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ORIGINAL ARTICLE

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Relationship between water quality variations and land use in the Batutegi Dam Watershed, Sekampung, Indonesia

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Abstract

The Sekampung Hulu and Sangharus rivers were selected as target sites to study improved use and conservation of dam reservoir water because the region is an important source of fresh water, irrigation water for downstream agriculture and production of hydropower. The two rivers exhibited differences in average water quality. Most water quality parameters exhibited clear differences between the two rivers at each sampling event, with the relative differences not changing during the sampling period. Analysis of water quality based on land use percentage indicated that upland fields had a major impact on most water quality parameters. In addition, forest and plantation conditions had a major impact on the suspended solids concentrations. The results of the present study suggest that current management of these land use categories may not be adequate to prevent or even decrease erosion.

KEYWORDS
erosion, fertilization, land use practice, watershed management

1 | INTRODUCTION

The land use characteristics of river watersheds are directly related to downstream lake and reservoir environments, with negative influences being reported in many previous studies (e.g. Beaver et al., 2014; Fraterrigo & Downing, 2008; Lizotte et al., 2012; Nielsen et al., 2012; Pilgrim, Mikhailova, Post, & Hains, 2014; Soranno, Cheruvelil, Wagner, Webster, & Bremigan, 2015; Twesigye, Onywere, Getenga, Mwakalila, & Nakiranda, 2011). River water chemistry is controlled by numerous natural and anthropogenic factors, including pollutants from point and nonpoint sources (Ahearn et al., 2005), transported downstream via river channels. In regard to nutrient pollution, lakes and reservoirs can become eutrophic if they receive excessive nutrient loads (Somura et al., 2012). Eutrophication causes increased growths of algae and aquatic weeds that can significantly interfere with the quality of the water used for fishing, recreation, industry, agriculture and drinking (Carpenter et al., 1998). Furthermore, excessive sediment loading from upstream decreases the storage capacity of lakes and reservoirs, affecting the potential availability of water resources (e.g. irrigation water).

Pollutant discharges from such point sources as municipal sewage treatment plants tend to be continuous, exhibiting little variability over time. They are relatively simple to measure and regulate and can often be controlled by treatment at the source (Smith, Tilman, & Nekola, 1999). In contrast, although nonpoint inputs can also be continuous, they are more often intermittent, being linked to seasonal agricultural activity or irregular events, such as heavy precipitation or major construction. Consequently, nonpoint sources are difficult to measure and regulate (Smith et al., 1999).

Collecting information on land use is important as the first step towards managing nutrient inputs to waterbodies because reducing nutrient loading is the cornerstone of aquatic

