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Water quality assessment of Bone River using STORET method

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ABSTRACT

Activities around Bone River, one of the largest rivers in Gorontalo Province, include agriculture, settlement, gold mining, sand excavation, industry, and illegal logging. This research aimed to report the water quality status of Bone River using the STORET method as an index commonly used for measuring pollution levels in a water body, which the Indonesian government regulates, as stated in the Decree of the Minister of Environment, No. 115, 2003. This work involved data from 2021-2023 along the upstream to downstream of the river. There were 12 water quality parameters measured: temperature, TSS, DO, pH, COD, BOD, nitrate, phosphate, ammonia, and the heavy metals (Pb, Cd, and Hg) concentration. This study revealed that parameters met water quality standards for class I and class II: temperature, pH, DO, Pb, and Cd. The index scores ranged from -96 to 0. The upstream area was categorized as good, and the midstream to downstream was recognized as heavily polluted. This pollution level is dominated by organic waste from agricultural and domestic household activities. The concentration value consistently exceeds the quality standard in all data from St 5 to St 12. These two parameters are enough to significantly cause worsening water quality based on the STORET with a total score contribution of -40. BOD and COD parameters contribute the most to the river pollution level.

Introduction

Rivers have a very important role in society. Apart from where the ecosystem takes place, it is also a source of life for the surrounding community. Various human activities, such as industrial and household waste disposal, cause a decline in river water quality. The continuous addition of large amounts of waste material from upstream to downstream of the river will result in the river being no longer able to recover, resulting in a disruption of the balance between chemical, physical, and biological factors in the river (Kadim *et al*., 2013; Pasisingi *et al*., 2014). Anthropogenic activities can change the input of organic matter, nutrients, and heavy metals to river ecosystems through changes in land use and urbanization (Singer & Battin, 2007; Akbar & Rahayu, 2023). Anthropogenic modification has disturbed aquatic ecosystems by modifying river water flows (Takao *et al*., 2008).

Anthropogenic activities are the main cause of pollution, especially in river ecosystems (Liu *et al*., 2018; Wang *et al*., 2019). The availability and quality of water, both surface and ground, have deteriorated due to several important factors such as increasing population, industrialization, urbanization, and others where water is considered as a primary need. Water needs are met by rivers, which provide water for human life and agriculture (Romdiana *et al*., 2018). Pollution originating from anthropogenic activities can cause changes in the environmental quality of river water (Islam *et al*., 2015), which also affects the biota in it (Barbieri *et al*., 2020). Water as an integrator in a watershed will reflect all qualitative and quantitative anthropogenic pressures. Continuous pollution can have an impact on biota and can even cause death, thereby affecting population numbers.

Pollution or environmental contamination is the entry or inclusion of living things, energy substances, and other components into the environment or changes in the environmental structure by human activities or by natural processes

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Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Volume 13, Number 3, Page 427-433

so that the quality of the environment decreases to a certain level which causes the environment to become less or no longer able to function in accordance with its designation (Indonesian Basic Environmental Management Law No. 4 of 1982). One way to control pollution in an ecosystem is by monitoring water quality over a certain period so that the water quality status is known. If pollution occurs, immediate prevention and control are carried out according to the level of pollution (Matahelumual, 2007). Pollution of an aquatic ecosystem depends on environmental conditions. A well-maintained ecosystem balance ensures that water ecosystem recycling occurs naturally.

One way to control an ecosystem is by monitoring groundwater quality over a certain period so that the condition of the waters is known. If pollution occurs, immediate prevention and control are carried out according to the level of pollution (Vaghela *et al.*, 2017). The traditional approach to determining water quality status is to compare data for each water quality parameter, whether physical, chemical, or biological, with normative conditions or quality standards for water use. Many scientists have developed various methods to transform a large number of water quality parameters into a single value or water quality index, making it easier to evaluate trends in changes in overall river water quality both spatially and temporally. Several countries have developed the method, while in Indonesia itself, two popular methods are accommodated in the Minister of Environment Decree No. 115 (2003) concerning Guidelines for Determining Water Quality Status, namely the Pollution Index and the STORET Method.

The STORET method is a commonly used method for determining water quality status. This method compares water quality data with standards according to its intended use (KEPMEN-LH, 2003). Determining water quality status using the STORET system is intended as a reference in monitoring the water quality of an aquatic system.

