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Impact of Human Activities and Natural Processes on the Seasonal Variability of River Water Quality in Two Watersheds in Lampung, Indonesia

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Abstract: This study identified seasonal water quality characteristics in two adjacent mountainous rivers (Sangharus and Sekampung Hulu Rivers) in Lampung, Indonesia and determined the impacts of fertilizer application on river chemistry as a result of social forestry management. In 2016, we measured water chemistry and conducted a farmers' questionnaire survey to obtain information on fertilizer application. The water quality results indicated that several parameters, including nitrate (NO_3) and phosphate (PO_4), were significantly higher in the Sangharus River than in the Sekampung Hulu River. In addition, several parameters were influenced by dilution from high river flow in the rainy season. Some parameters were likely influenced by the weathering of parent materials. By contrast, electrical conductivity (EC) and NO_3 were higher in the rainy season, which was likely linked to the dominant timing of urea fertilizer application during this season. Despite the application of fertilizers in the watersheds, NO_3 levels remained below the recommended standard. However, aluminum and iron concentrations were higher than the recommended level for drinking water, which was likely due to elevated soil erosion from improper land management. Therefore, we recommend that effective land management policies be implemented through the adoption of soil conservation practices for nutrient loss prevention.

Keywords: fertilizer application; dry and rainy seasons; parent material; social forestry; water quality; coffee plantation

1. Introduction

Indonesia has an estimated population of more than 237 million [1], and thus its economic growth should be managed effectively to ensure secure access to food, housing, education, and health. Population growth increases land use demand for agriculture commodities [2] and results in forest exploitation, particularly impacting communities nearby forested areas. Of particular environmental concern is the illegal practice of forest conversion into agricultural land in forested areas that are easy to access. Such practices result in accelerated soil erosion from increased land exposure [3] and increased nutrient loss [4] to rivers and streams.

The Indonesian government issues regulations on social forestry to involve the local community in sustainable forest management. These regulations support local economic growth and provide equity for social welfare, and also maintain and protect forest ecosystem functions [5]. The community forestry (*Hutan Kemasyarakatan, Hkm*) and forestry partnership (*Kemitraan Kehutanan, mitra*) regulations have been applied in Tanggamus Regency in Lampung Province. The farmers in this district predominantly plant coffee trees, as well as pepper, cacao, clove, and fruit trees (durian and avocado). Coffee is the largest export from the agricultural and forestry sector in Lampung Province, with a value USD 435,288,000 [6] and a production of 131,501 tons [7] in 2014. Furthermore, Indonesia is the fourth largest coffee producer after Brazil, Vietnam, and Colombia [8].

Coffee plantations require fertilization to maintain yield and quality. Eleven years ago, chemical fertilizers were not commonly applied in coffee plantations under the management of social forestry in the Tanggamus Regency [9]. However, due to lowered soil nutrient availability following the conversion of forests to agricultural land [10], the application of some chemical fertilizers was necessary to increase productivity. In particular, the application of N-fertilizers has been found to increase coffee yield [11] and improve bean quality [12]. Stream water in forested areas is typically higher in quality compared with water from rivers in other land use types [13]. Excessive fertilizer application can cause water quality degradation in rivers and/or reservoirs near agricultural land [14]. It is therefore necessary to monitor the water quality in nearby rivers and reservoirs in order to determine the impacts of excessive fertilization as a result of social forestry practices.

The links between water quality and land use have been studied in a number of watersheds throughout the world [15–17]. A recent study conducted from March to July 2016 in our study area detected clear differences in water quality between the two adjacent watersheds and briefly analyzed relationship between land use and water quality [18]. The study identified that Sangharus River had higher nitrate (NO_3) while Sekampung Hulu River had higher total suspended solids (TSS), aluminum, and iron. However, the seasonal patterns of river water quality have not yet been investigated in the area. Moreover, detailed analyses for understanding the reason for the differences in water quality between the watersheds have not been conducted. Seasonal climate variability plays an important role in water quality within ecosystems [19], as rainy and dry seasons can influence river water quality. The dry season has higher total solids (TS) and biochemical oxygen demand (BOD) because of low river discharges and increased industrial wastewater discharges, while in the rainy season a higher NO_3 concentration is detected because of high runoff that transports fertilizers [20].

In this study, we targeted two adjacent watersheds, Sekampung Hulu and Sangharus, where forested land has been predominantly converted into coffee plantations under social forestry management. The Batutegi Dam is a water supply source for irrigation, drinking water, and nearby power plants, and is located downstream of the rivers in our study area. Therefore, the hydrological characteristics of the rivers can influence the reservoir function [21]. As social forestry concept has also been adopted in other areas in Indonesia, management of water quality environment under a social forestry system is essential to give information to stakeholders about the sustainable use of mountainous areas. In this study, we aimed to determine the seasonal water quality characteristics through observations spanning one year and to identify the impacts of local fertilizer application on river water quality in the watersheds. In addition, we tried to understand reasons why clear differences in water qualities were observed in the adjacent watersheds. Based on our results, we provide recommendations for effective water quality management in these watersheds.

2. Materials and Methods

2.1. Study Area

The study area is located in the Sekampung Hulu (5°5′38″ S, 104°30′34″ E) and Sangharus (5°15′58″ S, 104°42′56″ E) watersheds in Lampung Province, Indonesia (Figure 1). The study area of the Sekampung Hulu watershed covers 141.3 km^2, consisting of social forestry (137.6 km^2) and private land (3.7 km^2). The study area of the Sangharus watershed covers 117.2 km^2, and also consists of social forestry (106.7 km^2) and private land (10.5 km^2). With regards to the local geology, the Sangharus watershed consists of 2% sandstones and tuff, 3.7% clay and sand deposits, 62.3% basaltic andesite tuff, and 32% pumice tuff. The Sekampung Hulu watershed consists of 7.2% clay and sand deposits, 1.9% granite, 2.9% schist, 57.8% basaltic andesite tuff, and 30.1% pumice tuff [22] (Figure 2A).

