Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 3, No. 11, p. 21-30, 2013
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Assessment of the relationship between land use land cover and water quality status of the tropical watershed: a case of Batang Merao Watershed, Indonesia

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Article published on November 2, 2013

Key words: Water resource, land change, water pollution index, STORET method, conservation.

Abstract

Considering the vital role of Batang Merao Watershed as the source of water reservoir for most regional economic activities and the buffer zone of Kerinci Seblat National Park, this study aimed to investigate the relationship between LULC and water quality in the watershed. A total of 15 stations from selected catchments were collected and analyzed for bio-physic-chemical parameters for water quality analysis. The parameters were analyzed by using the Water Pollution Index (WPI) and STORET methods as the national standard of river water quality in Indonesia. LULC was analyzed by using GIS and remote sensing from Landsat image data for 2006 and 2011. Analysis of variance, correlation analysis, and stepwise multiple regression analysis were used to investigate spatial and temporal variations of LULC, water quality, and the relationship between them. The water quality study revealed that Batang Merao watershed was classified as lightly polluted (86.67%) and moderately polluted (13.33%) meanwhile, the STORET results indicated that about 80% of them were moderately polluted. The results also indicated that the study area was mostly dominated by mixed plantation (35%) and shrub/bush (21%), and also showed decreases in forest and increase in cultivated area (mix plantation and agricultural land). Statistical analysis showed several important results that One-way Anova indicated significant spatial differences; Pearson's correlation showed the relationship between LULC and water quality parameters and regression analysis estimated the water quality parameter on changing LULC. The research could provide critical information on sustainable land use practice for water resource conservation for the tropical watershed.

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Introduction

The linkage between land change and water resources are complex (Weatherhead & Howden 2009). Land use land cover (LULC), one of the major environmental changes occurring around the globe (Zhang and Wang, 2012), has direct impacts on hydrologic systems within a watershed. The impacts of land change on the hydrology have been a major landscape and hydrol-ecologycal research topic over the last decade (Zhou *et al*., 2012). Water quality is one of such factors affected by land change and which is sensitive to changes in landscape patterns in a watershed (Xia *et al*., 2012), and it is generally linked to LULC in catchments (Ahearn *et al*., 2005). Water quality parameters in various aquatic systems have been closely linked to the proportions or types of land use within a watershed (Lee *et al*., 2009) and have been influenced by different landscape types (Fu *et al*., 2005).

Since the complex and dynamic relationships between land and water quality are yet to be elucidated and may differ substantially in developing countries due to differences in land use and land management practices (Baker, 2003), this study is very important to determine the status of river water quality and it is therefore important for developing integrated watershed management. Investigating the relationship between them has been recognized as a critical point for predicting potential pollution and developing watershed management practices (Xiao and Ji, 2007). In addition, this study can address the issue of land and water sustainability with appropriate land use practices and water protection management. However, more research especially in tropical region is needed because findings of this concern so far vary amongst the existing watersheds.

Due to dynamic land change especially deforestation, most of watersheds in Indonesia are still in critical level in both soil and water condition. Unfortunately, the studies of water quality were mostly done in the regions of Java Island, such as in Jakarta (Suwanda *et al*., 2011), West Java (Fulazzaky, 2010), and East Java (Sholichin *et al*., 2010). There is a general lack of information about water quality in watershed outside Java Island. To overcome the problems, Indonesian Government through the Ministry of Environment issued regulation on water quality management and pollution control in 2003 (Ministry of Environment of Indonesia, 2003). River water quality in Batang Merao watershed was classified in Category B (for service purpose while category A is for drinking water). Unfortunately, both river status and land use condition have not been evaluated neither their quality nor their linkage.

Batang Merao watershed is an important upland watershed in Sumatera (Indonesia), belonging to the Kerinci Seblat National Park, the UNESCO's tropical rainforest heritage site. It is a very important watershed for the people and the environment of Sungai Penuh City and Kerinci Regency as it supports various economic activities, such as fishing, irrigation, agriculture, micro-hydroelectric power, domestic water supply, and tourism. These activities have potentially created negative effects on the water quality over time. Unfortunately, there is a general lack of information about the water quality and land use land cover on the hydrology of the catchment in this tropical landscape. Hence, the objective of this paper is to investigate the dynamic of land use, water quality status and their relationship the watershed. By studying the relationship between land use change and water quality, issues on sustainability can be addressed and integrated with better land use practices and water protection strategies.