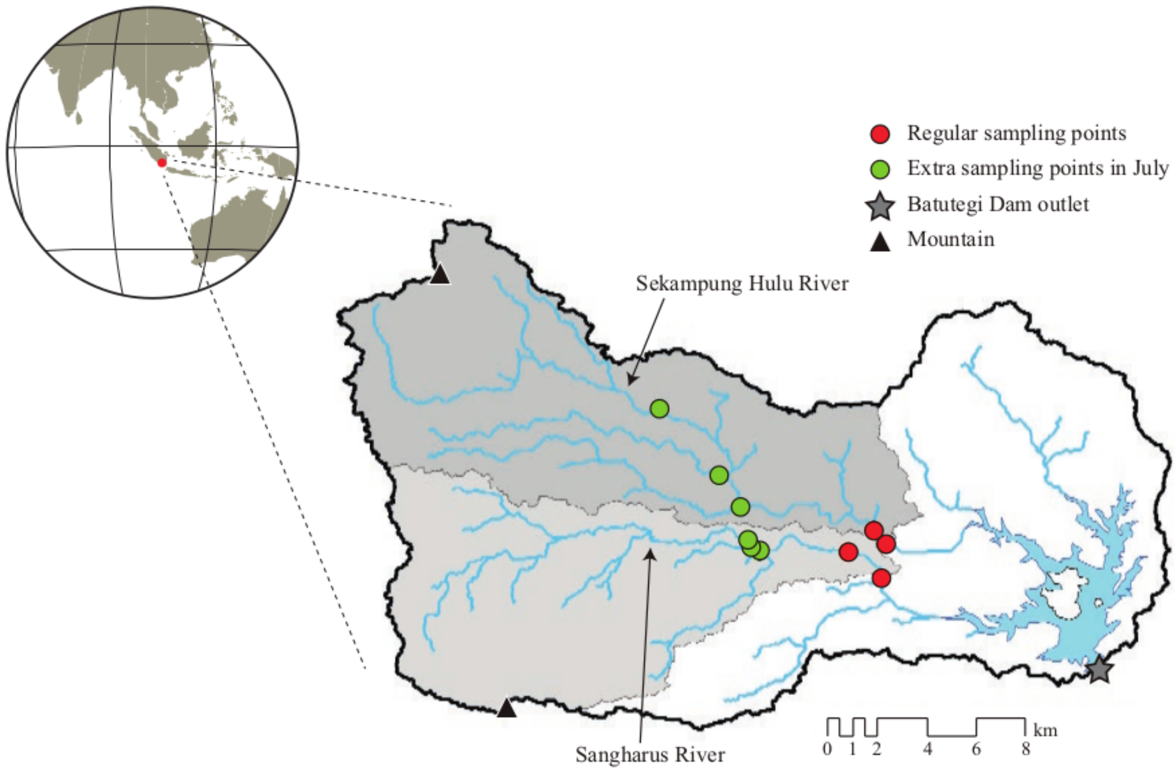

FIGURE 1 Location of study area

eutrophication control (Smith et al., 1999). Thus, the objectives of the present study were to understand the characteristics of water quality variations in river watersheds flowing to a downstream dam reservoir and to determine their relationship with the land uses in their watersheds.

2 | STUDY AREA

The Batutegi Dam watershed, covering about 430 km^2, is located in the Tanggamus region of Indonesia, approximately 60 km northwest of Bandar Lampung City in Sumatra (Figure 1). The watershed elevation lies between 138 and 1,740 m.a.s.l. It is situated in a humid tropical climate, with an average annual rainfall of 1,948 mm (from 2012 to 2016) and average monthly temperatures ranging from 25.8 to 28.7°C (from 2012 to 2016), varying along an altitudinal gradient (Indonesian Meteorological and Climatological Services, 2016). Three rivers (Sekampung Hulu; Sangharus; Rilau) flow into the dam reservoir. The dam was planned to respond to the growing rice demand in Indonesia and to regulate water resources while stabilizing rice production, especially in the dry season. The main purpose of the dam is to store agricultural water and generate hydroelectric power, with the available storage capacity of the reservoir being 578 million m^3 (Yunoki & Hargono, 2005). The water is used for irrigation in an extensive downstream agricultural area of 660 km^2.

The various watershed land uses are summarized, based on GIS data of the Indonesian Ministry of Forestry (2015). The major land use in the Batutegi Dam watershed is upland agricultural fields (54.0%), followed by communal forest (30.7%) and plantation (8.0%). Other land uses, including settlements (3.0%), paddy fields (0.7%), private forest (0.2%) and other (3.4%), account for the remaining portion of the watershed area. Communal forests refer to state forest lands, which are primarily used to improve local community welfare through the sustainable use of forest resources. Thus, the communal forest area has two purposes; namely, forest protection and production. Even in regard to forest production, local community members are required to rehabilitate the forest after tree harvesting (Indonesian Ministry of Forestry, 2007). Mainly secondary crops (cassava; maize; beans) and cash crops (coffee; cocoa; pepper) are cultivated in the upland fields. Agroforestry and shade trees are included in upland-field land use for the production of bananas, durians, mangoes, mangosteen and other fruits and vegetables as well as grasslands and grazing fields for livestock. Coffee is the major crop in plantation areas, although it can be interchangeable with other cash crops.

3 | METHODOLOGY

The Sekampung Hulu and Sangharus Rivers were selected as the target rivers because of the low accessibility by road of the Rilau

River, which can be accessed only by boat through the dam reservoir. Regular water sampling was conducted five times from the end of the rainy season (March) to the dry season (July) in 2016, with one sampling event in March, two in April, one in May and one in July. Two sampling sites located above the influence of the dam reservoir water level were established in downstream locations of each river (Figure 1). Furthermore, field surveys were conducted on 16 and 17 July 2016, and water samples were collected along the rivers. The Sekampung Hulu River was surveyed on 16 July and the Sangharus River on 17 July. Because of the road conditions and limited accessibility, sampling points were chosen on-site after discussion with local bike drivers. Electric conductivity (EC), dissolved oxygen (DO), pH and water temperature were measured with field and laboratory equipment (DO Meter Hanna Instruments HI 9142, Bench Meters Hanna Instruments HI 2550, and Horiba Multi-parameter Water Quality Meter U-53G).