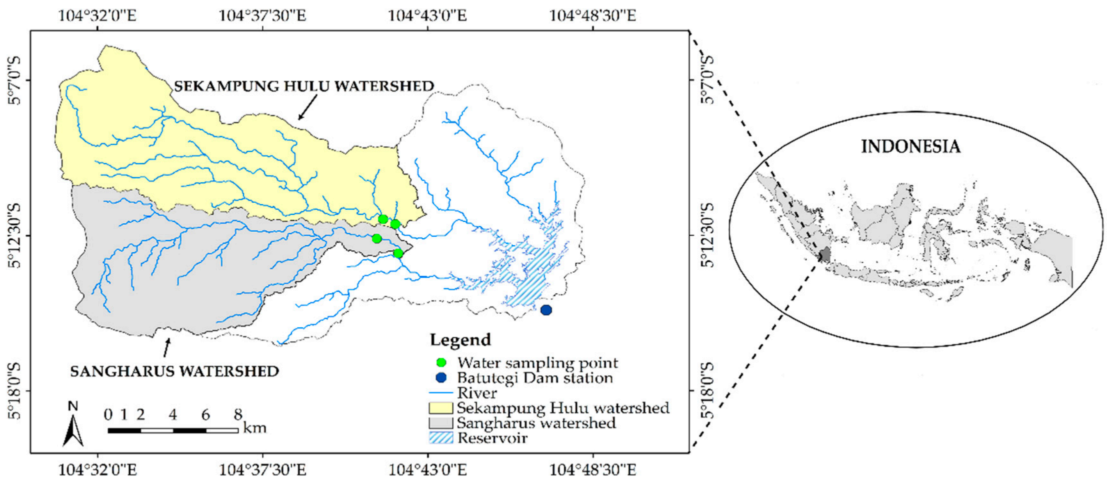

Figure 1. Map of study area showing the location of the Sekampung Hulu and Sangharus watersheds in Indonesia. The sampling locations are highlighted by the green circles.

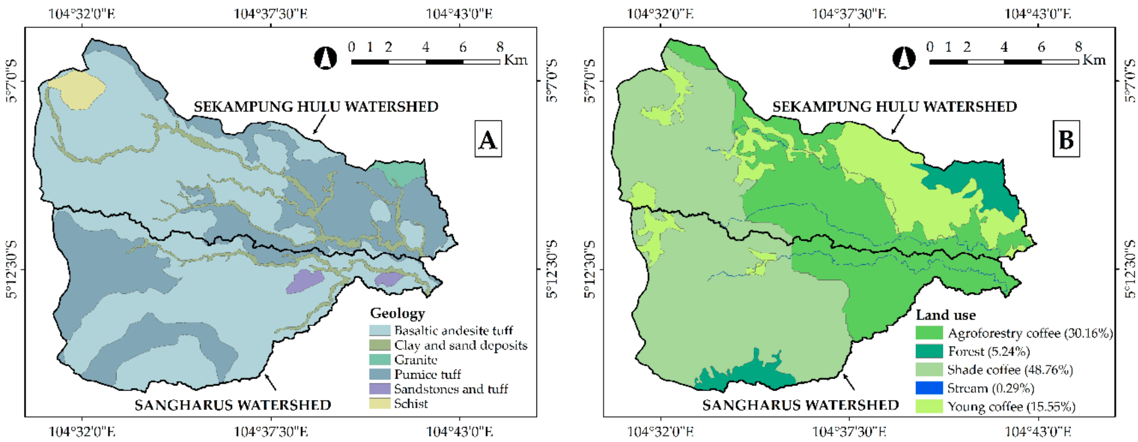

Figure 2. (**A**) Geology and (**B**) land use of the Sekampung Hulu and Sangharus watersheds.

The watershed topographies are characterized by mountain ranges and hills at elevations ranging from 282 to 1767 m above sea level. The total annual precipitation in 2016 was 1294 mm [23]. The precipitation data for the study period (2016) and the 17-year precipitation mean are illustrated in Figure 3. The study region is defined as climate type Af (rainfall in the driest month is at least 60 mm) based on the Koppen classification [9]. The study region is located in the tropics and therefore experiences rainy and dry seasons. In 2016, the dry season in the Tanggamus Regency occurred in June–August, while the rainy season occurred in January–May and September–December [24].

Based on field observations and land use data analyses [25] (Figure 2B), the watersheds were predominantly covered by coffee trees. Commercial trees such as pepper, cacao, clove, rubber, durian, and avocado were also identified. In addition, timber tree species of high economic value, such as mahogany (*Swietenia mahagoni*) and sonokeling trees (*Dalbergia latifolia*) were found. The land area in the Sekampung Hulu watershed consists of 33.9% agroforestry coffee, 34.3% shade coffee, 25.7% young coffee, 5.8% forests, and 0.3% rivers. The land area in the Sangharus watershed consists of 25.6% agroforestry coffee, 66.3% shade coffee, 3.3% young coffee, 4.6% forests, and 0.2% rivers. The land use of young coffee involves coffee plantation in early growth and has less coverage condition. Shade coffee refers to coffee plantations with shade trees such as *Gliricidia sepium, Paraserianthes falcataria,* and others. Agroforestry coffee is a multistory system that consists of coffee plantations with more than five other tree species.

