

# Community structure and diversity of benthic macroinvertebrates as bioindicators of water quality in some waterfall ecosystems, Bawean Island, Indonesia

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**Abstract.** Retnaningdyah C, Arisoesilaningsih E, Vidayanti V, Purnomo, Febriansyah SC. 2023. Community structure and diversity of benthic macroinvertebrates as bioindicators of water quality in some waterfall ecosystems, Bawean Island, Indonesia. *Biodiversitas* 24: 370-378. Bawean Island is a small island with a fairly dense population, so the need for water resources is quite high. On Bawean Island, several waterfalls have been found that have a hydrological function capable of supplying water continuously for drinking water, raw materials, agricultural irrigation functions and other daily activities that are very important for the people of Bawean Island. However, the quality of the waterfall ecosystem on Bawean Island has never been studied. This study aims to evaluate the water quality of some waterfall ecosystems on Bawean Island using the community structure and diversity of benthic macroinvertebrates as a complement to water physicochemical monitoring. This study used the Ex Post Facto method. The research was conducted at 6 waterfalls found on Bawean Island. The physicochemical quality of the water observed included air temperature, water temperature, pH, Dissolved Oxygen (DO), conductivity, Biochemical Oxygen Demand (BOD), nitrate, and Total Phosphate (TP). The quality of the benthic macroinvertebrate that had been monitored included Importance Value Index (IVI), taxa richness, total density, Shannon-Wiener Diversity Index (H'), and an ecological index, namely the Family Biotic Index (FBI). The monitoring data then be used to analyze the interaction between water quality profiles and macroinvertebrates profiles by conducting Principal Component Analysis (PCA). Based on the results obtained, the water quality in the Bawean Island waterfall, according to the FBI index categorized as Good-Excellent. According to Indonesian government regulation (PP. No. 22 of 2021), some parameters of water quality in Putri and Suwari waterfall were classified as class 2, which can be used for water tourism infrastructure, fish farming also agriculture and the others are categorized as class 3 which is only used for fish farming and agriculture. To maintain good water quality, the waterfall manager needs to control human activities around the waterfall's ecosystem.

**Keywords:** Bawean, macroinvertebrate, physicochemical, waterfall

## INTRODUCTION

The Bawean Islands are located in the Java Sea, between S5°43' until S5°52' latitude and E112°34' until E112°44' longitude, about 164 from Java Island (Armono et al. 2018). These volcanic islands consist of a big island, Bawean, and several satellite islands, including Batukebo, Birangbirang, Cina, Karangbila, Selayar, Nusa, Noko, Manukan, Gili Noko, and Gili (Trimanto et al. 2016; Armono et al. 2018; Hendratno and Khoir 2019). Bawean Islands, which is administratively part of Gresik Regency, has more than 68,000 people, most of whom stay on the main island, Bawean (Trimanto et al. 2016; BPS Kabupaten Gresik 2021). Geographically, Bawean islands is surrounded by sea (Hendratno and Khoir 2019). This similar condition limits the freshwater availability of high volcanic islands. The surface water availability is more vulnerable than groundwater because of increased runoff rates due to steep slopes and shallow base rock. In Bawean Island, the freshwater sources to meet the people's needs

come from groundwater, such as springs, and surface water, such as lakes and waterfalls (Trimanto et al. 2016).

As surface water is exposed, it is more likely threatened than groundwater sources. Human population, land use-land cover change, and surrounding vegetation are some factors that affect surface water condition (Grinevskii 2014; Mezgebu et al. 2019; Lei et al. 2021). Furthermore, the population growth rate of Bawean is only 2% within two decades. On the other hand, a tourist visiting Bawean rises gradually from time to time (UPT Dinas Pariwisata Gresik) and can increase anthropogenic activities that lead to water shortage and water pollution (Trimanto et al. 2016; Liyanage and Yamada 2017; Kanownika et al. 2020). For example, land use change causes declining water infiltration and increases erosion, landslides, sedimentation, and surface runoff (Gao et al. 2017; Hasan et al. 2020). Agricultural activities around aquatic ecosystems to fulfill tourist needs also impact decreasing water quality due to residues of chemical compounds such as synthetic fertilizers and pesticides (Retnaningdyah and Arisoesilaningsih 2019a). Thus, it can be concluded that

the decline in the water quality of surface water ecosystems is largely determined by poor land management and environmental pollution due to human activities (Liyanage and Yamada 2017). The consequences of these changes in environmental quality are (1) disturbances to the conservation of aquatic ecosystems and (2) a decrease in the use value of the waters, which in turn can have a negative impact on human health (Mofor et al. 2017).

