

Benthic Macroinvertebrates Diversity as Bioindicator of Water Quality of Some Rivers in East Kalimantan, Indonesia

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Research Article

Benthic Macroinvertebrates Diversity as Bioindicator of Water Quality of Some Rivers in East Kalimantan, Indonesia

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The objectives of this study were to clarify and evaluate the water quality of a number of rivers in East Kalimantan province of Indonesia. For this purpose, our study successfully utilized the benthic macroinvertebrates diversity as well as physical-chemical parameters of river's water. For instance, based on the values of Average Score per Taxon (ASPT) and the National Sanitation Foundation-Water Quality Index (NSF-WQI), Karang Mumus River was categorized as polluted with *Chironomus* sp. and *Melanoides tuberculata* as codominant taxa. In addition, Jembayan River exhibited doubtful or moderate quality containing *M. tuberculata* and *A. parvula* as codominant taxa. However, Pampang River was found to be the cleanest river with Odonata and Baetidae families as codominant taxa.

1. Introduction

As open water ecosystems, rivers get strongly influenced by the surrounding environment. Water quality of a river is influenced by several parameters like land use, settlement patterns, farming, and industrial activities around that river [1]. For example, rivers in East Kalimantan province of Indonesia are also facing the problems with recent activities of residents like coal mines construction and oil-palm plantations exactly along the river banks. These activities destroy the water quality of rivers and consequently lead to a certain change in the benthic macroinvertebrates community structure. The study of biodiversity, species abundance, dominance, and distribution of macroinvertebrate fauna to determine the extent of changes in their structure and composition associated with water quality changes therefore should be conducted [1, 2].

Studying macroinvertebrate diversity is one of the most effective and inexpensive ways to estimate the ecological quality of the waters [2, 3]. For instance, measurement of the physical and chemical properties of water can also be utilized to estimate its quality but such measurements cannot exactly represent the actual state of the waters. Therefore it is necessary to combine physical, chemical, and biological

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evaluation along with other monitoring methods to provide a comprehensive picture of environmental water quality [4, 5]. Biological monitoring using macroinvertebrates has been found accurate and advantageous compared with using other organisms because macroinvertebrates are extremely sensitive to organic pollutants, widely distributed, and easy and economical to sample [2, 6].

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Research reports on the use of macroinvertebrates to assess the water quality in aquatic ecosystems have been extensively published by several researchers [2, 3, 6–14]. For example, the use of the ecological index and the macroinvertebrate biotic index has been widely developed in America and Europe [3, 14–16]. On the other hand, to the best of our knowledge limited studies were found in literature utilizing the application of the biotic indexes to evaluate the river water quality in Indonesia and particularly in Kalimantan. Therefore, we envisioned first ever use of macroinvertebrates to assess the water quality in Indonesia to clarify and confirm the presence of harmful pollutant in Indonesian river water. For this purpose, we conducted this study to analyze and observe the changes in water quality of three rivers in East Kalimantan, Indonesia, and successfully utilized macroinvertebrates as a bioindicator of water quality. Our approach was

TABLE 1: Detailed information of sampling stations.

River's name	Sampling station	Geographical position	Surrounding environment
Karang Mumus	K-1	00°30.491'S and 117°09.426'E	Populated area, population density: 12,785 people/km ² , harbor with motor ship activities, usage of river for bathing, washing, and latrines
	K-2	00°29.073'S and 117°09.064'E	
	K-3	00°28.238'S and 117°09.442'E	
Jembayan	J-1	00°33.138'S and 117°01.100'E	Activity of coal-mining and oil-palm plantation, population density: 66 people/km ²
	J-2	00°33.057'S and 117°00.790'E	
	J-3	00°33.085'S and 117°00.574'E	
Pampang	P-1	00°19.927'S and 117°11.555'E	Natural habitat, activity of oil-palm plantation, population density: 397 people/km ²
	P-2	00°20.076'S and 117°11.874'E	
	P-3	00°19.850'S and 117°11.132'E	