Material and methods

Study area

Batang Merao watershed is located in the northwest of Jambi Province and in the middle of Sumatera Island, Indonesia. It is bounded by latitude between 01°42'19" - 02°08'14" South and 101°13'11"- 101°32'20" East (Fig.1.). The altitude ranges from 767 to 3,266 m above sea level. The watershed falls within the humid tropical zone characterized by dry and rainy season with an estimated annual mean precipitation of 2,495 mm.y^{-1}over the last 20 years (Fig.2.) and annual mean temperature of 23.1°C over the last 10 years. The watershed, which covers10 sub regencies and 124 villages, plays an important role in serving regional economic development of Kerinci Regency and Jambi Province. It supports various human activities along its stretch, such as agricultural activity, fishing, tourism, etc. Since 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 watershed is facing environmental degradation that is critically threatened by the effects of anthropogenic activities. This issue is among great concerns of the local government of Kerinci Regency and Jambi Province.

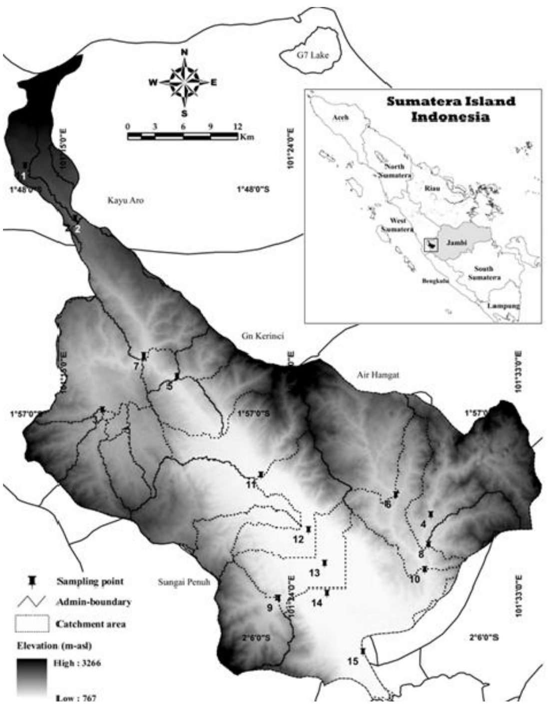

Fig. 1. Overview of water quality sampling in Batang Merao Watershed, Indonesia.

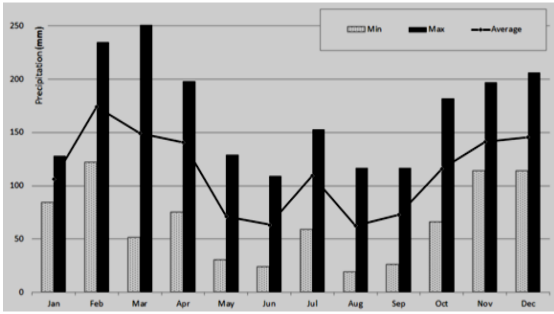

Fig. 2. Seasonal variations of precipitation over the Batang Merao Watershed from 2000 to 2010.

Materials

The basic data-sets required for this research are water quality data and land use data, as discussed below. For water quality data, water samples were collected from 15 stations or catchments within Batang Merao Watershed (Fig.1.). Most of these stations distribute in the upper-middle-downstream area of Batang Merao Watershed. The primary data were collected from field survey on September 20, 2011 while the secondary data for the year 2006 and 2011 were obtained from the Environmental Management Agency of Jambi Province. The water quality parameters for this study were temperature physical data (TDS and TSS), chemical data (pH, DO, BOD_5, COD, P, and NO_3N), and biological data (Coliform).

For land use land cover data, Landsat image TM data for the year of 2006 and 2011 (path 126/row 61) downloaded from the USGS Earth Resource Observation System were used in this study. For supporting image analysis, some ancillary data were used including ground truth data (83 samplings) acquired through the field survey (September 10-15, 2011), digital administrative map of Jambi Province provided by the Geo-spatial Information Agency of Indonesia, and digital watershed boundary map of Jambi Province published by the Ministry of Forestry of Indonesia. All the ancillary data were used to assist the training area in image classification and to collect the reference data in accuracy assessment.