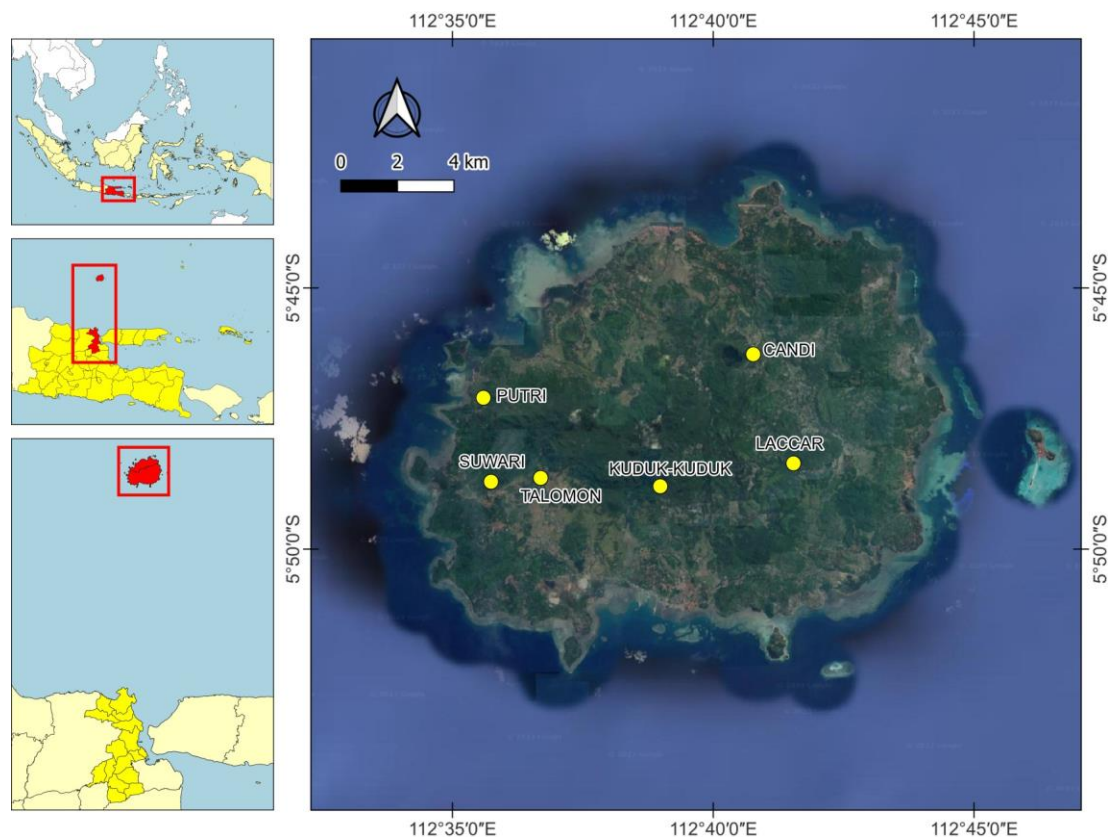
Mitigation efforts are needed to conserve surface water sources. Water quality monitoring using physicochemical and biological methods was developed as a complementary mitigation step (Setyono and Himawan 2018). Physicochemical parameters can be used to measure water quality while biological methods describe the effects of several environmental changes in the short and long term (Retnaningdyah et al. 2017; Retnaningdyah and Arisoesilaningsih 2019b; Chazanah et al. 2020). The use of benthic macroinvertebrates as one of the bioindicators and biological methods is based on its response to vary of environmental variables. Basyuni et al. (2018) and Maida et al. (2018) show that benthic macroinvertebrates are used as indicators because of their limited movement, sensitivity level towards environmental changes, and long development period in the aquatic environment. To complete the water quality assessment, ecological indexes are needed, such as (a) Shannon-Wiener diversity index and (b) Family Biotic Index (FBI) who depends on the type of benthic macroinvertebrate (Mezgebu et al. 2019; Etemi

et al. 2020; Tampo et al. 2021). In Bawean Island, the initial steps towards monitoring freshwater ecosystems should be taken since there is no information about the water quality of its surface water sources. The purpose of this study was to evaluate the water quality of some waterfall ecosystems found on Bawean Island using community structure and diversity of benthic macroinvertebrates as a complement to water quality evaluation using physicochemical water parameters.

## MATERIALS AND METHODS

### Study area

The study was conducted from May-November 2022 in several waterfalls on Bawean Island, the main island of the Bawean Islands. There were six waterfalls as the study's locations where two waterfalls, Candi and Putri, were in the Tambak sub-District and the rest of the waterfalls Laccar, Kuduk-kuduk, Suwari, and Talomon, were in Sangkapura sub-District. The selection of location of the waterfall used purposive random sampling based on the results of interviews with local people regarding the location of the waterfall that is often found. The area around the waterfall location was still dominated by secondary forest and there was no massive anthropogenic activity.



