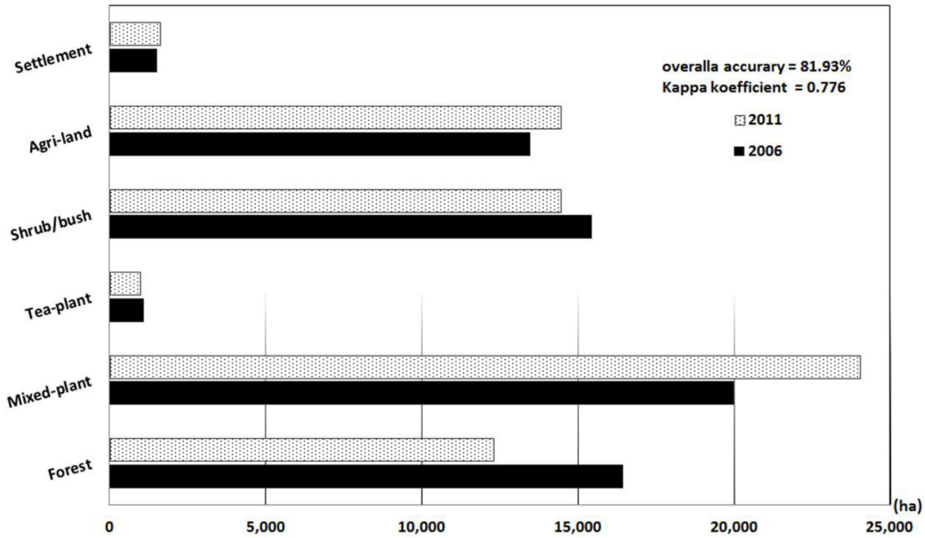

Fig. 3 Land use land cover change in Batang Merao watershed from 2006 to 2011

5. Conclusion

Sustainability assessment of watershed can be described as sustainability of watershed management in completely important aspects, namely hydrological response, environmental performance, life indicator, and policy-making. The HELP indicators have advantages in integrity [9], simplicity, flexibility, and adaptability [10]. The results showed that the watershed was at an intermediate level of sustainability and was still in high pressure due to its pressure parameter score which was higher than the state and the response parameters. Therefore, it is urgent to improve the integrated watershed management programs for achieving the better sustainability of this watershed.

The achievement of watershed sustainability is not as simple as technical issues. It has become part of a complex interaction of ecology, socio-economic and policy process. It also needs to be ensuring a long-term watershed management program while, at the same time, minimizing ecosystem degradation and maintaining the multi-functions of hydrology, environment, life, and policy indicators. However, there are still many possible pathways for sustainable future of watershed management as what this research suggests. Improving watershed sustainability will require some combinations of regulation, such as better land-use planning, education, and economic incentives [18], improvement in criteria and indicators for temporal and spatial assessment [17], conservation programs, and improve institutional capability and broad community participation. For humid tropical watershed like Batang Merao Watershed, the sustainability can be achieved by improving sustainability guidelines of HELP indicators.

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