Data analysis

The laboratory analyses of the water quality parameters were determined according to the standard of water quality status in Indonesia (Table 1.).

Table 1. Selected parameters of water quality standard for river water in Indonesia.

	No	Parameters	Unit	Water Quality Level			
				Class I	Class II	Class III	Class II
Physical	1	Total Dissolved Solids (TDS)	mg/l	1,000	1,000	1,000	1,000
	2	Total Suspended Solids (TSS)	mg/l	*50*	*50*	*400*	*400*
Chemical	3	pH		6.5 – 9.0			
	4	Biological Oxygen Demand (BOD)	mg/l	*2*	3	*6*	6
	5	Chemical Oxygen Demand (COD)	mg/l	*10*	25	*50*	100
	6	Dissolved Oxygen (DO)	mg/l	*6*	4	*3*	0
	7	Phosphate (P)	mg/l	*0.2*	0.2	*1*	5
	8	Nitrate (NO_3N)	mg/l	10	10	20	20
Biological	9	*Coliform*	MPN/100 ml	1,000	5,000	10,000	10,000

Sources:

1. Government regulation No. 82/2001 regarding the water quality management and water pollution control
2. Ministry of environment's Decree No. 115/2003 regarding the guidance of water quality status
3. The Jambi Governor regulation No. 20/2007 regarding regional water quality standard

Definition:

Class I	Drinking water or any other use with the similar requirements
Class II	Service water, recreational, gardening or any other use with the similar requirements
Class III	Fresh water agricultural, farming and any other use with the similar requirements
Class IV	Irrigation and any other use with the similar requirements

In order to evaluate water quality status in the watershed, both WPI and STORET method were used as they have been stated by Indonesian government through Environment Ministerial Decree No. 115/2003 (Ministry of Environment of Indonesia, 2003) and have been widely implemented by the Government of Jambi Province since 2007(Government of Jambi Province, 2007). The WPI was utilized for assessing the degree of water environmental pollution and the integrative assessment of river water quality standard in the watershed. The WPI can be suggested for the decision maker or landscape manager to manage water quality status. The formulation of WPI is:

$$WPI_j = \sum_{i=1}^{n} \sqrt{\frac{(C_i/L_{ij})^2_M + (C_i/L_{ij})^2_R}{2}} \quad (3)$$

Where C_i is the measured concentration of parameter i, L_{ij} is the permissible values (*PV)* for parameter i determined for water use j, and

$(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$ are maximum and average values of C_i/L_{ij} for water use j, respectively. The assessment of WPI can be followed by classification as follows

$0 \leq WPI \leq 1.0$=Not Polluted (NP)
$1.0 < WPI \leq 5.0$=Lightly Polluted (LP)
$1.0 < WPI \leq 10.0$=Moderately Polluted (MP)
$WPI > 10.0$=Highly Polluted (HP)

STORET (STOrage and RETrieval) method was used in order to evaluate water quality status for decision maker. It is also widely used by government and non–government agencies (Sholichin *et al.*, 2010). The basic concept of STORET is to compare between water quality data and its standard. As a result, the status of water quality depends on the score of water sampling based on the following classification system:

0.0 =Not Polluted (NP)
-1.0 to -10.0=Lightly Polluted (LP)
-11.0 to -30.0=Moderately Polluted (MP)
≥ -30.0=Highly Polluted (HP)

A total of six LULC categories was considered in this study namely forest, mix plantation, tea plantation, shrub/bush, agricultural land, and settlement. This classification was modifed from LULC categories of Indonesian National Standar no. 7645:2010 by National Standard Agency of Indonesia which referred to the FAO's land cover classification system and ISO 19144-1 (BSN - National Standarization Agency of Indonesia, 2010). Supervised classification, the most widely used technique for quantitative analysis of remote-sensing image data (Sun *et al.*, and Liang 2008, Pôças *et al.*, 2011) was used to perform image classification. An accuracy assessment or confusion contingency matrix was implemented for evaluating the accuracy of the classified images. The error matrix compares the relationship between the known reference data (ground truth) and the corresponding results of an automated classification. The kappa coefficient, the value for estimation of how well remotely sensed classification accuracies to the reference data, was used for accuracy assessment (Jensen, 2004). Furthermore, All LULC data were analyzed in ERDAS version 8.1 and Arc GIS version 10.1.