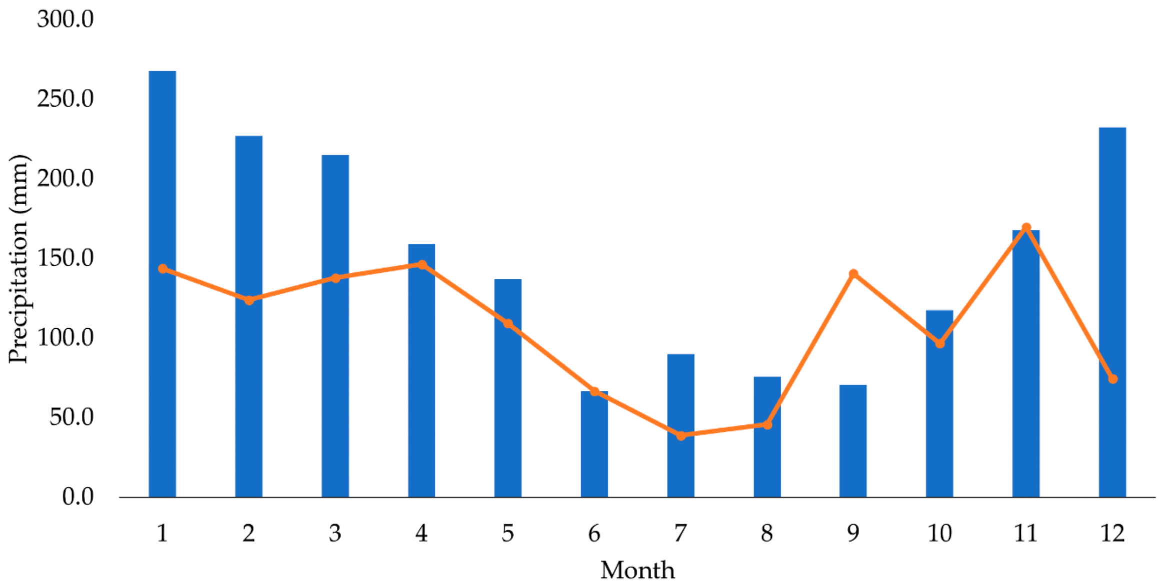

Figure 3. Long-term 17-year mean precipitation (bars) and monthly precipitation for 2016 (line); source from Batutegi Dam station, Directorate General of Operation and Maintenance Water Resources Mesuji Sekampung (DGOMWRMS) [23].

2.2. *Water Sampling and Analyses*

The water sampling sites in the Sekampung Hulu and Sangharus Rivers were located downstream of the watersheds because of ease of accessibility (Figure 1). Water samples were collected in 23rd October, 6th and 20th November, and 4th December, 2016. To determine the water quality characteristics for the entire year, we compared water quality data collected in 26th March, 10th and 23rd April, 8th May, and 17th July, 2016 from a previous study [18]. Water sampling from a previous study had the same locations as our sampling sites. We analyzed 15 water quality parameters, including calcium, potassium, magnesium, sodium, chloride (Cl), NO_3, phosphate (PO_4), sulfate (SO_4), Al, Fe, silicon, water temperature, electric conductivity (EC), dissolved oxygen (DO), and pH. Through the analyses, we can understand the circumstances of water quality in the area and use the information to consider the effects of human activities and natural processes on water quality characteristics. Water quality information can also support recommendations to handle water quality issues in the study area.

Water temperature, EC, DO, and pH were measured on site using a Horiba multi-parameter water quality meter (U-53G, Horiba, Kyoto, Japan), a DO meter (Hanna Instruments HI 9142, Woonsocket, RI, USA), and a bench pH meter (Hanna Instruments HI 2550, Woonsocket, RI, USA), respectively. Other parameters were analyzed according to the available methods and equipment in our laboratory. Ca, K, Mg, Na, Cl, NO_3, PO_4, and SO_4 were measured by ion chromatography (Dionex ICS-1600, Sunnyvale, CA, USA) and Al, Fe, and Si were analyzed by inductively coupled plasma atomic emission spectroscopy (ICPE-9000, Shimadzu, Kyoto, Japan).

2.3. *Survey of Local Fertilizer Application*

We obtained information regarding fertilizer application in the Sekampung Hulu and Sangharus watersheds via a questionnaire to local farmers because no statistical information related to this aspect was available in the area. In addition, there are many advantages to understanding the local manner of farming activities through direct communication because chemicals contained in fertilizers are a key parameter determining water quality characteristics. The questions were framed to obtain information regarding the amount of fertilizer applied, kinds of fertilizers applied, and the schedule of fertilizer application. Each watershed contains a habitat of approximately 2500 farmers. We surveyed 93 farmers in each watershed based on the total number of farmers, a confidence level of 95%, and a margin of error of 10%. The respondents were categorized as farmers of private land tenure, farmers of *HKm*, and farmers of *mitra*. The dominant crop in the study area is coffee. Area size of farmers' fields ranges 0.25–6 ha with the predominant size being 1–2 ha.

The social forestry farmers selected in the Sekampung Hulu watershed for the survey were grouped as follows: *HKm* Sinar Harapan, *HKm* Wana Tani Lestari, *Hkm* Mandiri Lestari, *HKm* Bina Wanajaya 1, and *HKm* Bina Wanajaya 2. The farmers in the Sangharus watershed were grouped as follows: private land tenure, *Hkm* Sidodadi, *HKm* Trisno Wana Jaya, *HKm* Karya Tani Mandiri, *HKm* Sinar Harapan, and *mitra* Sumber Rejeki. As *Hkm* Sinar Harapan is located both in the Sekampung Hulu and Sangharus watersheds, the respondents were surveyed for both watersheds.

2.4. Statistical Analysis

The water quality data and fertilizer application survey were statistically evaluated. We applied an independent samples t-test or a Mann-Whitney U-test based on normality distributions. These statistical analyses were performed to determine the significant difference of water quality in the two rivers and fertilizer application amount in the two watersheds. We conducted a one sample t-test to determine the seasonal variability of water quality. The one sample t-test was conducted to compare a single data observation in the dry season with that of the mean sample in the rainy season in order to determine the significant differences. Statistical analyses were conducted using Statistical Product and Service Solutions (SPSS) 17.0 software [26]. SPSS is user friendly and widely used throughout the world.

2.5. Uncertainties and Shortcomings of the Study

Water samples were not collected every month at the target sites. Thus, sampling numbers of stream water may not be sufficient to show the level of water concentrations in the watersheds, though differences in water quality characteristics can be understood through our study. Besides this, as the sampling was conducted only downstream because of low accessibility to the mountainous streams, and no observations were conducted along the rivers from middle to upper streams, our research is not able to discuss any trends in water concentrations along the rivers from upstream to downstream in the watersheds.

In addition, the characteristics of seasonal variability of water quality are affected by the climate condition of El Niño or La Niña. Normally, the dry season in the study area is from June to September, but in 2016, the season was shorter, and was from June to August (Figure 3). Moreover, the application of fertilizer may vary across years depending on farmers' preference for applying fertilizer and their financial conditions. Thus, climate variability and farmers' decisions will also affect stream water quality.