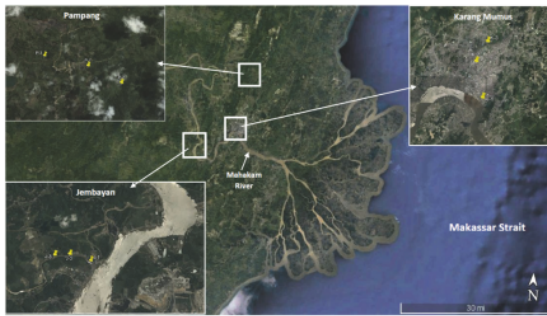


FIGURE 1: Sampling locations of benthic macroinvertebrate and water quality parameters (source: Google Earth Pro 7.3.1.4507, Build Date February 6, 2018).

to determine current status of these rivers using the Shannon-Weaver diversity index [17], Average Score per Taxon (ASPT) [18], and the National Sanitation Foundation-Water Quality Index (NSF-WQI) [19].

2. Materials and Methods

2.1. Study Area. The study was conducted mainly on three rivers of East Kalimantan with the help of three sampling stations of each river (Figure 1). Selection of the sampling stations was based on the possible pollutant loads and the magnitude of human activities along the rivers. Detailed location information of these sampling sites, and the latitude and longitude of all stations, are presented in Table 1.

2.2. Sampling and Identification of Benthic Macroinvertebrates. Minimum of 100 individuals of benthic macroinvertebrates were collected, stored, and transported by each sampling station [20, 21]. Furthermore, sampling of macroinvertebrates was conducted in December 2015 (rainy season) and June 2016 (dry season). Samples of benthic macroinvertebrate were collected using Surber net (30 × 30 cm²) for rocky substrate, Ekman-grab (25 × 25 cm²) for muddy substrate, and kick net for habitat containing dense aquatic plants. Organisms collected were rinsed with water, separated from debris and

sediment using forceps, and finally preserved in 70% ethanol. All macroinvertebrates were identified to the family level using appropriate references [22–35].

2.3. Water Quality Measurement. A wide range of water quality parameters were measured at all sampling locations, with key parameters being dissolved oxygen (DO), pH, biological oxygen demand (BOD), temperature, total phosphate, nitrate, turbidity, and total dissolved solid (TDS). The analytical methods of water quality parameters were followed by the Standard Method for the Examination of Water and Wastewater [35].

2.4. Data Analysis. After identification and enumeration of macroinvertebrates, we then calculated the diversity index (H), the dominance index (C), the Evenness index (E), the important value index (IVI) of each species, and the Average Score per Taxon (ASPT).

The Shannon and Weaver [17] diversity index was estimated by the following equation:

$$H = - \sum \left(\frac{n_i}{N} \right) \ln \left(\frac{n_i}{N} \right), \quad (1)$$

where n_i is number of individuals of i^{th} species, N is total number of individuals, \ln is the natural log, and \sum is the sum of the calculations.

The Evenness index (E) is computed from Pielou's index [36]:

$$E = \frac{H}{\ln S}, \quad (2)$$

where H is Shannon-Weaver diversity index and $\ln S$ is natural log of the total number of species recorded.

In addition, Simpson's dominance index [37] was calculated by the following equation:

$$C = \sum \left(\frac{n_i}{N} \right)^2 \quad (3)$$

Importance value index (IVI) was calculated by [38]

$$\text{IVI} = \text{Relative density} + \text{relative frequency} + \text{relative dominance}, \quad (4)$$

TABLE 2: New weight score (W_i) for 8 parameters on NSF – WQI [39].