**Figure 1.** Research location on Bawean Island, Indonesia

### Water physicochemical quality determination techniques

Determination of water quality was carried out during the dry season (August 2022) at 6 waterfalls that had been determined. At each waterfall, water sampling was carried out at three different sites, namely around 5, 10 and 25 m from the waterfall point. Measurement of abiotic factors was carried out in the morning until noon for the time range around 08.00-13.00 WIB. Water sampling in the morning was carried out at Candi, Suwari, and Kuduk-kuduk Waterfalls. While sampling during the day was carried out at Putri Waterfall, Talomon, and Laccar. Sampling was carried out on three different days, namely the first day at the Candi and Putri waterfalls; the second day was held in Suwari, Talomon, and Laccar; the third day was held at the kuduk-kuduk waterfall. Therefore, 18 samples were collected, and 8 water quality physicochemical parameters were measured (Table 1). At each site, some of the water parameters, such as water temperature, air temperature, pH, conductivity, total suspended solids (TSS), and dissolved oxygen (DO), were measured on the site by using probes. After the onsite measurements, as much as 1 L of water was taken by using a water sampler, then it was moved into a plastic bottle and stored in a cool environment for chemical parameters analysis. The other parameters, including biochemical oxygen demand (BOD), nitrate, and total phosphate, were measured in the laboratory (Table 1).

### Benthic macroinvertebrate sampling technique and identification

Benthic macroinvertebrates sampling was carried out at the same site as water sampling. Sampling was carried out on the bottom substrate with a water depth of about 10-30 cm. Benthic macroinvertebrates were collected by using Surber nets (rectangular opening, 25×40 cm, mesh size 350 µm). By putting the frame foot portion against the water flow, the benthic macroinvertebrates were collected. The surface substrate to a depth of around 10 cm within the frame foot was washed gently and carefully by hand, so all the benthic macroinvertebrates that attached to the substrate were trapped. The samples were obtained in buckets to be sorted and separated from the trapped garbage and dirt. The selected benthic samples were put in a glass jar and preserved with 70% alcohol (Hussen et al. 2019).

The benthic macroinvertebrates obtained were observed using a stereo microscope. Furthermore, identification was carried out using identification keys according to Thorp and Covich 2001; Bouchard 2004; Moog 2006; Ristiyanti et al. 2011. The amount (density) of benthic macroinvertebrates per m<sup>2</sup> was calculated using the following formula (Vyas et al. 2012).

$$N = \frac{O}{S} \times 10000$$

Where:

- N : Number of individuals per m<sup>2</sup> (ind/m<sup>2</sup>)  
 O : number of benthic calculated per sample (ind)  
 S : Area (Surber Net) (cm<sup>2</sup>)

### Data analysis

The results of measuring water physicochemical parameters in each aquatic ecosystem were compiled into one table. The data were calculated to get the average value and standard deviation for each water quality parameter and each station for all research locations. The physicochemical parameters were compared to Water Quality Standard based on Indonesia government regulation (PP RI) No. 22 of 2021 concerning National Water Quality Standards to know the level of water pollution.

The data from the identification and calculation of the community structure of benthic macroinvertebrates in all locations were also compiled and determined the values of the Importance Value Index (IVI), species abundance, Taxa Richness (TR), and Shannon Wiener diversity Index (H') using the following formula:

$$H' = - \sum_{i=1}^S P_i^2 \log P_i$$

Where:

- H' : Shannon Wiener's diversity index  
 P<sub>i</sub> : proportion of all individuals in a sample that belongs to species *i*  
 S : total number of species in a sample  
 Σ : sum of species 1 to species S

To see an overview of the community structure and diversity of benthic macroinvertebrates, the results of the above data processing are entered in a table and then described. Determining the category of waterfall quality based on community structure and diversity of benthic macroinvertebrates as bioindicators can also be carried out by calculating the biotic index, namely the Family Biotic Index (FBI) (Mandaville 2002). Determination of water quality based on benthic macroinvertebrate species diversity can be seen from Shannon-Wiener diversity indices (Basyuni et al. 2018). The principal analysis component (PCA) was applied to establish the relationship model between ecological indices and water quality parameters. The analysis was performed under the Paleontological Statistics (PAST) software (version 4.0). These results were used to develop a management strategy for aquatic ecosystems that have experienced water quality degradation.