Water samples were filtered through a 0.20-µm cellulose acetate membrane filter (Advantec Dismic-25CS, Japan) for analyses of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), ammonium (NH_4), chloride (Cl), nitrate (NO_3), phosphate (PO_4), sulphate (SO_4), aluminium (Al), iron (Fe), manganese (Mn) and silicon (Si). The first nine of these species were analysed with ion chromatography (Dionex ICS-1600, Thermo-Fisher), and the rest measured by inductively coupled plasma atomic emission spectroscopy (ICPE-9000, Shimadzu). In addition, total organic carbon (TOC) was analysed with a total organic carbon analyser (TOC-Vcsn, Shimadzu), while total suspended solids (TSS) were measured by centrifugation (CN-1050, AS-ONE), drying in a universal oven (UN55, Memmert), and weighing with an analytical balance (AUY220, Shimadzu).

Statistical analysis was performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R (the R Foundation for Statistical Computing, Vienna, Austria).

4 | RESULTS

4.1 | Characteristics of surface water quality at regular sampling sites

The two target rivers exhibited different average water quality (Table 1). Ammonium was not detected in the analyses, likely reflecting a low concentration. Most parameters, including Ca, K, Mg, Na, Cl, NO_3, PO_4, SO_4, Mn and Si, exhibited significantly greater concentrations in the Sangharus River than in the Sekampung Hulu River. Conversely, three water quality parameters (Al, Fe and TSS) exhibited higher values in the Sekampung Hulu River than in the Sangharus

TABLE 1 Summary of water quality in Sangharus and Sekampung Hulu Rivers

Water quality parameters	Sangharus River Mean ± *SE*	Sangharus River *N*	Sekampung Hulu River Mean ± *SE*	Sekampung Hulu River *N*	*p*-value Sangharus vs. Sekampung Hulu
Ca (mg/L)	5.67 ± 0.56	10	2.04 ± 0.26	10	0.000***
K (mg/L)	2.00 ± 0.15	10	1.34 ± 0.11	10	0.005**
Mg (mg/L)	2.09 ± 0.24	10	0.62 ± 0.09	10	0.000***
Na (mg/L)	6.29 ± 0.58	10	3.35 ± 0.17	10	0.000***
NH_4 (mg/L)	N.D.	10	N.D.	10	-
Cl (mg/L)	1.21 ± 0.07	10	0.96 ± 0.02	10	0.000***
NO_3 (mg/L)	1.11 ± 0.09	10	0.46 ± 0.08	10	0.000***
PO_4 (mg/L)	0.25 ± 0.03	10	0.07 ± 0.01	10	0.000***
SO_4 (mg/L)	4.46 ± 0.56	10	1.22 ± 0.13	10	0.000***
Al (mg/L)	0.64 ± 0.13	10	1.25 ± 0.14	10	0.003**
Fe (mg/L)	0.38 ± 0.05	10	0.68 ± 0.04	10	0.002**
Mn (mg/L)	0.0029 ± 0.0002	10	0.0021 ± 0.0002	10	0.019*
Si (mg/L)	26.07 ± 1.83	10	15.34 ± 0.82	10	0.000***
TOC (mg/L)	0.71 ± 0.05	10	0.80 ± 0.07	10	0.346
TSS (mg/L)	46.5 ± 9.39	8	291.4 ± 111.8	8	0.028*
EC (mS/cm)	32.5 ± 7.38	10	27.1 ± 4.12	10	0.520
DO (mg/L)	6.12 ± 0.27	10	6.52 ± 0.35	10	0.472
pH	7.56 ± 0.25	10	7.25 ± 0.26	10	0.405
TEMP (°C)	28.35 ± 0.47	10	28.37 ± 0.33	10	0.623

DO: dissolved oxygen; EC: electric conductivity; *N*: represents number of samples; N.D.: represents not detected; SE: represents standard error; TEMP: water temperature (TEMP); TOC: total organic carbon; TSS: total suspended solids.
p-values are calculated with Mann–Whitney U test and $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$.