No.	Parameter	Original weight score	Modified weight score
1	DO	0.17	0.20
2	pH	0.11	0.13
3	BOD	0.11	0.13
4	Temperature	0.10	0.12
5	Total phosphate	0.10	0.12
6	Nitrate	0.10	0.12
7	Turbidity	0.08	0.10
8	Total solid	0.07	0.08
9	Fecal coliform	0.16	0.16
Total		1	1

where relative density = (density of a specie/total density of all species) \times 100, relative frequency = (frequency of a specie/total frequency of all species) \times 100, and relative dominance = (dominance of a specie/total dominance of all species) \times 100. The value of IVI may range from 0 to 3.00 (or 300%). This value is referred to the importance percentage. The importance value or the importance percentage gives an overall estimation of the influence of importance of a species in the community.

Furthermore, the Average Score per Taxon (ASPT) represents the average tolerance score of all taxa within the community and ASPT value can be calculated by dividing the Biological Monitoring Working Party (BMWP) over the number of families represented in the sample. The BMWP system considers the sensitivity of invertebrates to pollution; families are assigned a score which is the sum of the values for all families present in the sample. Values greater than 100 are associated with clean streams [40, 41]. On the other hand, scores of heavily polluted streams are less than 10 [41]. The ASPT value equals the average of the tolerance scores of all macroinvertebrate families found and ranges from 0 to 10. The index values for ASPT are classified into four categories as follows (>6: clean water; 5-6: doubtful quality; 4-5: probable moderate pollution; <4: probable severe pollution) [16].

Also, National Sanitation Foundation-Water Quality Index (NSF-WQI) is often used to determine the level of water quality based on nine parameters such as BOD, DO, nitrate, total phosphate, temperature, turbidity, total solids, pH, and fecal coliform. In this study, eight parameters were applied without fecal coliform; hence, there was a modification of weight as shown at Table 2. The modification was allowed if the water quality parameter number was reduced and modified total weight score remained 1. Weight score modification of each parameter was proportional to its original weight score [39]. Furthermore, the weight score of each parameter (W_i) was multiplied by the subindex value of each parameter (L_i). For obtaining score of subindex, we used the online NSF-WQI Calculator at www.water-research.net/watqualindex/waterqualityindex.htm. Finally, scores from all of parameters are summed up using the following formula:

$$NSF-WQI = \sum_{i=0}^n W_i L_i, \quad (5)$$

where NSF-WQI is Water Quality Index Score, W_i is the weight score of i^{th} parameter, and L_i is the subindex value of i^{th} parameter.

The index of water quality (NSF-WQI) values is classified into five categories as follows: 0-25: very bad; 26-50: bad; 51-70: medium or moderate; 71-90: good; >91-100: excellent [19]. A Principal Component Analysis (PCA) with a focus on sampling site was performed to examine the relationships between biotic measures used (H, C, E, and ASPT) and physical-chemical variables (BOD, DO, nitrate, total phosphate, temperature, turbidity, total solids, and pH) [42, 43]. The PCA was carried out using the open source software (PAST program Version 3 b7).

3. Results and Discussion

The diversity index (H), the dominance index (C), and the Evenness index (E) are frequent tools to predict the conditions of an aquatic environment based on the biological components. Figure 2 shows that the highest H value of benthic macroinvertebrates in December 2015 was recorded at P-3 (2.602) and the lowest H at K-2 (0.383). The highest value of C was noted at K-2 (0.776) and lowest at P-3 (0.09). The highest E was found at J-2 (0.982) and the lowest E at K-2 (0.552). In June 2016, the highest H value was observed at J-2 (1.941) and the lowest H at K-2 (0.2). The highest C was recorded at P-1 and the lowest C at K-2. The highest E was noted at J-1 and lowest E at K-2 (Figure 3).

In December 2015, the highest number of taxa (taxa richness) of benthic macroinvertebrates was found in the Pampang River (21 taxa) and the lowest in the Karang Mumus River (4 taxa) (Figure 4). In June 2016, the highest macroinvertebrate taxa was found in the Pampang River (14 Taxa) and lowest in the Karang Mumus River (6 Taxa) (Figure 4).