A number of statistical tests were then performed with the LULC and water quality data. Descriptive statistics were used to analyze the basic characteristics of the data. Analysis of variance (ANOVA) was used to compare variations in water quality under different land uses with significance set at $p < 0.05$. Relationships among the considered variables were tested using Pearson's correlation with statistical significance set priori at $p < 0.05$. For further analysis of the relationship, the stepwise multiple regression analyses with water quality as dependent variable were carried out to assess the relationship between the land use composition in each part of the watershed. All of the statistical tests were performed in SPSS version 18.0 for Windows.

Results and discussion

Water quality of Batang Merao watershed

The status of water quality in Batang Merau watershed had been evaluated based on the WPI method (Fig.3.) and STORET method (Fig.4.). Based on WPI analysis, most of the water quality observation stations (13 stations) were at the condition of lightly polluted (86.67%) and 2 stations were moderately polluted (13.33%). It can be observed from the graph that the average concentrations of some water quality parameters were already above the threshold (permissible values). For example, the average concentration of BOD was 5.0 mg/l beyond the PV (3.0 mg/l); the average concentration of DO was 4.21 mg/l beyond the PV (4.0 mg/l), and the average concentration of P was 0.31 mg/l beyond the PV (0.20 mg/l).

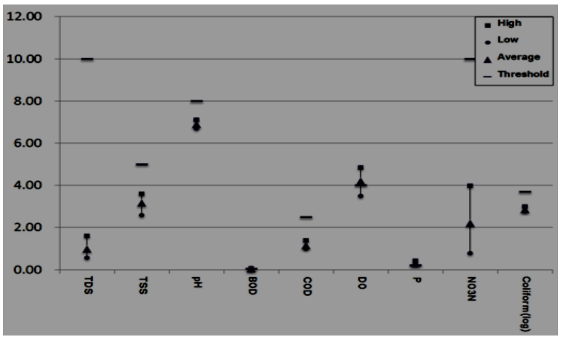

Fig. 3. The standardized water quality status of WPI method in Batang Merao Watershed.

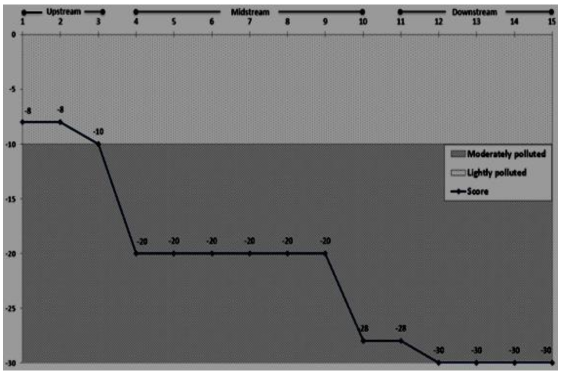

Fig.4. Water quality status of STORET method in Batang Merao Watershed.

Conversely, based on STORET method, most of the stations (12 stations) were at the condition of moderately polluted (80.00%) and 3 stations (20.00%) were lightly polluted. The different result between the two methods could happen because of different principles of data input in calculation [12]. The combination of these two methods was related to the final assessment of the watershed served in Table 2. As previously discussed, the status of water quality in Batang Merau watershed in general was at category "B" (river water category). However, based on the combination assessment of WPI and STORET, only the upstream can be classified as "B". Meanwhile, the midstream might be lowered into "C", along with the downstream that had been in the category.

Table 2. Resume of water quality status using WPI and STORET methods in Batang Merao Watershed.