River. Based on field observations, the water of the Sangharus River exhibited a clearer appearance, while the Sekampung Hulu River contained more soil particles (Figure 2). Accordingly, it was expected that the Sekampung Hulu River water samples would exhibit poorer water quality. However, the opposite result was observed for most of the parameters.

Water quality varied on each sampling day (Figure 3). The weather conditions on and immediately prior to the sampling days were as follows: relatively strong rainfall during sampling in March; rainfall 2 days before sampling in both days in April; rainfall 1 day before sampling in May; and no rainfall in July. The water quality parameter values varied among sampling days, although most exhibited similar trends in each river. Except for Mn and TOC, all parameters exhibited markedly different values during each sampling event, with the general trends of each parameter not changing during the sampling period. Most of the parameters, specifically Ca, K, Mg, Na, Cl, PO_4 and Si, exhibited increasing concentrations from March to July (Figure 3). Conversely, Al and NO_3 exhibited decreasing concentrations during the same period. In addition, SO_4 and Fe exhibited opposite trends between the two rivers, with SO_4 increasing in the Sangharus River and declining in the Sekampung Hulu River, and Fe showing inverse trends. Mn exhibited an increasing trend in the Sekampung Hulu River, but a differing trend in the Sangharus River at the two sampling points because of a large concentration difference in July, although similar trends and concentrations were observed from March to May. The TOC concentration in the Sekampung Hulu River exhibited an increasing trend, with a decreasing trend observed in the Sangharus River, although the concentrations were similar from March to May, exhibiting a larger difference in July.

4.2 | Water quality variation from upstream to downstream

The variations in parameter concentrations along the rivers, beginning at the lowest downstream sampling point in each river, are summarized in Figure 4. The circles represent parameters in the main stream, while the triangles represent parameters in tributaries. Cl, NO_3, PO_4, SO_4, Na, K, Mg, Ca, Mn and Si concentrations in the tributary were higher than the values in the main stream of the Sangharus River. Water concentrations in the main stream differed slightly before and after confluence because of the influence of the tributary. The Al and Fe concentrations were almost equivalent in the tributary and main stream. Only TOC exhibited a different tendency, with one anomalously high value in the main stream, the reason for which is not yet known. No significant longitudinal changes in the water quality parameters were observed in the main stream of the Sangharus River. In the Sekampung Hulu River, however, the two observed tributaries did not exhibit markedly higher concentrations than in the main stream. Only the PO_4 concentrations in the tributaries exhibited slightly higher values than in the main stream. The NO_3, Al, Fe and TOC concentrations were highest at most upstream sampling points of the main stream, becoming gradually diluted downstream. The Cl, SO_4, Na, K, Mg, Ca and Mn concentrations did not exhibit strong increasing or decreasing tendencies from upstream to downstream, while the Al and Fe concentrations exhibited clear differences between the two Sekampung Hulu River tributaries.

4.3 | Relationship between land use and water quality

Land use (Figure 5) was used to clarify the differences in water quality between the Sangharus and Sekampung Hulu Rivers. The land use ratio of each watershed was calculated from GIS land use data. The average water quality parameter concentrations at the lowest downstream sampling sites (i.e. the outlet of each watershed) were compared to the patterns of land use. Only the major land uses of forest, plantation and upland fields were considered for this analysis because of their greater potential to affect water quality, compared to minor land uses. For the Sangharus River watershed, forest occupies 21.0%, plantation 3.4% and upland fields 73.9% of the watershed area. These major land uses together total 98.3% of the watershed. In the Sekampung Hulu River watershed, forest occupies 26.7%, plantation 11.3% and upland fields 58.6% of the watershed, accounting for 96.6% of the watershed area. Upland fields represent the largest land use in both watersheds, with forests accounting for the second largest land use. Although the percentage of forest in both watersheds is similar, there is a relatively large difference in the area of upland fields, and a slightly difference in plantation area. Most parameters, specifically Cl, NO_3, PO_4, SO_4, Na, K, Mg, Ca, Mn and Si, exhibited a strong trend towards lower concentrations with increasing forest area percentage, and somewhat lower TOC, EC and pH values. Conversely, Al, Fe and TSS concentrations exhibited higher values with increasing forest area. Similar tendencies