The important value index (IVI) of each species is presented in Table 3. During sampling in December 2015, *Chironomus* sp. and *Melanoides tuberculata* were codominant taxa in Karang Mumus River. Four taxa: *Melanoides tuberculata*, *Macrobrachium* sp., *Acentrella parvula*, and *Chironomus* sp., were codominant in Jembayan River. In Pampang River, the codominant taxon was *Coenagrion* sp. During sampling period of June 2016, *Melanoides tuberculata* and *Chironomus* sp. were codominant in Karang Mumus River.

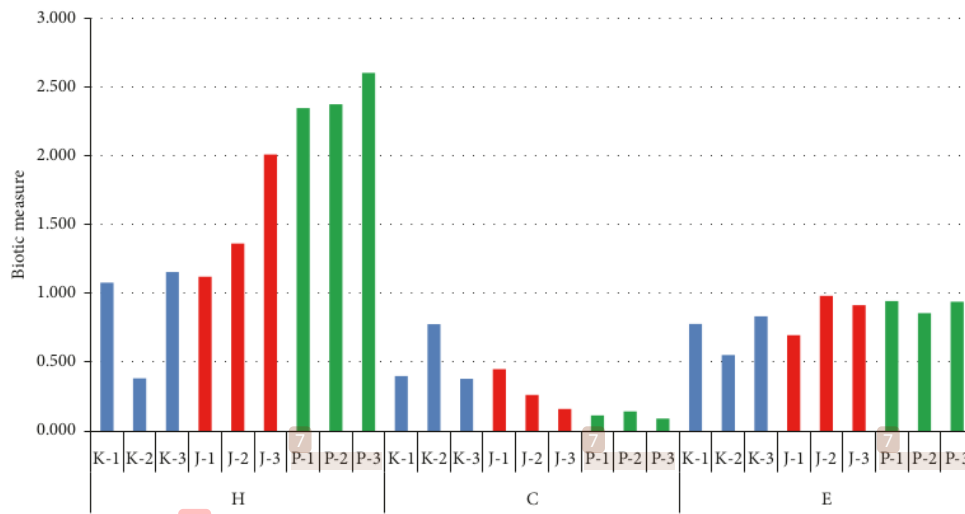


FIGURE 2: Diversity Index (H), Dominance Index (C), and Evenness Index (E) in December 2015.

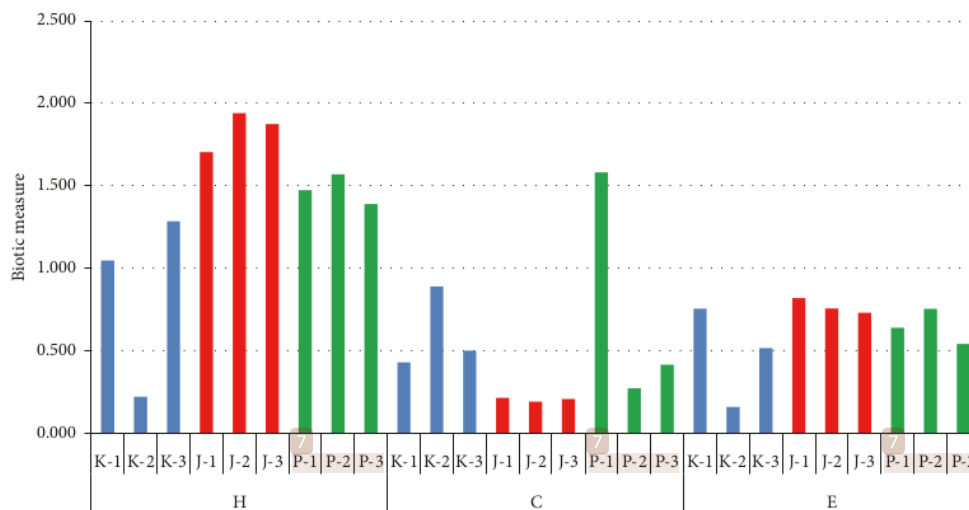


FIGURE 3: Diversity Index (H), Dominance Index (C), and Evenness Index (E) in June 2016.