Station	Type	WPI Method		Storet Method		Class Determination	
		PI Value	Status	Score	Status	Base on Current Regulation	Base on Analysis
1	Upstream	1.28	LP	-8.00	LP	B	B
2	Upstream	1.23	LP	-8.00	LP	B	B
3	Upstream	1.29	LP	-10.00	LP	B	B
4	Midstream	2.42	LP	-20.00	MP	B	B/C
5	Midstream	2.53	LP	-20.00	MP	B	B/C
6	Midstream	2.54	LP	-20.00	MP	B	B/C
7	Midstream	2.58	LP	-20.00	MP	B	B/C
8	Midstream	3.58	LP	-20.00	MP	B	B/C
9	Midstream	3.66	LP	-20.00	MP	B	B/C
10	Midstream	3.70	LP	-28.00	MP	B	B/C
11	Downstream	3.72	LP	-28.00	MP	B	B/C
12	Downstream	3.75	LP	-30.00	MP	B	B/C
13	Downstream	4.34	LP	-30.00	MP	B	B/C
14	Downstream	5.21	MP	-30.00	MP	B	C
15	Downstream	5.62	MP	-30.00	MP	B	C

Dynamics of LULC of Batang Merao watershed

As summarized in Table 3., there was a decrease in forest, tea plantation, and shrub/bush by 25.09%, 7.51%, and 6.35%, respectively. On the other hand, there was an increase in mix plantation, agricultural land, and settlement by 20.31%, 7.46%, and 2.41%, respectively. The distribution pattern of LULC in Fig.5.showed that the most areas of the watershed were covered by mix plantation (35.00%), forest (24.00%), shrub/bush (21.00%), and agricultural land (17.00%).

Table 3. Summary of LULC at different periods in Batang Merao watershed.

LULC Classsification	2006		2011		Change		Average rate of change	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)/yr	%/yr
forest	16,425.48	24.20	12,304.79	18.13	-4,120.69	-25.09	-412.07	-2.51
mix plantation	19,977.76	29.43	24,034.57	35.41	4,056.81	20.31	405.68	2.03
tea plantation	1,070.08	1.58	989.68	1.46	-80.39	-7.51	-8.04	-0.75
shrub/bush	15,432.46	22.74	14,452.70	21.29	-979.76	-6.35	-97.98	-0.63
agricultural land	13,454.08	19.82	14,457.84	21.30	1,003.76	7.46	100.38	0.75
settlement	1,514.62	2.23	1,634.89	2.41	120.27	7.94	12.03	0.79
	67,874.48		67,874.48					

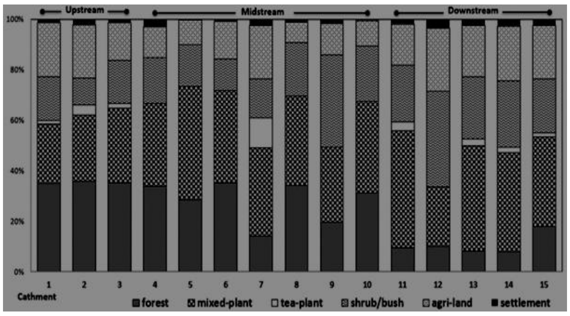

Fig. 5. LULC gradients in the 15 monitoring catchments in 2011.

In general, the patterns showed a tendency towards more land being brought under mix plantation and agricultural land. These given data expressly stated that the increase in cultivated function resulted in deforestation, meaning that some forest areas (protected areas were removed and converted to cultivated areas, such as mix plantation, paddy-field, and potato plantation.

The relationship between land use land cover and water quality

The statistical test of Anova in Table4. revealed differences with regard to both land cover and water quality among the upstream, midstream, and downstream of the watershed. As summarized in Table5., the result of Pearson's correlation analysis indicated that LULC types were significantly correlated with some water quality parameters. For example, mix plantation showed a significant positive correlation with BOD and COD by 0.922 and 0.646, respectively. The negative correlation was shown between agricultural land and BOD (-0.67) and between settlement and BOD (-0.594). These results suggested that local expansion of mix plantation, agricultural land, and settlement could be the primary driving forces of BOD and COD parameters.

Table 4. One-way Anova among parameters and watershed types in Batang Merao watershed.

			Mean square	F	Sig
Difference among parameters	TSS	Between groups	22.000	3.578	<0.001
		Within groups	6.148		
	BOD	Between groups	1.648	3.958	<0.001
		Within groups	0.414		
	COD	Between groups	2.121	8.355	<0.001
		Within groups	0.254		
	DO	Between groups	0.494	4.481	<0.001
		Within groups	0.102		
	PO4	Between groups	0.004	2.556	<0.001
		Within groups	0.002		
Difference among watershed types (Upstream, Midstream, and Downstream)	TSS	Between groups	155.589	27.925	<0.001
		Within groups	5.572		
	BOD	Between groups	11.813	31.49	<0.001
		Within groups	0.376		
	COD	Between groups	15.278	53.218	<0.001
		Within groups	0.287		
	DO	Between groups	3.713	40.691	<0.001
		Within groups	0091		
	PO4	Between groups	0.023	15.826	<0.001
		Within groups	0.001		

Table 5. Pearson's correlation coefficient between LULC and water quality parameters.