FIGURE 2 River water colour and land uses in downstream reaches of Sangharus (left) and Sekampung Hulu (right) Rivers on 1 August 2015 (pre-field investigation)

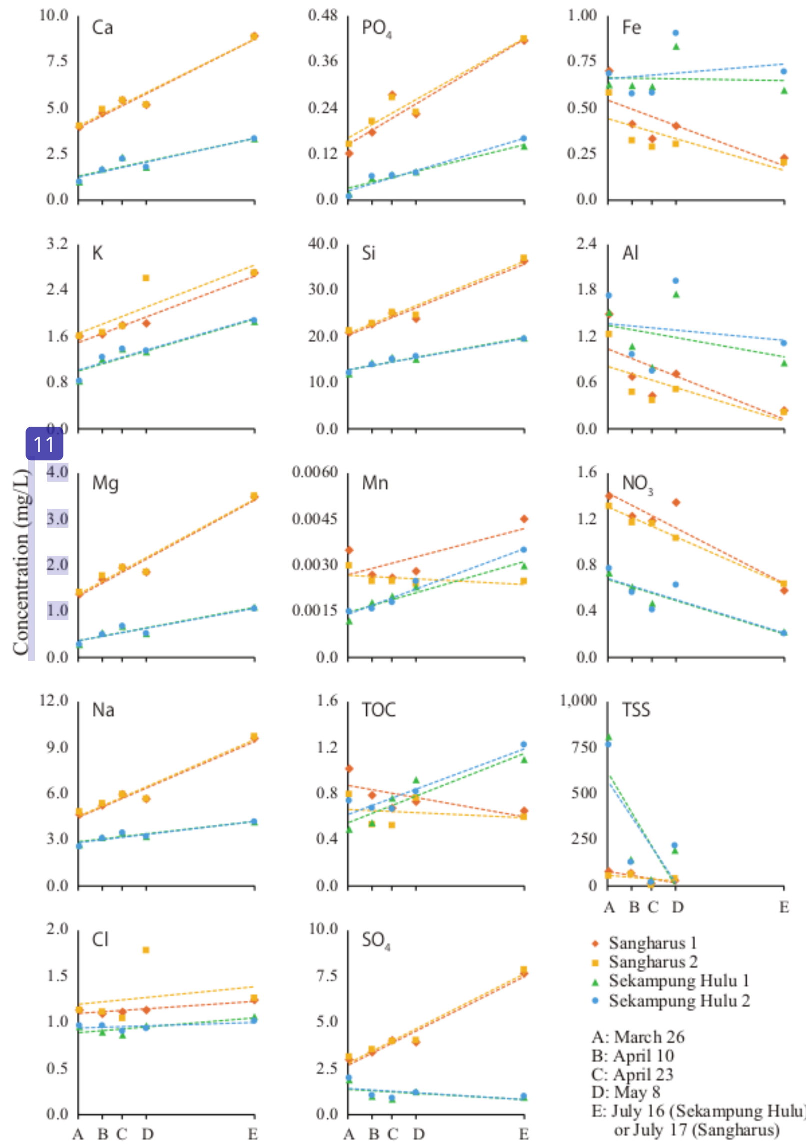

FIGURE 3 Water quality variations on each sampling day (approximate trend lines are shown; *x*-axis identifies sampling days; *y*-axis indicates concentrations (mg/L) of measured parameter

were observed with the increasing percentage of plantation area. Meanwhile, the values of Cl, NO_3, PO_4, SO_4, Na, K, Mg, Ca, Mn and Si exhibited a tendency to be greater with increasing percentage of upland fields, and slight increases were observed for EC and pH. The TOC did not exhibit large differences or strong trends, and Al, Fe and TSS appeared to decrease with increasing percentage of upland fields.

5 | DISCUSSION

The results of the present study demonstrated that the two adjacent watersheds of the Batutegi Dam watershed possess different water quality characteristics. Statistically significant differences in water quality were observed not only in the average values but also in water quality trends. This observation demonstrates that the differences were not driven by incidental processes affecting water quality, but from continuous activities in the watersheds. Surface waters are controlled by both natural processes, such as precipitation, erosion, weathering and anthropogenic activities, via both point sources (industrial effluents; wastewater treatment facilities) and non-point sources (run-off from urban areas and farm lands) (Carpenter et al., 1998; Li, Gu, Tan, & Zhang, 2009; Silva & Williams, 2001). The present study assumed natural processes would affect the water environment of the two watersheds in similar ways, because they are adjacent and the magnitude of natural influences, such as the quantity of precipitation and rate of weathering, is likely to be similar. As there are no point discharges of industrial effluent or wastewater treatment facilities in either watershed, land use practices are the major driver of the water quality differences between them.