To collect information on fertilizer application, the survey was conducted in such places as farmers' homes, fields, and pathways. Hence, accurate location of all respondents' land tenure was difficult to identify on the map. This means it is difficult to understand the exact location of farmland to which amounts of fertilizer are being applied. Increasing the number of respondents and surveys to all farming groups will provide more detailed information. Accumulation of knowledge through long-term observation of water qualities and local surveys should be conducted in future for a comprehensive understanding of water quality circumstances in the watersheds.

3. Results

3.1. Water Sampling

Results from our statistical analyses showed that Ca, K, Mg, Na, Si, Cl, NO_3, PO_4, and SO_4 concentrations were significantly higher in the Sangharus River relative to the Sekampung Hulu River (Table 1). By contrast, Fe concentrations were significantly higher in the Sekampung Hulu River (0.53 ±

0.19 mg/L) relative to the Sangharus River (0.27 ± 0.22 mg/L). Al, DO, EC, pH, and water temperature showed no significant difference between the two rivers.

Table 1. Statistical parameters of water quality concentrations in the Sekampung Hulu and Sangharus Rivers.

Parameters	River	Mean ± SD	*p* Value
Al (mg/L) [1]	Sangharus Sekampung Hulu	0.43 ± 0.48 0.93 ± 0.52	0.052
Ca (mg/L) [1]	Sangharus Sekampung Hulu	5.91 ± 1.48 2.16 ± 0.71	0.000 ***
Cl (mg/L) [1]	Sangharus Sekampung Hulu	1.12 ± 0.05 0.91 ± 0.08	0.000 ***
DO (mg/L) [2]	Sangharus Sekampung Hulu	5.84 ± 0.47 6.08 ± 0.97	0.965
EC (mS/cm) [1]	Sangharus Sekampung Hulu	43.44 ± 24.75 26.12 ± 9.90	0.078
Fe (mg/L) [1]	Sangharus Sekampung Hulu	0.27 ± 0.22 0.53 ± 0.19	0.015 *
K (mg/L) [1]	Sangharus Sekampung Hulu	1.96 ± 0.34 1.36 ± 0.29	0.001 **
Mg (mg/L) [1]	Sangharus Sekampung Hulu	2.16 ± 0.63 0.65 ± 0.24	0.000 ***
Na (mg/L) [1]	Sangharus Sekampung Hulu	6.63 ± 1.55 3.40 ± 0.46	0.000 ***
NO_3 (mg/L) [1]	Sangharus Sekampung Hulu	1.08 ± 0.25 0.58 ± 0.21	0.000 ***
pH [1]	Sangharus Sekampung Hulu	7.99 ± 0.98 7.60 ± 0.82	0.368
PO_4 (mg/L) [2]	Sangharus Sekampung Hulu	0.18 ± 0.11 0.04 ± 0.05	0.003 **
Si (mg/L) [1]	Sangharus Sekampung Hulu	26.71 ± 4.83 15.21 ± 2.15	0.000 ***
SO_4 (mg/L) [2]	Sangharus Sekampung Hulu	4.72 ± 1.46 1.14 ± 0.33	0.000 ***
Water temperature (°C) [2]	Sangharus Sekampung Hulu	28.13 ± 1.99 28.23 ± 1.79	0.965

* Significant *p* value 0.05, ** significant *p* value 0.01, *** significant *p* value 0.001, SD = standard deviation, [1] = independent samples t-test, [2] = Mann-Whitney U-test. Legend: Cl, chloride; DO, dissolved oxygen; EC, electric conductivity; NO_3, nitrate; PO_4, phosphate; SO_4, sulfate.

Seasonal patterns of Ca, K, Mg, Na, Si, Cl, and PO_4 concentrations were significantly higher in the dry season (July) for both rivers (Figure 4, Table 2) relative to the rainy season. NO_3 concentrations were lower in the dry season for both rivers with concentrations of 0.23 mg/L in the Sekampung Hulu River and 0.58 mg/L in the Sangharus River. SO_4 concentrations in the Sangharus River were higher in the dry season (7.66 mg/L) but showed no significant difference in concentration between the rainy (1.16 mg/L) and dry seasons (0.97 mg/L) in the Sekampung Hulu River. Similarly, we observed no significant difference in the seasonal patterns of Al and Fe concentrations in both rivers. The pH and EC were lower in the dry season for both rivers. The pH values in the dry season in the Sekampung Hulu River and the Sangharus River were 6.01 and 6.37, respectively, and the EC concentrations in the dry season in the Sekampung Hulu River and the Sangharus River were 5.20 mg/L and 12.60 mg/L, respectively. DO was higher in the dry season for both rivers with concentrations of 7.29 mg/L in the Sekampung Hulu River and 6.73 mg/L in the Sangharus

River. Water temperature in the Sangharus River was higher during the rainy season (28.38 °C) while the water temperature in the Sekampung Hulu River showed no significant difference between the two seasons (27.31 °C in the dry season and 28.35 °C in the rainy season).