**Table 1.** Physicochemical parameters of water measured in research and measurement methods

Parameters	Unit	Tools/methods
Water temperature	°C	Thermometer
Air temperature	°C	Thermometer
pH	-	pH meter
Conductivity	mS/cm	Conductivity meter
Dissolved Oxygen	mg/L	TSS meter
BOD	mg/L	BOD Chamber
Nitrate	mg/L	Brucine method
Total Phosphate	mg/L	Stannous Chloride

## RESULTS AND DISCUSSION

### Physicochemical quality profile of water in some waterfall ecosystems found on the Bawean Island

Assessment using physical, chemical, and biological parameters can be useful in determining water quality. Based on the measurement of water quality parameters, the results of the physicochemical values of water in the waterfall ecosystem on Bawean Island can be seen in Table 2. Measurements of the physical and chemical parameters of the water included air temperature (°C), water temperature (°C), conductivity (mS/cm), pH, DO (mg/L), BOD (mg/L), nitrate (mg/L), and total phosphate (mg/L).

Based on the measurements, the water temperature in the waterfalls ranged from 25.03-27.93°C, while the air temperature ranged from 26.33-28.17°C (Table 2). Based on the national water quality standard, PP. No. 22 of 2021, the temperature of waterfalls on Bawean Island belongs to the Class 1 category. This temperature value is normal for the tropics, where the effective temperature for agricultural irrigation water is 25°C (Harahap et al. 2018). Temperatures in the tropics range from 20-28°C, and the temperature decreases with increasing water depth (Basyuni et al. 2018). Temperature is an important environmental factor that can determine the presence or absence of several animal species because it is used for photosynthesis by producer organisms (Boyd et al. 2013). According to Basyuni et al. (2018) the optimum temperature for the living of benthic macroinvertebrates ranges from 25-32°C.

The average pH values for the six monitored waterfalls ranged from 7.65-8.30 (Table 2). All water at the six locations observed still meets PP. No. 22 of 2021 concerning National Water Quality Standards for Class 1, the water quality standards are 6-9. Also, all observed water also meets the requirements as irrigation water with the provisions of the international irrigation water quality standard from FAO of 6.5-8.4. Fluctuations in the waters' acidity can interfere with organisms' survival, such as

disrupting the respiratory system and metabolism (Selleslagh et al. 2012). The optimal pH value for benthic macroinvertebrate life is  $5 < \text{pH} < 9$  (Wang et al. 2012). According to Darajat et al. 2020, chemical and organic pollution is often the cause of drastic fluctuations in pH values. Meanwhile, the presence of acid in free minerals and carbonic acid will increase the acidity of the water.

DO levels in the observed waterfalls ranged from 3.83 to 4.59 mg/L (Table 2). The DO range is included in class 2 and 3 water quality standards. However, Putri, Suwari, Talomon, and Laccar already met Class 2, while Candi and Kuduk-Kuduk met class 3 water quality standards based on PP. No. 22 of 2021. Low DO concentrations are caused by several factors, such as temperature, salinity, and atmospheric pressure (Sahidin et al. 2018). In addition, low DO levels are also influenced by organic matter availability because aerobic microorganisms use oxygen in the water to decompose the organic matter (Filter et al. 2017; and Calleja et al. 2019).

BOD values in 6 waterfalls ranged from 0.45-4.19 mg/L (Table 2). The highest BOD value was found at Laccar (4.19 mg/L), and the lowest BOD value belonged to Kuduk-Kuduk (0.45 mg/L). The location that met the Class 1 water quality standard ( $< 2$  mg/L) was Kuduk-Kuduk. Candi, Suwari, Putri, and Talomon met Class 2 ( $2 < \text{BOD} < 3$  mg/L), and Laccar was classified into Class 3 water quality standard ( $3 < \text{BOD} < 6$  mg/L) based on PP. No. 22 of 2021. BOD has a negative correlation with the DO value since the higher DO value, the lower BOD value is and vice versa. BOD describes water microorganism activities because oxygen accommodates microorganisms in decomposing process. Moreover, the BOD level gets higher when the microorganisms availability is abundant in the water (Al-Dulaimi 2017). According to Wibowo et al. (2017), the level of organic matter pollution in the waters can be observed with BOD levels, where the low BOD ranges from 0-10 mg/L, moderate by 10-20 mg/L, and high by  $> 25$  mg/L.