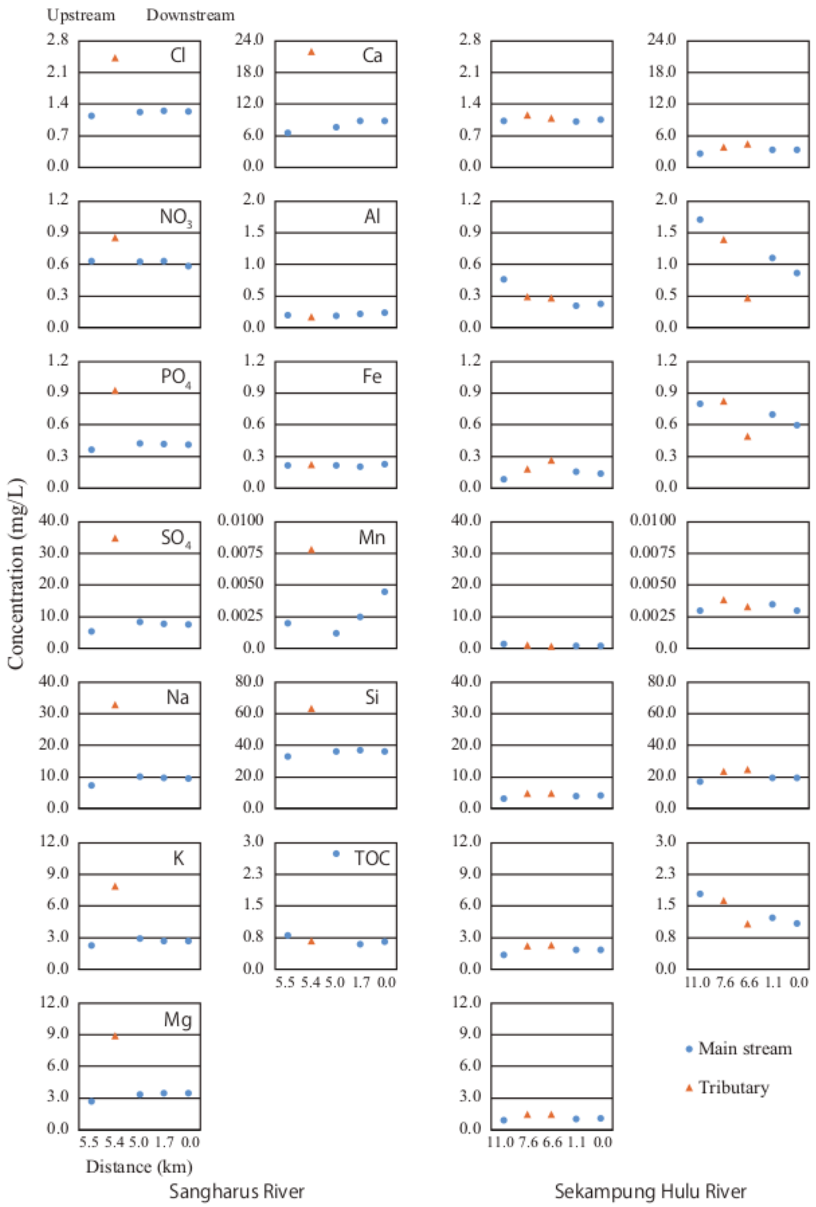

FIGURE 4 Water quality changes along Sangharus and Sekampung Hulu Rivers on 16 or 17 July 2016 (*x*-axis illustrates straight distance from lowest downstream sampling points; *y*-axis indicates water concentration (mg/L); circles represent water quality in main stream; triangles represent water quality in tributaries)

Agricultural land uses and related activities particularly influenced the in-stream concentrations of nitrogen (Johnson, Richards, Host, & Arthur, 1997; Smart et al., 1998), phosphorus (Parry, 1998) and sediment (Ahearn et al., 2005; Allan, Erickson, & Fay, 1997). Areas of communal forest and related production activities in the watersheds may also influence river water quality.