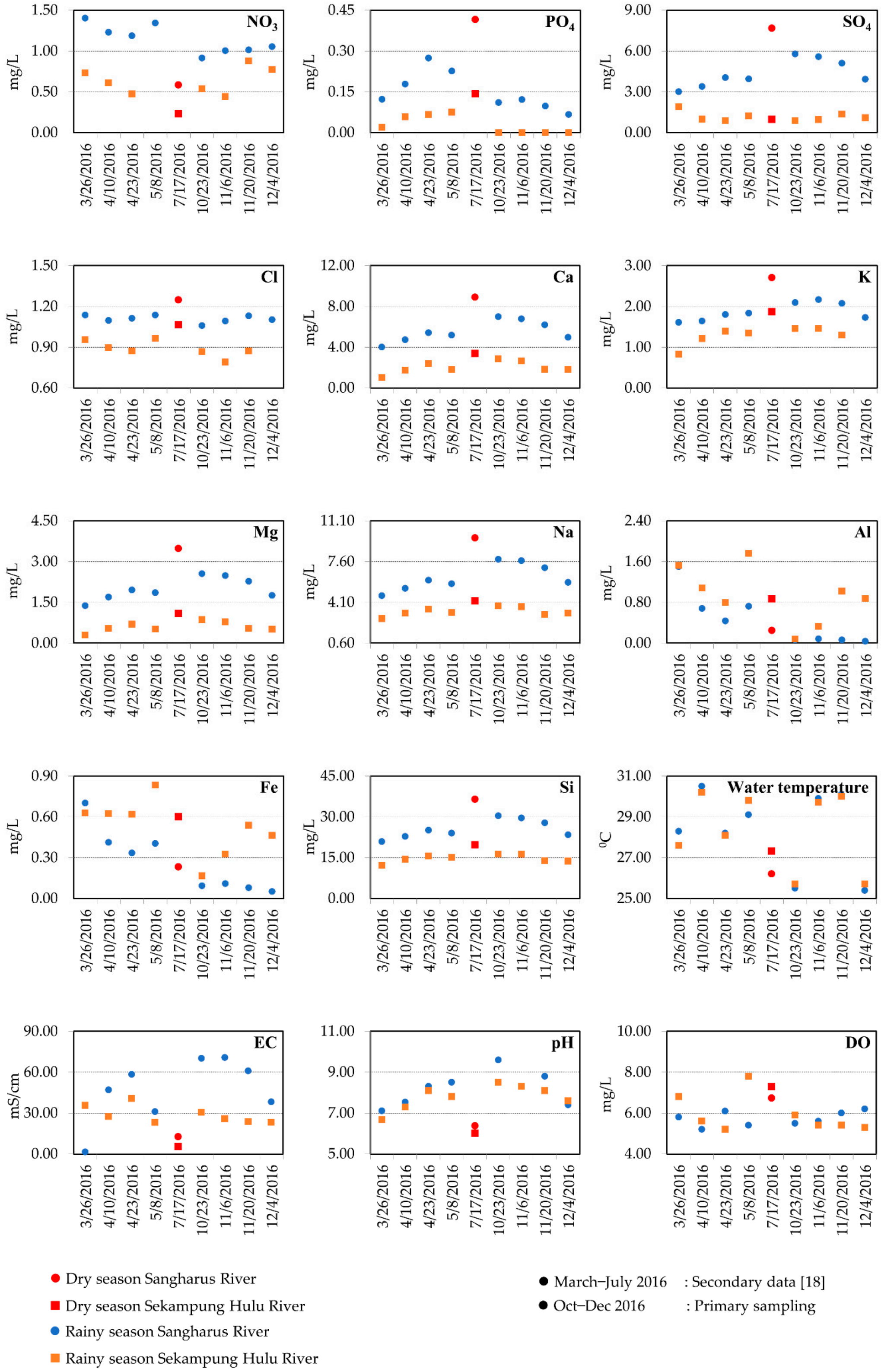

Figure 4. Water quality comparisons between the Sekampung Hulu and Sangharus Rivers.

Table 2. Seasonal patterns of water quality concentration between the rainy and dry seasons.

Parameters	River	Mean ± SD in Rainy Season	Concentration in Dry Season	p Value
Al (mg/L)	Sangharus Sekampung Hulu	0.45 ± 0.51 0.93 ± 0.56	0.25 0.87	0.311 0.761
Ca (mg/L)	Sangharus Sekampung Hulu	5.53 ± 1.04 2.01 ± 0.59	8.89 3.35	0.000 *** 0.000 ***
Cl (mg/L)	Sangharus Sekampung Hulu	1.11 ± 0.03 0.89 ± 0.06	1.25 1.06	0.000 *** 0.000 ***
DO (mg/L)	Sangharus Sekampung Hulu	5.73 ± 0.36 5.93 ± 0.91	6.73 7.29	0.000 *** 0.004 **
EC (mS/cm)	Sangharus Sekampung Hulu	47.30 ± 23.39 28.74 ± 6.46	12.60 5.20	0.004 ** 0.000 ***
Fe (mg/L)	Sangharus Sekampung Hulu	0.27 ± 0.23 0.52 ± 0.21	0.23 0.60	0.614 0.336
K (mg/L)	Sangharus Sekampung Hulu	1.87 ± 0.22 1.28 ± 0.22	2.70 1.87	0.000 *** 0.000 ***
Mg (mg/L)	Sangharus Sekampung Hulu	1.99 ± 0.41 0.59 ± 0.18	3.48 1.10	0.000 *** 0.000 ***
Na (mg/L)	Sangharus Sekampung Hulu	6.26 ± 1.14 3.30 ± 0.36	9.62 4.22	0.000 *** 0.000 ***
NO_3 (mg/L)	Sangharus Sekampung Hulu	1.14 ± 0.17 0.64 ± 0.16	0.58 0.23	0.000 *** 0.001 **
pH	Sangharus Sekampung Hulu	8.19 ± 0.82 7.80 ± 0.60	6.37 6.01	0.000 *** 0.000 ***
PO_4 (mg/L)	Sangharus Sekampung Hulu	0.15 ± 0.07 0.03 ± 0.03	0.42 0.14	0.000 *** 0.000 ***
Si (mg/L)	Sangharus Sekampung Hulu	25.50 ± 3.41 14.65 ± 1.44	36.40 19.70	0.000 *** 0.000 ***
SO_4 (mg/L)	Sangharus Sekampung Hulu	4.35 ± 1.02 1.16 ± 0.34	7.66 0.97	0.000 *** 0.156
Water Temperature (°C)	Sangharus Sekampung Hulu	28.38 ± 1.98 28.35 ± 1.88	26.20 27.31	0.017 * 0.162

* Significant p value 0.05, ** significant p value 0.01, *** significant p value 0.001.