	F	MP	TP	S/B	AL	S
BOD	-.201	.922	-.377	.369	-.670	-.594
COD	-.206	.646	-.119	-.082	-.295	-.181
DO	.174	-.379	.024	.148	.108	.038
P	-.320	.318	-.080	-.255	.067	.129
TSS	-.234	.680	-.187	.148	.415	-.356

Note: p<0.05 (Bold)

Water quality parameters are: TSS, BOD, COD,DO, and P
LULC types are: F (forest), MP (mix plantation), TP (tea plantation), S/B (Shrub/Bush), AL (agricultural land), and S (Settlement)

Only water quality parameters in the upstream (2 parameters) and downstream (5 parameters) could be estimated since only in those locations the regression model was significant (Table 6.).

Table 6. Stepwise regression for water quality parameters and LULC in Batang Merao watershed.

	Dependent	Independent	Equation	R^2
Upstream	COD	F, MP, AL	COD = 8.54+2.82F+1.48MP+1.88AL	.714
	BOD	MP, AL, S	BOD = 2.10+1.83F-1.06MP+46.46AL	.665
Midstream	Insignificant			
Downstream	TSS	F, MP, AL	TSS =10.92+16.85F+25.52MP+56.80AL	.596
	COD	F, MP, AL	COD = 5.12+5.91F+7.34MP+20.25AL	.710
	BOD	F, MP, AL	BOD = -2.99+3.96F+6.90MP+13.67AL	.687
	DO	F, MP, AL	DO = 6.74–2.26F–3.22MP-7.18AL	.539
	P	MP, AL, S	PO4 = 0.158+0.29MP+0.34AL+0.07S	.516

Note: significance at 0.05 probability level (p = 0. 05)

In the upstream case, the COD predicators were forest, mix plantation, and agricultural land while the BOD predicators were mix plantation, agricultural land, and settlement. In the downstream case, there were similar predicators for the TSS, COD, BOD, and DO parameters, namely forest, mix plantation, and agricultural land. Meanwhile, the P predicators in this segment were mix plantation, agricultural land, and settlement. From this regression analysis, it was found that forest, mix plantation, and agricultural land were the three main predicators affecting the changes of some parameters of the water quality in the watershed. This result was in line with other studies finding that the water quality in a watershed was determined by forest condition (Dessie and Bredemeier, 2013) Dan agriculture (Zampella *et al.*, 2007) particularly in the tropical landscape (Uriarte *et al.*, 2011).

Conclusion

This study showed the condition of Batang Merao watershed as a representative of tropical watersheds facing the LULC changes which affected the water quality. In this case, WPI and STORET method can be used for evaluating the status of water quality effectively. To evaluate the humid tropical watershed like Batang Merao Watershed, it is strongly recommended to use the methods periodically.

In this study, LULC types showed a significant relationship with water quality parameters. Some water quality parameters, like TSS, COD, BOD, DO, and P, were predicted by using regression models on land use indicators. It was noticed that mix plantation, agricultural land, and forest were the most important parameters to predict water quality parameters. Deforestation due to agricultural activities (expansion of plantation, paddy field, and potato) and increasing demand for settlement imposed threat on water quality degradation. Furthermore, it could be concluded that water quality degradation in the Batang Merao watershed was associated with LULC, which were generally good predicators of water quality conditions.

Since this study can help us better understand LULC status, water quality, and their relationship, LULC should be well managed and some conservation programs should be taken in order to minimize the potential impact on water quality.

Acknowledgements
The authors would like to acknowledge National Planning Agency of Republic of Indonesia (Bappenas-RI), Regional Development Planning Board of Jambi Province, Mr. Asropi, the head division of Environmental Analysis, Environmental Management Agency of Jambi Province (BLHD) and the Global Environmental Leaders (GELs) Program of IDEC, Hiroshima University.

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