Higher concentrations of the major nutrients NO_3, PO_4 and K were observed in the Sangharus River than in the Sekampung Hulu River, with a positive correlation between their average values and upland field percentages. Thus, upland fields are considered to be a major nutrient contributor. This assumption supported by the dynamics of SO_4 and Ca, especially in the Sangharus River watershed because SO_4 is contained in fertilizers such as calcium superphosphate, potassium sulphate and ammonium sulphate, and Ca is also contained in calcium superphosphate and double superphosphate. These two parameters showed similar trends with PO_4 and K, but not NO_3. The reason for the different behaviour of NO_3 is unclear, although the timing and amount of fertilizer applications may influence these trends.

Forest and plantation areas could have major impacts on TSS, Al and Fe concentrations, indicating the current land management of these areas may not be adequate to prevent or decrease erosion. According to a chief of the farmer's group in the Sekampung Hulu watershed, at least 20% of the coffee trees in his territory planted within the last 3 years are still growing, with minimum shade trees. Thus, the land surface is not well covered with vegetation, therefore

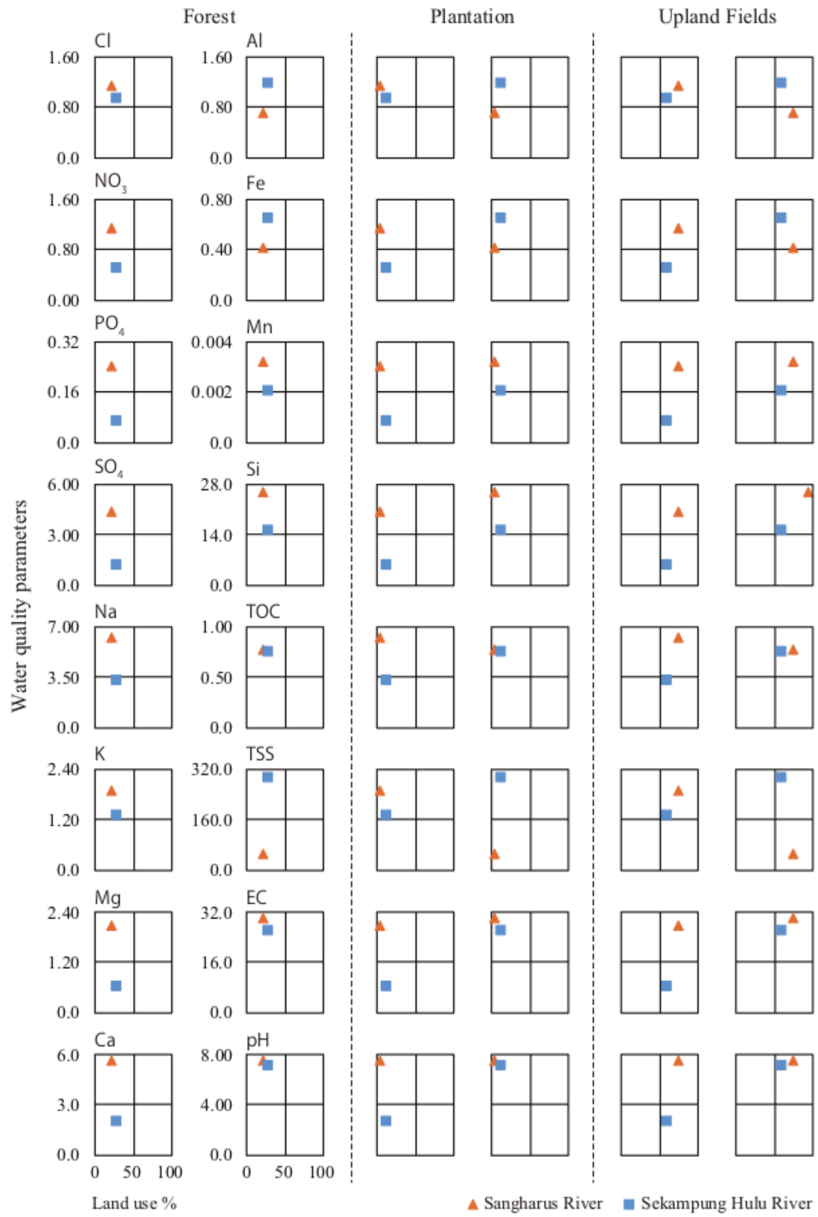

FIGURE 5 Relationship between major land uses and water quality (*x*-axis indicates percentage of each land use; *y*-axis indicates water parameter values (mg/L, pH units, or mS/cm, as appropriate))