3.2. Fertilizer Application

Fertilizers used by farmers in each watershed are summarized in Table 3 based on the questionnaire survey. In the Sekampung Hulu and Sangharus watersheds, farmers applied inorganic fertilizers such as urea (N 46%), phonska fertilizer (N 15%, P_2O_5 15%, K_2O 15%, S 10%), mutiara fertilizer (N 16%, P_2O_5 16%, K_2O 16%, MgO 0.5%, CaO 6%), and triple super phosphate (TSP) fertilizer (P_2O_5 45%, Ca 15%). Furthermore, farmers in the Sekampung Hulu watershed also applied super phosphate (super *fosfat* or SP-36) (P_2O_5 36%, S 5%), ammonium sulfate (*amonium sulfat* or ZA) (N 21%, S 24%), and KCl (K_2O 60%) fertilizers.

Based on the survey, it was determined that urea application was significantly higher in the Sangharus watershed (166.8 kg/ha) relative to the Sekampung Hulu watershed (120.3 kg/ha), as noted in Table 4. By contrast, the application of mutiara and phonska fertilizers showed no significant difference in both watersheds. TSP, SP-36, ZA, and KCl fertilizers in the Sangharus watershed were not detected in the independent samples t-test and The Mann-Whitney U-test due to their small number or complete absence in the dataset.

Table 3. Types and number of fertilizers applied in the watersheds.

Fertilizer	Fertilizer Use by Number of Respondents	
	Sangharus Watershed	Sekampung Hulu Watershed
Urea	63	62
Phonska	44	54
Mutiara	7	8
TSP	1	3
SP-36	0	5
ZA	0	2
KCl	0	1

Legend: TSP, triple super phosphate; SP-36, super phosphate (super *fosfat*); ZA, ammonium sulfate (*amonium sulfat*).

Table 4. Urea, mutiara, and phonska applications in the Sangharus and Sekampung Hulu watersheds.

Fertilizer	Watershed	Application Rate Mean ± SD (kg/ha)	*p* Value
Urea	Sangharus Sekampung Hulu	166.8 ± 131.8 120.3 ± 122.1	0.002 *
Mutiara	Sangharus Sekampung Hulu	94.7 ± 140.9 48.9 ± 38.5	0.908
Phonska	Sangharus Sekampung Hulu	122.1 ± 80.9 109.3 ± 82.6	0.21

* Significant *p* value 0.01. All the tests were conducted by Mann-Whitney U-test.

The annual schedule of fertilizer application had varied between the farmers (Figure 5). The recommendation for minimum fertilizer application is twice a year at the beginning and end of the rainy season [27]. However, most farmers applied fertilizers once a year rather than twice a year. Altering the timings at which fertilizers are applied can have large impacts on stream water quality. Fertilizers applied in the middle of the rainy season are likely to degrade water quality, while splitting fertilizer application between the beginning and end of the rainy season is beneficial, as coffee trees have a longer duration to absorb nutrients. Furthermore, precipitation at the beginning and end of the rainy seasons is typically lower in intensity compared to that in the middle of the rainy season, allowing for lower fertilizer concentrations in surface runoff.

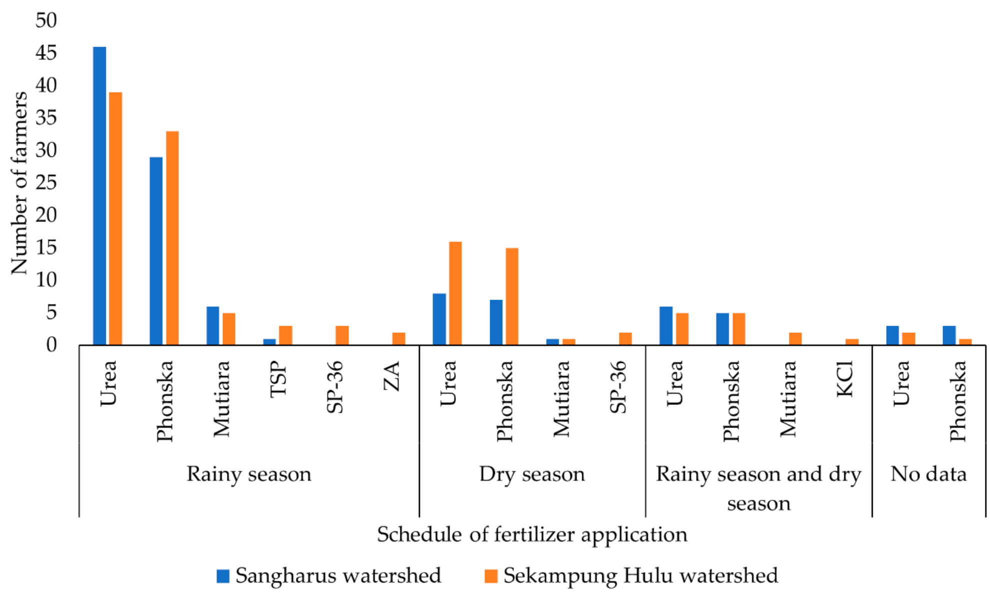

Figure 5. Seasonal schedule of fertilizer application in the Sangharus and Sekampung Hulu watersheds based on the number of farmers.

4. Discussions

4.1. Fertilizer and Land Use Effects on Water Quality Characteristics

The concentration of NO_3 was significantly higher in the Sangharus River relative to the Sekampung Hulu River. This trend correlates with urea fertilizer application. Farmers apply nitrogen fertilizers to increase coffee bean quality [12]. Farmers in the Sangharus watershed applied significantly higher amounts of urea fertilizer (166.8 kg/ha) relative to the Sekampung Hulu watershed (120.3 kg/ha). Higher concentrations of NO_3 and nitrogen in the stream water of watersheds in the Czech Republic, Germany, and China have been linked to fertilization in agricultural land [13,15].

The application of phonska and mutiara fertilizers did not statistically vary between both watersheds (Table 4) but K, Ca, Mg, PO_4, and SO_4 were significantly higher in the Sangharus River relative to the Sekampung Hulu River (Table 1). However, the fertilizer doses of phonska and mutiara fertilizers in the Sangharus watershed (122.1 kg/ha and 94.7 kg/ha) were slightly higher than the those in the Sekampung Hulu watershed (109.3 kg/ha and 48.9 kg/ha). Shade coffee agricultural fields in the Sangharus watershed covered 66.3% of the total land use, which was significantly higher than in the Sekampung Hulu watershed (34.3%). As such, the agricultural fields in the Sangharus watershed required higher levels of fertilizer application to maintain agricultural fertility. Higher concentrations of SO_4 in agricultural lands have been associated with higher fertilizer application [28]. Mg concentrations have also been correlated with agriculture land use [29] due to fertilizer application.