**Table 2.** Spatial varia of physicochemical parameter values in Bawean Island waterfall, Indonesia

Parameters	Waterfall (Mean±STDEV)						Indonesian Water Quality Standard*			
	Candi	Putri	Suwari	Talomon	Laccar	Kuduk-Kuduk	Class 1	Class 2	Class 3	Class 4
Water temperature (°C)	26.77±0.12	27.93±0.15	25.70±0.70	25.97±0.15	25.03±0.06	25.03±0.06	Dev 3	Dev 3	Dev 3	Dev 3
Air temperature (°C)	28.0±0.00	28.17±0.29	26.33±0.29	27.33±0.29	26.83±0.29	27.00±0.00				
pH	8.30±0.13	8.16±0.04	7.65±0.31	8.06±0.07	8.14±0.02	7.94±0.09	6-9	6-9	6-9	6-9
DO (mg/L)	3.83±0.49	4.20±1.25	4.12±0.45	4.59±0.09	4.25±0.39	3.50±0.05	>6	>4	>3	>1
BOD (mg/L)	2.48±0.34	2.84±0.31	2.43±1.92	2.73±0.30	4.19±0.53	0.45±0.19	<2	<3	<6	<12
Nitrate (mg/L)	0.21±0.05	0.33±0.02	0.09±0.07	0.19±0.03	0.21±0.05	0.43±0.20	10	10	20	20
P Total (mg/L)	0.17±0.14	0.10±0.02	0.02±0.01	0.05±0.01	0.04±0.02	0.31±0.21	0.2	0.2	1.0	-
Conductivity (mS/cm)	0.20±0.00	0.15±0.01	0.16±0.06	0.19±0.00	0.27±0.17	0.26±0.22	-	-	-	-
Category of water quality*)	Class 3	Class 2	Class 2	Class 2	Class 3	Class 3				

Note: \*) Government Regulations No. 22 in 2021 about National Water Quality Standard (Class 1 for raw material of drinking water; Class 2 for water tourism infrastructure, fish farming and plantation/agriculture; Class 3 for fish farming, animal husbandry and plantation/agriculture; Class 4 for plantation/agricultural)

The nitrate content from waterfalls ranged from 0.09-0.43 mg/L (Table 2). The lowest nitrate level was in Suwari (0.09 mg/L), while the highest nitrate level was in Kuduk-Kuduk (0.43 mg/L). Based on the national water quality standard in Indonesia (PP. No. 22 of 2021), all of the study locations met the Class I water quality standard for nitrate content, which is <10 mg/L. Nitrate content is influenced by organic matter deposited in the waters that come from the residue of the plantation, agricultural and livestock activities. In addition, according to Krishna and Mohan (2017), the addition of organic matter levels in the waters comes from litter, weathered tree trunks, and the rest of other organisms. Those organic matters are carried by water (soil and rain) to the rivers and sea (Rohila et al. 2017). Based on a previous study, the optimal nitrate content to support macrozoobenthos growth is 3.9-15.5 mg/L (Harahap et al. 2018).

The average value of TP in the waterfall ranged from 0.02-0.31 mg/L, where the lowest value belonged to Suwari (0.02 mg/L) and the highest one was Kuduk-Kuduk (0.31 mg/L) (Table 2). Based on the national water quality standard in Indonesia, the TP value in some locations met Class 1 (TP<0.2 mg/L). However, Kuduk-Kuduk was the only site that met the Class 3 (TP water of less than 1 mg/L). The high phosphate content can also be caused by bedrock weathering, organic matter decay, synthetic fertilizers, industrial and domestic waste (Numbere and Camilo 2016; Wimbanigrum et al. 2016).

The average conductivity value in the waterfall ranges from 0.15-0.27 mS/cm. The lowest value was found in Putri Waterfall, with a value of 0.14 mS/cm or 0.014 dS/m. Kuduk-Kuduk Waterfall has the highest average conductivity with a value of 0.27 mS/cm or 0.027 dS/m (Table 2). The range of waterfall conductivity values has met the FAO irrigation water quality standard, which requires 0-3 dS/m. Conductivity values below 0.7 dS/m indicate no salinity problems in these waters, so they can be used for any agricultural crops (without restrictions). Meanwhile, suppose the value is more than 0.7 dS/m. In that case, it indicates a slight to moderate degree of restriction on use, which indicates a slight problem related to the speed of water infiltration into the soil, so that if the water is used for irrigation, it will affect the quality of plants, including crop yields. The conductivity value can reflect the presence or absence of salinity problems (dissolved salt levels), affecting agricultural crops (Darojat et al. 2020).

From the results of the physicochemical parameters obtained, the location of the waterfall on Bawean Island has varied characteristics. The location of the observed waterfall is based on the Indonesian national water quality standard. No. 22 of 2021 is classified as Classes 2 and 3. Class 2 water quality standards are used for water recreation, freshwater fish cultivation, animal husbandry, water for irrigation, and/or other activities that require water quality. Class 3 water quality standards are used for freshwater fish cultivation, animal husbandry, water for irrigating crops, and/or other activities that require water quality. The waterfall location is included in class 2, i.e., Putri, Suwari, and Talomon. Whereas the waterfall's

location is included in group 3, i.e., the Candi, Laccar, and Kuduk-Kuduk.