exhibiting a high potential for erosion. From conversational-style interviews conducted with a total of 400 farmers in both watersheds on 16 and 17 July 2016 (Table 2), it was determined that the proportion of farmers implementing soil conservation activities in the Sekampung Hulu watershed was much higher than in the Sangharus watershed. The most popular techniques for soil conservation were vegetation mats and ditches. Despite the higher environmental consciousness among the farmers in the Sekampung Hulu watershed, however, the suspended solid concentrations in the river were much greater. The under use of shade trees could also contribute to elevated suspended solid concentrations.

Most of the farmers in both watersheds were new migrants, especially in the Sekampung Hulu watershed. Migrants generally face serious opposition from local residents in claiming existing cleared land, resulting in their tending to clear forest lands for their livelihoods or conversion into agricultural plantations (Darmawan, Klasen, & Nuryartono, 2016). In field research conducted in July 2016, a high TSS concentration (approximately 200 mg/L) was detected in the Sekampung Hulu River at the most upstream sampling site (Figure 6), suggestive of problems with land use practices in the upstream mountainside located far from the sampling site, were a source of high TSS concentrations in the river. The NO_3, Al, Fe and TOC concentrations also were greatest at the most upstream sampling point on this date. The reason for this finding is unclear because no physical observations could be made (due to bad road conditions) of land use management in that

TABLE 2 Environmental consciousness among farmers and soil conservation techniques

	Sekampung Hulu watershed	Sangharus watershed
Soil conservation activity		
Yes	54.7%	11.8%
No	45.3%	88.2%
Soil conservation method		
Vegetation mat	53.2%	91.3%
Ditch	45.0%	8.7%
Mulch	0.0%	0.0%
Others	1.8%	0.0%
Farmers status		
Original local residents	13.7%	22.0%
Migrants	86.3%	78.0%

FIGURE 6 Most upstream sampling point in Sekampung Hulu River, illustrating high turbidity condition observed on 16 July 2016

area. However, a Google Earth satellite image (generally located in the area of 5°07′55″S, 104°31′40″E) indicated many dot-type cultivated lands on the mountainsides in the Sekampung Hulu watershed. Brechin, Surapaty, Heydir, & Roflin (1994) indicated that illegal farming in protected forests in Lahat, south Sumatra (approximately 200 km northwest of the target watersheds) led to a dramatic loss of forest cover between 1982 and 1985. Thus, some of the cultivated lands in the mountainous area could be illegal farms, contributing to the high TSS concentration in the upstream watershed.

The findings of the present study demonstrated that the two target watersheds had different problems affecting water quality. Poor land use management, especially in upstream mountainsides, may be a major source of high TSS concentrations. Meanwhile, poor fertilizer management in upland fields may be a major source of high nutrient concentrations in the Sangharus River watershed.

6 | CONCLUSIONS

The present study resulted in the following findings:

- There were clear differences in water quality between the Sangharus and Sekampung Hulu Rivers;
- Clear trends in water quality did not change throughout the sampling period, although some parameters showed increasing trends and others showed decreasing trends;
- The Sangharus River exhibited similar concentrations from upstream to downstream, although one tributary exhibited higher concentrations of some parameters than in the main stream, while the Sekampung Hulu River exhibited higher concentrations of NO_3, Al and Fe at most upstream sampling sites, gradually decreasing downstream; and
- TSS, Al and Fe concentrations increased with increasing forest and plantation area, while NO_3 and PO_4 increased with increasing upland field area.

The two adjacent target rivers exhibited different water quality characteristics, which may be associated with different sources driving the water quality changes. Different approaches should be employed in the two watersheds, therefore, to conserve the water environment of the downstream dam reservoir. To identify the causes of decreased water quality and the most optimal and feasible approaches to address them, it is necessary to also consider the socioeconomic aspects of the local inhabitants such as population pressures and crop production cycles.

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