4.2. Additional Factors Controlling Stream Water Quality

Parent material can also influence water quality in the Sangharus River by increasing K, Ca, Mg, and Na concentrations. As the Sangharus watershed predominantly consists of larger basaltic andesitic tuff, chemical weathering of this parent material can release higher amounts of K, Ca, Mg, and Na nutrients to the rivers in this watershed [30].

The concentration of Si in the Sangharus River varied from 20.9 to 36.4 mg/L compared to 12.1 to 19.7 mg/L in the Sekampung Hulu River, with peak concentrations in the dry season. Research in Java in Indonesia demonstrated higher Si availability in areas with parent material consisting of tuff and volcanic ash rather than clay sediment [31]. The parent material in the Sangharus watershed is dominated by 62.3% basaltic andesitic tuff relative to 57.8% basaltic andesitic tuff in the Sekampung Hulu watershed, which is likely a cause of the higher observed Si concentrations in the Sangharus River. Furthermore, pumice tuff—which is high in SiO_2 [32]—contributed 32% of the parent material in the Sangharus watershed, while the contribution of pumice tuff in the Sekampung Hulu watershed was 30.1%.

In this study, the Fe concentrations in the Sekampung Hulu River were significantly higher than those in the Sangharus River (Table 1). Al concentrations in both rivers were not significantly different but the concentrations were slightly higher in the Sekampung Hulu River. The soil pH in the Sekampung Hulu and Sangharus watersheds was found to be acidic, ranging 4.18–5.11 [9]. Acidic soil influences the mobility of Al and Fe cations in soil. Al and Fe concentrations are derived from the weathering of parent material [33] and are higher in concentration in acidic relative to basaltic rocks [30]. Higher Fe and Al in the Sekampung Hulu River compared to the Sangharus River is likely due to the watershed's lower basaltic content relative to the Sangharus watershed (Figure 2). Additionally, the higher Al and Fe concentrations also result from erosion [34], which is supported by higher concentrations of total sediment solids in the Sekampung Hulu River relative to the Sangharus River [18].

Anthropogenic activities in the Sekampung Hulu and Sangharus watersheds also affect water quality because people use streams for washing, bathing, and toilet facilities. In addition, human population density influences NO_3 and Cl concentrations through the amount of human waste. Mayo et al. [35] have stated that human waste could contribute to the NO_3 load in the river, while Cl concentrations in rivers could be influenced by human waste, fertilizer, livestock waste, and seawater aerosols [36]. In particular, treated wastewater has been found to influence Cl concentrations in stream water [37]. As sodium chloride (NaCl) is a significant food ingredient, chlorides tend to accumulate in stream water via human waste. Furthermore, there are no human waste treatment facilities in the two watersheds, and thus human waste is directly transferred to the rivers. The NO_3 and Cl concentrations are significantly higher in the Sangharus River compared to the Sekampung Hulu River, possibly due to the higher population in the Sangharus watershed relative to the Sekampung Hulu watershed as the Sangharus watershed has a larger area of private land. Furthermore, Cl concentrations in rivers are also influenced by precipitation derived from seawater aerosols, as regions closer to the ocean tend to have higher Cl concentrations in precipitation relative to mid-continental regions [38]. The relative proximity of the Sangharus watershed to the sea (56 km) compared to the Sekampung Hulu watershed (72 km) might be the cause of the higher Cl concentrations in the Sangharus River.

4.3. Trends in Seasonal Water Quality Characteristics

The impact of agricultural land use on water quality can vary between the rainy and dry seasons [39,40]. The concentration of NO_3 in stream water depends both on the amount of runoff and the rate of fertilizer application in agricultural land [41]. The concentration of NO_3 is typically higher in the rainy seasons [40] due to increased runoff. Urea fertilizer application in both watersheds is predominantly scheduled during the rainy season, which further adds to the increased NO_3 concentrations in stream water (Figure 5). Because of less runoff, the concentration of NO_3 was lowest during the dry season in both the Sangharus and Sekampung Hulu Rivers at 0.58 and 0.23 mg/L, respectively, which is in agreement with previous research in Tanzania [42]. Furthermore, lowered NO_3 concentrations during the dry season influence biological activity and denitrification processes, which further reduces NO_3 concentrations [43].

The concentration of PO_4 in both rivers was significantly higher in the dry season (Figure 4, Table 2). This observation is also consistent with high phosphate values reported during the dry season in Kenya [44]. Higher PO_4 concentrations may be due to lower water discharge and therefore lower dilution of PO_4 during the dry season [45]. By contrast, the dilution effect during the rainy season reduces PO_4 concentrations. The dilution effect during the rainy season also influences the concentrations of K, Ca, Mg, Cl, Na, and Si, which were also lower in the rainy season relative to the dry season in both rivers.

SO_4 concentrations in the Sangharus River were lower in the rainy season as well, which was likely caused by the dilution effect under high discharge. By contrast, SO_4 concentrations in the Sekampung Hulu River showed no significant difference between the rainy and dry seasons. The lack of variability in sulfate concentrations may be due to the larger variety of fertilizers applied in the Sekampung Hulu watershed (phonska, SP-36, and ZA), which include fertilizers containing sulfur. Thus, SO_4 concentrations during the rainy season are likely to become less diluted in the Sekampung Hulu River.

EC was higher during the rainy season, which was likely due to higher nitrate fertilizer application and increased runoff from agricultural land. Yakovlev et al. [46] have showed a correlation between NO_3 concentration and EC. Similar observations in EC trends were also reported in a previous study [40] that showed that EC was higher in the rainy season compared to the dry season. Water temperature in the Sangharus River was lower in the dry season compared to the rainy season, possibly because of groundwater effects. Silva et al. [47] have stated that the dry season has lower stream water temperature than the rainy season predominantly because of groundwater contributions.