In the Jembayan River, we noted that *Melanoides tuberculata*, *Acentrella parvula*, and *Baetis flavistriga* were codominant taxa. *Acentrella parvula* and *Baetis flavistriga* were also codominant taxa in Pampang River.

Water quality measurements based on biotic index (ASPT) are shown in Table 4. In December 2015, according to ASPT criteria, Karang Mumus River was in moderate to severe polluted category, Jembayan River in doubtful quality, and Pampang River in doubtful to clean quality. In June 2016, Karang Mumus River was in doubtful to severe polluted category, Jembayan River was in doubtful quality, and Pampang River was in clean quality.

Water quality parameters in December 2015 and June 2016 of each station are presented in Tables 5 and 6. Based on the WQI values, in December 2015, the water quality of Karang Mumus River was in bad condition, and Jembayan and Pampang Rivers were in moderate condition, respectively (Table 5). In June 2016, Karang Mumus, Jembayan, and Pampang Rivers were in moderate condition (Table 6).

According to the PCA, during the rainy season (October 2015), sampling sites J-1, J-2, and J-3 (Jembayan) show a strong affinity to high ASPT, pH, DO, and E values. Sampling sites P-1, P-2, and P-3 (Pampang) demonstrate a strong affinity to high H and nitrate values, while sampling sites K-1, K-2,

TABLE 4: Biotic index (ASPT) of benthic macroinvertebrates in all sampling locations.

Sampling station	Biotic Index (ASPT)	
	December 2015	June 2016
K-1	5.00	3.00
K-2	4.00	4.00
K-3	3.50	5.80
J-1	5.67	5.25
J-2	6.00	6.00
J-3	5.70	5.38
P-1	6.69	6.10
P-2	5.87	6.00
P-3	5.93	6.20

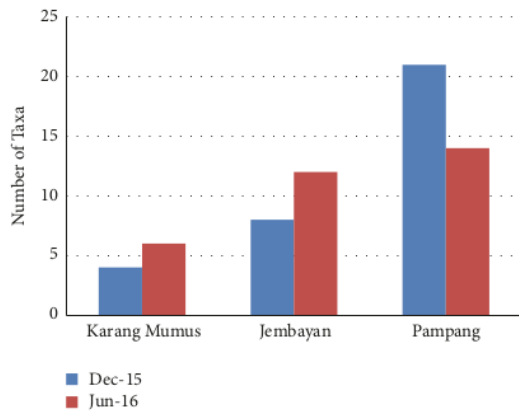


FIGURE 4: Taxa Richness of benthic macroinvertebrate.

and K-3 (Karang Mumus) present a strong affinity to high values of C, BOD, and TDS (Figure 5). In June 2016 (dry season), Jembayan River (J-1, J-2, and J-3) shows a strong affinity to DO, temperature, TDS, H, and E; Pampang River (P-1, P-2, and P-3) presents a strong affinity to pH, phosphate, nitrate, and ASPT; and Karang Mumus (K-1, K-2, and K-3) demonstrates a strong affinity to turbidity, BOD, and C (Figure 6).

In December 2015 (rainy season), 16 taxa of macroinvertebrates were noted in P-3. The high diversity of macroinvertebrates at P-3 was supported by moderate water quality (highest WQI) (Table 5) during this period. According to PCA, a strong affinity to high H (diversity index) and nitrate was also shown by Pampang River (Figure 5). Dense riparian vegetation found on the banks of the river may provide high nutrient sources for macroinvertebrates. These plants also play a prominent role in the remediation of contaminated water by pesticides and detergent active ingredients before entering the rivers [44]. In contrast, station K-2 had very low diversity of macroinvertebrate. The intense human activities (for examples the uses of this river for bathing, washing, and latrines) which produced the high BOD and TDS values (Figure 5) and lack of riparian vegetation near this station were probably major causes of the very low diversity of