### Community structure profile and diversity of benthic macroinvertebrates in several waterfall ecosystems found on Bawean Island

In the aquatic ecosystems monitored at the Bawean Island waterfall, various taxa and species richness of benthic macroinvertebrates were found (Table 3). It can be seen that the number of taxa found was 19 taxa, with details in each waterfall consisting of 7-14 taxa. The highest number of taxa was found in Candi waterfall, with 14 taxa, and the lowest was in the Kuduk-kuduk waterfall, with 9 taxa. In addition, the total abundance of each location varied between 443-2034 individuals/m<sup>2</sup>. The highest total abundance value of macroinvertebrates was at Laccar Waterfall at 2034 individuals/m<sup>2</sup>, while the lowest total abundance value was at Suwari Waterfall at 443 individuals/m<sup>2</sup>. The environmental conditions around the waterfall on Bawean Island are relatively unspoiled. Some of the environment around the site is a habitat for natural shrubs and a secondary forest. This condition will provide sufficient nutrients for the growth of benthic macroinvertebrates derived from good organic matter derived from the amount of litter from plants around the waters (Hamid and Rawi 2017).

Based on the results of the importance value index (IVI) calculation, the percentage of an abundance of each taxon found can be seen in Figure 2. It can be seen that different taxa dominate each research location. The dominant families in the Waterfall ecosystem, Bawean Island, is the Ephemerellidae, Hydropsychidae, Leuctridae, and Baetidae. The Ephemerellidae and Baetidae of the order Ephemeroptera, Hydropsychidae of the order Trichoptera, and Leuctridae of the order Plecoptera (Tampo et al. 2021). Candi Waterfall found 5 codominant species: Ephemerellidae, Hydropsychidae, Leuctridae, Perlodidae, and Baetidae. Putri Waterfall was found to have a dominant family, namely Baetidae. Suwari Waterfall was found to have three codominant species between Baetidae, Hydropsychidae, and Ephemerellidae. Talomon Waterfall was found to have two codominant species, namely Baetidae and Hydropsychidae. Laccar Falls found codominant species i.e., Baetidae, Ephemerellidae, and *Sulcospira* sp.. Kuduk-Kuduk Waterfall found codominant species: Hydropsychidae and Ephemerellidae. Most of the taxa found and dominated, including benthic macroinvertebrates, are indicators of good-quality waters, which are sensitive to pollutants. According to Hamid and Rawi (2017); Jumaat and Hamid (2021), benthic macroinvertebrates belonging to EPT (Ephemeroptera, Plecoptera, and Trichoptera) are indicators of good water quality. In addition, species dominated by *Sulcospira* sp., which is a cosmopolitan species (Hussen et al. 2019). This result supports the measurements of the physicochemical parameters that are still included in class 1 water quality standards or can be designated drinking water.

Water quality criteria can be determined based on the diversity index of benthic macroinvertebrates. Water quality can be determined based on the Shannon-Wiener

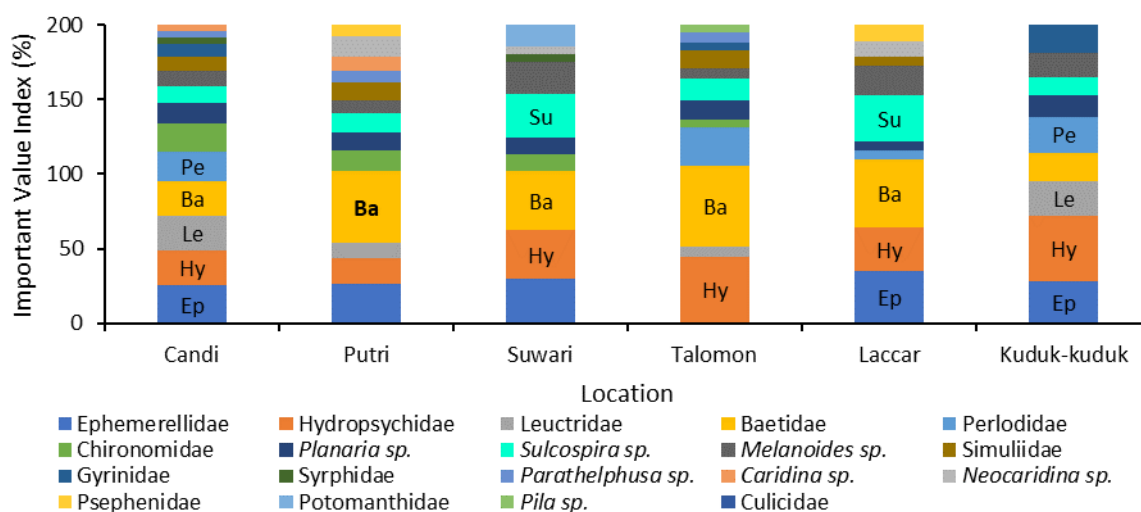
diversity index of benthic macroinvertebrates as a bioindicator, as shown in Figure 3. The value of the Shannon-Wiener Diversity Index in the observed waterfall ranges from 2.35-3.36. All research locations showed the Shannon-Wiener Diversity Index value above 2. These waters, according to Mandaville (2002) are in the unpolluted category. The high value of benthos diversity indicates that environmental conditions are improving and the community is classified as stable (Reshetnikova et al. 2017).