It is likely that the lower water temperatures during the dry season in this study increased the DO levels in the stream water [48], as oxygen is more soluble in colder temperatures. Gandaseca et al. [49] have stated that oxygen dissolves more easily in water with low temperatures compared to warm water. We observed lower water temperatures and higher DO concentrations in the dry season in both the Sangharus and Sekampung Hulu Rivers. The pH was higher in the rainy season (8.19 in the Sangharus River and 7.80 in the Sekampung Hulu River) compared to that in the dry season (6.37 in the Sangharus River and 6.01 in the Sekampung Hulu River) and was likely influenced by increased pollution (such as detergent or washing powder) from human activities in the study area under high discharge/runoff.

4.4. Water Quality Status and Recommendations to Improve Water Quality

The converting of NO_3 to NO_3-N resulted in 0.24 mg/L and 0.13 mg/L NO_3-N in the Sangharus River and the Sekampung Hulu River, respectively. These NO_3-N concentrations were below the United States Environmental Protection Agency (USEPA) national primary drinking water standard [50] and the recommended level from the Ministry of Health of the Republic of Indonesia for sanitation hygiene of 10 mg/L [51]. However, Fe concentrations of 0.53 mg/L in the Sekampung Hulu River exceeded the maximum national secondary USEPA level of 0.3 mg/L [50]. Furthermore, the Al concentrations in both the Sangharus and Sekampung Hulu Rivers were 0.43 mg/L and 0.93 mg/L, respectively, and exceeded the national secondary USEPA's maximum recommended Al level of 0.05–0.2 mg/L.

The adoption of soil conservation techniques could reduce contaminant flow to water streams, as Al and Fe concentrations are influenced by soil erosion [34]. The application of soil conservation practices such as cover cropping, contour cropping, terracing, and agroforestry could minimize soil erosion [52–55] in land use shade coffee and young coffee plantations. Furthermore, the application of soil conservation practices could also reduce nutrient transport to water streams. For example, riparian buffers have been found to increase nutrient retention in watersheds and minimize nutrient transport to rivers [56]. Therefore, the adoption of soil conservation practices in this study area is necessary to prevent nutrient loss to rivers and minimize metal contamination. Additionally, proper timing of fertilizer application for coffee trees should be considered because application in the middle of the rainy season had higher rainfall intensity, which can promote higher surface runoff. Splitting fertilizer in the beginning and end of the rainy seasons can minimize nutrient losses to stream water. Gildow et al. [57] have stated that the timing of application of seasonal fertilizers reduces phosphorus load to water bodies. The optimal timing of N fertilizer application could reduce NO_3-N loss to stream water [58]. Timing of N fertilizer, if adjusted to the highest N requirements of the crop, that is, the stage before fruit filling, could decrease N application routines without a decline in the yields of coffee beans [59]. Implementation of effective land management policies on the watershed scale is necessary to prevent water quality degradation in the Batutegi Dam in order to improve water supply for irrigation and drinking water downstream.

5. Conclusions

Our study has revealed seasonal water quality characteristics and possible reasons for the observed characteristics in adjacent two watersheds for the first time. Although the study sites were located close to each other, they showed different water quality characteristics. The human activities of fertilizer application and young coffee plantations, as well as the natural processes of geological characteristics, influenced the differences between the two watersheds. Based on the results, the Sangharus River contained higher amount of nutrients than the Sekampung Hulu River due to higher fertilizer application amounts in the watershed. Moreover, geological characteristics played an important role in the Sangharus River in determining its water quality characteristics because the watershed consisted of higher basaltic andesite tuff compared to the Sekampung Hulu watershed. Seasonal water quality measurements and questionnaire surveys to local farmers revealed that NO_3 concentrations in both watersheds were higher in the rainy season to correspond with the annual schedule and total amounts of fertilizer application in the watersheds. Despite the application of fertilizers, NO_3 levels remained below the recommended water quality standard. However, Al and Fe levels in stream water exceeded the recommended level for drinking water, which was likely due to soil erosion from improper land management in the Sekampung Hulu watershed.

To protect the environment from the adverse effects of soil erosion and nutrient loss, soil conservation practices should be implemented in the study area such as cover cropping, contour cropping, terracing, and agroforestry. Agroforestry practices in coffee plantations have already been applied in several sites; however, the practice of planting young coffee plantations needs to be implemented for effective soil conservation practices. Moreover, application of soil conservation practices in shade coffee plantations can provide more environmental benefits to reduce surface runoff.

Policy makers are required to develop regulations for a sound water environment based on the different characteristics of the two watersheds. The policies should consider background reasons to determine water quality characteristics in the area. In addition, farmers are recommended to adopt soil conservation practices to prevent sustainable land from experiencing reducing nutrient loss and erosion.

This study was conducted for only a year, with missing information for a five-month duration. A one-year period of research is too short to investigate all aspects of a water environment. Thus, long-term research on water quality should be conducted to understand comprehensive aspects of water characteristics across dry and wet years. In addition, we could not conduct studies on water quality in the upper and middle watersheds due to low accessibility. To determine effective management strategies, further studies on the upper and middle reaches of the watersheds are necessary for a holistic view of the watershed water chemistry characteristics. In addition, the number of respondents in our questionnaire survey was minimal according to the total number of famers in the study area. To increase the accuracy of the information regarding the schedule and the amount of fertilizer applied, the number of respondents in questionnaire survey needs to be higher.

In recent years, new technology of artificial intelligence (AI) and machine learning tools have begun to be used for water quality forecasts [60–64]. These tools are very robust; however, for obtaining good results, it is very important to accumulate local information for a water quality database. By conducting our kind of research in ungauged and poorly gauged watersheds continuously, AI and machine learning based analyses can be conducted to implement water resources management, protect fresh water resources, and develop future conservation plans regarding these watersheds.

Author Contributions: R.D.Y. conducted the questionnaire survey and statistical analyses and collected necessary information from the local sites. H.S. coordinated the research activities and conducted water quality analyses. S.B.Y. managed the water sampling in the target rivers and supported the gathering of site information. T.M. provided suggestions for interpreting results. All members collaborated to discuss the results and develop the manuscript.

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