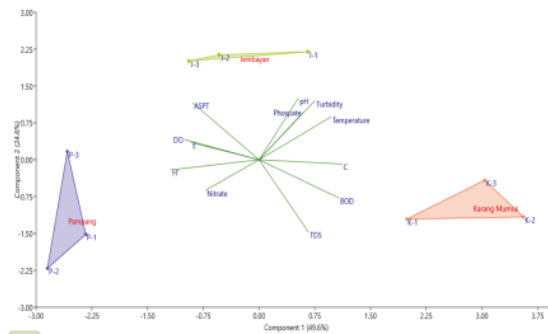


FIGURE 5: Diagram of sampling sites by Principal Component Analysis (PCA), based on the biotic measures and physical-chemical variables in East Kalimantan of Indonesia in December 2015.

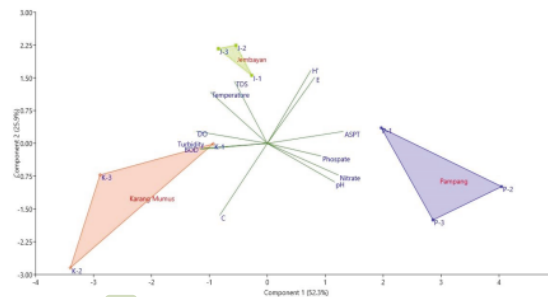


FIGURE 6: Diagram of sampling sites by Principal Component Analysis (PCA), based on the biotic measures and physical-chemical variables in East Kalimantan of Indonesia in June 2016.

macroinvertebrates in this station. We noted during our survey in December 2015 that water hyacinth (*Eichhornia crassipes*) was more dominant in this station.

In both December 2015 and June 2016, *M. tuberculata* and *Chironomus* sp. were codominant taxa in Karang Mumus River. *Chironomus* sp. is a species indicator of waters contaminated by high load of organic waste. In fact, it can live in waters even at low oxygen levels [45, 46]. The high dominance

TABLE 5: Water quality parameters in December 2015 in each station.

No.	Parameter	Karang Mumus			December 15			Pampang					
		K-1	K-2	K-3	Mean ± SD	J-1	J-2	J-3	Mean ± SD	P-1	P-2	P-3	Mean ± SD
1	Dissolved Oxygen	5.97	6.05	3.97	5.33±1.18	7.23	7.15	7.17	7.18±0.04	7.35	7.33	7.4	7.36±0.04
2	pH	5.6	5.55	5.19	5.45±0.22	5.86	5.98	5.65	5.83±0.17	3.53	3.7	5.98	4.40±1.37
3	BOD	79.81	66.71	61.27	69.27±9.53	1.27	0.1	0.96	0.78±0.61	3.35	2.57	0.1	2.01±1.70
4	Temperature Change	30	29.81	29.97	29.93±0.10	29.7	29.92	29.38	29.67±0.27	27.13	25.54	25.61	26.09±0.90
5	Total Phosphate	0.28	0.16	0.68	0.37±0.27	0.58	0.12	0.66	0.45±0.29	0.05	0	0.11	0.05±0.06
6	Nitrates	0.1	0.04	0	0.05±0.05	0.38	0.43	0.15	0.32±0.15	0.38	1.8	0.14	0.78±0.89
7	Turbidity	15.2	20.3	32.6	22.70±8.94	33.6	39.9	18.6	30.70±10.94	2.46	1.19	2.23	1.96±0.68
8	TDS	245	258	270	257.67±12.50	104	103	96	101.00±4.36	216	214	102	177.33±65.25
	WQI = $\sum (Wi \times Ii)$	42.23	42.53	34.71	39.82±4.43	50.99	56.6	51.62	53.07±3.07	50.19	51.47	62.14	54.60±6.56
	Criteria	B	B	B	B	M	M	M	M	B	M	M	M

Note: B: bad; M: medium or moderate.

TABLE 6: Water quality parameters in June 2016 in each station.