Water quality based on the community structure of benthic macroinvertebrates can also be seen from the calculation of several biotic indices of benthic macroinvertebrates as bioindicators, such as Family Biotic Indices/FBI (Mandaville 2002). The results of calculating

the FBI value can be seen in Figure 4. It can be seen that the water quality in the Candi Waterfall and Kuduk-Kuduk ecosystem is free from contamination with organic matter (excellent); Putri and Talomon Waterfalls include the possibility of being slightly polluted with organic matter (very good), and Suwari and Laccar Waterfalls are polluted with a small amount of organic matter (good). The FBI value is included in the low category because the waterfall’s location is still found in many macrozoobenthos families with a low tolerance value of 0-4, such as Baetidae and Hydropsychidae (Mandaville 2002; Darajat et al. 2020). Previous study shows EPT organisms (Ephemeroptera, Plecoptera, and Trichoptera) indicate good water quality in another freshwater ecosystem (Hamid and Rawi 2017)

**Table 3.** Total density and taxa richness of benthic macroinvertebrates in waterfall ecosystem, Bawean Island, Indonesia

Order	Family	Species name	Density (ind/m <sup>2</sup> )					
			Candi	Putri	Suwari	Talomon	Laccar	Kuduk-kuduk
Ephemeroptera	Baetidae		124	323	122	376	637	57
	Ephemerellidae		149	137	76	0	417	131
	Pothamintidae		0	0	10	0	0	0
Plecoptera	Perlodidae		130	0	0	103	33	98
	Leuctridae		131	33	0	15	0	93
Trichoptera	Hydropsychidae		132	65	89	285	402	264
Coleoptera	Gyrinidae		11	0	0	4	0	56
	Psephenidae		0	10	0	0	34	0
Diptera	Syrphidae		63	22	12	34	18	53
	Simuliidae		13	0	3	0	0	0
	Chironomidae		34	45	0	26	22	0
	Culicidae		89	33	11	4	0	0
Tricladida	Planariidae	<i>Planaria</i> sp.	0	0	0	0	0	0
Architaenioglossa	Pachychilidae	<i>Sulcospira</i> sp.	43	56	74	47	338	32
	Thiaridae	<i>Melanoides</i> sp.	37	23	43	21	116	37
	Ampullariidae	<i>Pila</i> sp.	0	0	0	6	0	0
Decapoda	Atyidae	<i>Neocaridina</i> sp.	0	39	3	0	17	0
		<i>Caridina</i> sp.	7	25	0	0	0	0
	Gecarcinucidae	<i>Parathelphusa</i> sp.	10	13	0	12	0	0
Total density (ind/m <sup>2</sup> )			973	824	443	933	2034	821
Taxa richness			14	13	10	12	10	9



**Figure 2.** Species dominance based on importance value index (IVI) value was found at the study site. Notes: Ba: Baetidae; Le: Leuctridae; Hy: Hydropsychidae; Ep: Ephemerellidae; Su: *Sulcospira* sp.; Pe: Perlodidae

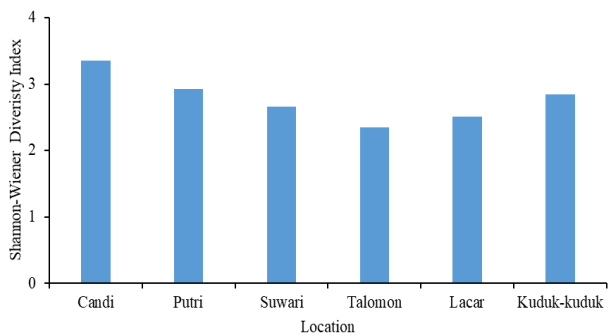


Figure 3. The value of the Shannon-Wiener Diversity Index of benthic macroinvertebrates found at the study site

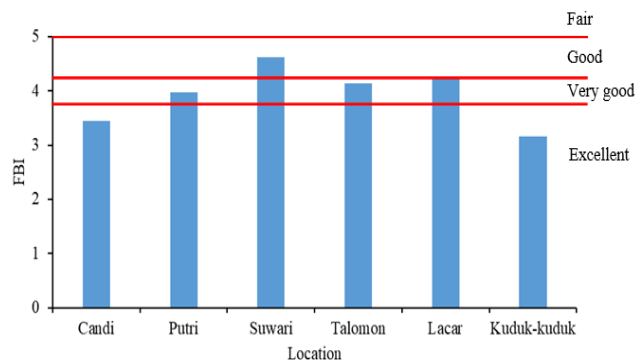


Figure 4. Family biotic indices (FBI) value of benthic macroinvertebrates found at the study site