No.	Parameter	Karang Mumus			June 2016 Jembayan			Pampang			
		K-1	K-2	K-3	J-1	J-2	J-3	P-1	P-2	P-3	Mean ± SD
1	Dissolved Oxygen	8.09	7.84	8.23	7.56	7.82	7.66	6.66	7	6.78	6.81±0.17
2	pH	7	7.01	7	6.9	6.9	7.01	7.39	7.4	7.4	7.40±0.01
3	BOD	1.11	1.98	1.54	1.26	1.49	1.68	1.03	1.05	1.04	1.04±0.01
4	Temperature Change	30	30	30	30	30	30	29	27	26.6	27.53±1.29
5	Total Phosphate	0	0	0	0.06	0.04	0.09	0	0.72	0.08	0.26±0.39
6	Nitrates	0.26	0.14	0.01	0.13	0.10	0.14	0.26	0.69	0.45	0.47±0.22
7	Turbidity	15.2	20.3	32.6	12.3	8.2	16.8	17.3	2.24	2.2	7.25±8.71
8	TDS	16	17.8	16.7	23.9	58.3	85.5	12	27	12	17.00±8.66
	WQI = $\sum (Wi \times Ii)$	63.04	60.07	60.79	62.76	63.64	61.73	63.36	60.39	66.16	63.30±2.89
	Criteria	M	M	M	M	M	M	M	M	M	M

Note: M: medium or moderate.

index indicates that the waters were instable causing imbalance of ecosystem. Under this condition, usually only certain types of organism like *Chironomus* sp. can survive because of their ability to tolerate the high organic contamination [45]. Some of Chironomidae larvae are efficient indicators of mesotrophic waters, and these are usually found at location having high decomposed organic matter. Thus, presence of the Chironomidae family (indicated by high percentage of IVI) reflected that the Karang Mumus River was in polluted category. Likewise presence of *Melanoides tuberculata* of the Thiaridae family is well known as a species that can tolerate the presence of low dissolved oxygen and high suspended particulate matter in river's water [46]. Gastropod especially *Melanoides* is very abundant in waters affected by agricultural waste even at low level of dissolved oxygen [47]. *M. tuberculata* is tolerant not only in oligotrophic ecosystems [45] but also in ecosystem contaminated by low level of organic matter [47]. *M. tuberculata* remains active at night, and it likes the temperature in the range of 18–32°C. *M. tuberculata* has an operculum that can protect itself from drought so that it can survive on dry land and high salinity [48, 49]. In addition, operculum also serves to increase their tolerance to toxic chemicals in the environment. So, these taxa are recommendable to be used as a bioindicator of polluted ecosystems [48, 49].

In both October 2015 and June 2016, *M. tuberculata* and *Acentrella parvula* were codominant taxa in Jembayan River. *A. parvula* (family of Baetidae) is also known as one of benthic macroinvertebrates which is intolerant to the contaminants. Therefore, Baetidae family can also be used as a bioindicator of low levels of organic matter contamination [50].

In October 2015, *Coenagrion* sp. (order: Odonata) and *A. parvula* were codominant organism in Pampang River. Odonata is a facultative or intermediate organism that can survive in moderate level of the environmental change. This group can survive in waters containing organic matter. However, they are quite sensitive to water quality degradation [46]. In June 2016, Pampang River is dominated by *Acentrella parvula* and *Baetis flavistriga*. These two taxa are insects from the Baetidae family which can serve as low organic pollutant bioindicators [50, 51]. During dry season (June 2016), it is most likely that Pampang River was contaminated by low level of organic matter due to the decreased water debit and decreased input of allochthonous materials into the water body.

Water Quality Index (WQI) serves as single index that describes water quality of certain location at certain time. In December 2015, according to the WQI values, Karang Mumus River was in poor water quality but in June 2016 it was improved to moderate quality (Tables 5 and 6). Meanwhile Jembayan and Pampang Rivers were found in moderate quality in both December 2015 and June 2016. Regarding the low value of WQI in October 2015 (rainy season) compared to June 2016 (dry season), we concluded that this can be flood water and run-off during the rainy season bringing allochthonous materials into the water body or from the resuspension of the sediment (autochthonous) materials. Similar effects were observed in Shiroro Lake [52] and Gbako River, Nigeria [53]. The accumulation of these materials in the

water body led to decreased water quality. Moreover, Karang Mumus is located near to populated area and harbor with intense loading-unloading and motor ship activities, and the low WQI in Karang Mumus River was also most probably due to all those activities. For Jembayan River, coal-mining activities and oil-palm plantations around this river are the potential activities which contribute to worsening the river water quality and benthic macroinvertebrate diversity. On the other hand, the potential sources affecting the water quality of Pampang River were oil-palm and pecan plantation activities along this river.

4. Conclusion

Based on the ASPT and WQI values, our study clarified and estimated that Karang Mumus River recently received certain pollutants and can be categorized as dangerously polluted river. In fact, macroinvertebrates in the river were dominated by *Chironomus* sp., and *Melanoides tuberculata* which are clearly indicated. On the other hand, Jembayan River was found to be of doubtful or moderate quality according to ASPT and WQI values with *M. tuberculata* and *A. parvula* as codominant taxa. Furthermore, Pampang River was the cleanest river based on ASPT and WQI values, and Odonata and Baetidae families were codominant in the river. These two families are quite sensitive to water quality degradation and only tolerant to low organic pollution. However, if organic pollution continues at this rate, the water of these rivers will become seriously harmful.

15 Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

6 The Permanent Address of Fatmawati Patang is Department of Biology, Faculty of Mathematics and Natural Science, Universitas Mulawarman, Kampus Gunung Kelua, Jl. Barong Tongkok, Samarinda, Indonesia.

22 Conflicts of Interest

The authors declare no conflicts of interest regarding the use of research contents and publication of this paper.

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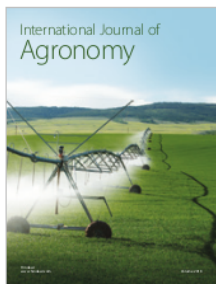
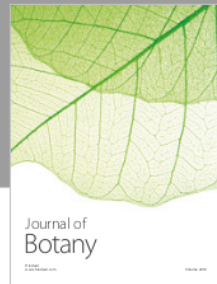
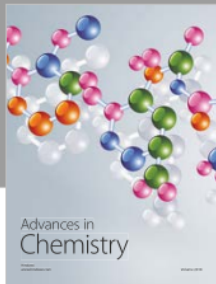
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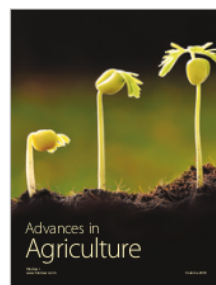
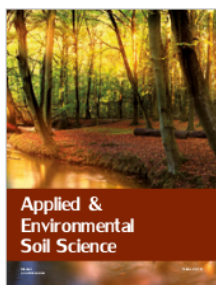
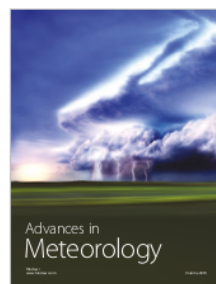
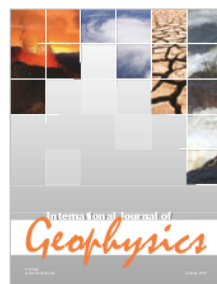
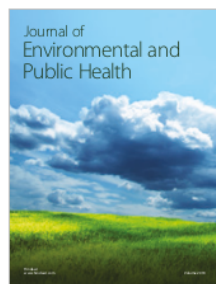
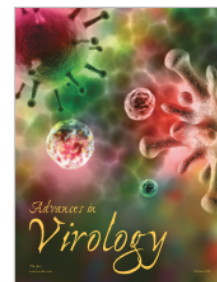
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