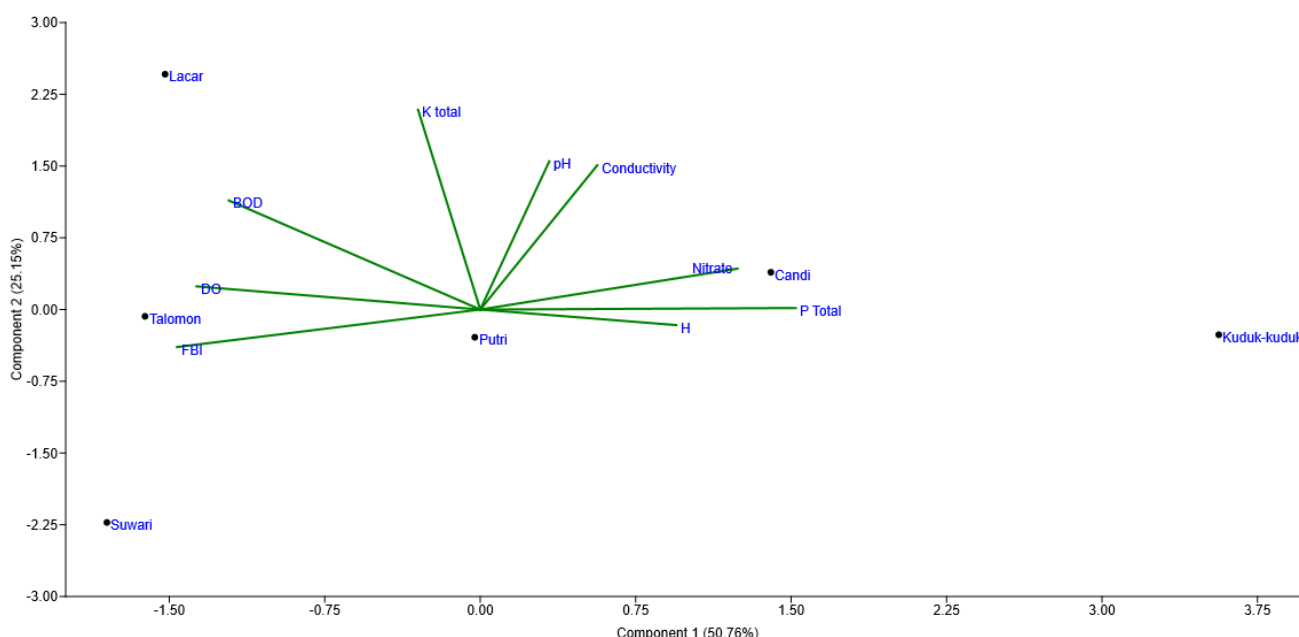


Figure 5. The relationship between water physicochemical parameters with community structure and benthic macroinvertebrate diversity by PCA test

Based on the PCA results, Putri Waterfall and Kuduk-kuduk have similar characteristics. They had the best water quality, which was characterized by the high value of the Shannon-Wiener diversity index (H) and a low FBI value (Figure 5). Although the levels of organic matter (nitrate and phosphate) are high, it showed that the organic matter in the waters is still in accordance with the water quality standards, which provide nutrients to aquatic organisms. Organic matter that causes high nitrate in waters comes from the rest of the litter (dry leaves), rotten wood, and the rest of the twigs (Krishna and Mohan 2017). Putri, Talomon, and Suwari Waterfalls' locations have similar characters, characterized by nitrate levels, low Total P, moderate H Shannon-Wiener, and high FIB values. The location of Laccar Falls is characterized by high BOD values, as well as low levels of nitrate and Total P. Water

quality in Bawean Island waterfall, according to PP. Number 22 of 2021 was classified as class 2 (Putri, Suwari, and Talomon waterfalls) and class 3 (Candi, Laccar, and Kuduk-Kuduk waterfalls). Based on the FBI index, Bawean Island waterfall is in the Excellent-Good category. It is proven that the condition of some waterfall ecosystems on Bawean Island has anthropogenic activities that can disrupt the quality of the ecosystem.

The results of this study indicate that based on benthic macroinvertebrates as bioindicators, all waterfalls on Bawean Island have good to excellent quality. However, this water quality is starting to degrade, as indicated by a decrease in water use from class 2 to 3. Therefore, the local government needs to manage the waterfall ecosystem properly by controlling human activities around it.

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