One of the largest rivers in Gorontalo Province is the Bone River. The Bone River Corridor is a means of water conservation for the surrounding area because it provides various water needs (managed by PDAM), ranging from clean water, and agriculture to tourism activities. The Bone River is also part of the Bogani Nani Wartabone National Park area. Apart from that, research results (Sahami & Habibie, 2020) found that the Bone River is the habitat of the adult of the Nike fish, which is an economically important fish for the people of Gorontalo. Balihristi data for 2008-2011 shows that several land use activities around the river have the potential to threaten the Bone River ecosystem, these activities include agriculture, settlement, gold mining, sand excavation, industry, and illegal logging. Lihawa and Mahmud (2012) reported that mercury concentrations were high in the water and sediment in the tributaries of the Bone Watershed, where there was gold tailings activity. Therefore, this research was conducted to assess the water quality status of the Bone River to provide information on water pollution conditions based on water quality parameters measured during the research.

Materials and Methods

Location, time, and data collection procedure.

The research location covers the main flow area of the Bone River. There are 12 monitoring points representing the upstream, midstream, and downstream parts (see Figure 1). Sampling points are determined based on the activities of the surrounding community, which allows pollutant loads to enter the waters of the Bone River. There were 12 water quality parameters were recorded during our research series from 2021 to 2023. Still, these parameters were not always measured every year, as were the frequency of measurements and the number of monitoring points (see Table 1). The measured water quality parameters are temperature, TSS, DO, pH, COD, BOD, nitrate, phosphate, ammonia, and the heavy metals Pb, Cd, and Hg. The sampling procedure is based on the APHA standard method (2012). Water samples for heavy metal measurements were put into a 600 ml plastic bottle from each station.

Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Volume 13, Number 3, Page 427-433

Table 1. Measured water quality parameters in the Bone River from 2021, 2022, 2023.

Stations/ Sampling periods	Parameters											
	Temperature	TSS	DO	pH	COD	BOD	Ammonia	Nitrate	Phosphate	Pb	Cd	Hg
1	√	√	√	√	√	√	√			√	√	√
2	√	√	√	√	√	√	√					
3	√	√	√	√	√	√	√					
4	√	√	√	√	√	√	√					
5	√	√	√	√	√	√	√	√	√			
6	√	√	√	√	√	√	√	√	√			
7	√	√	√	√	√	√	√	√	√	√	√	√
8	√	√	√	√	√	√	√	√	√	√	√	√
9	√	√	√	√	√	√	√	√	√			
10	√	√	√	√	√	√	√	√	√	√	√	√
11	√	√	√	√	√	√	√	√	√	√	√	√
12	√	√	√	√	√	√	√	√	√			
April' 21	√	√	√	√	√	√	√	√	√			
July' 21	√	√	√	√	√	√	√	√	√			
June' 22	√	√	√	√	√	√	√	√	√			
July' 23	√		√	√								
August' 23	√		√	√	√	√				√	√	√
September' 23	√		√	√								

Note: √ = measurements were done

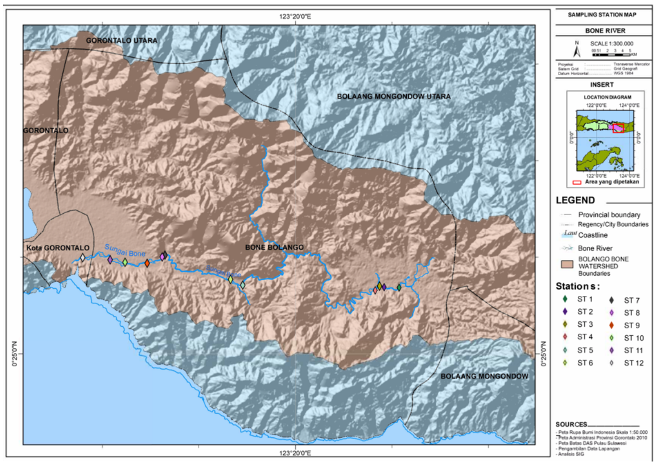

Figure 1. Maps showing the location of the sampling station in Bone River.

Water Use Targets

In this research, the target of river water quality management for determining the STORET index is water conservation, ecological function, and rivers as natural water bodies and multifunctional water sources (general use) for various purposes (drinking water, agriculture, drainage, and others) according to their intended use rivers in Gorontalo Province based on Regional Regulation no. 11 (2014) concerning Management of River Watersheds in Gorontalo Province. Data on the natural water quality of the Bone River, which should be a benchmark, is not yet available, therefore a water quality standard approach is used referring to Indonesian Government Regulation No. 22 (2021).

Data analysis

The existing water quality data will then be analyzed using the STORET Method (KEPMEN-LH, 2003) by comparing the water quality parameter values with water quality standards (PP No. 22 of 2021) class I and class II.

Determining water quality status using time series data. If the measurement results meet the quality standard value, then they are given a score = 0, while if the measurement results exceed the quality standard, then they are given a score according to Table 2. Water quality status is classified into 4 classes: Class A (very good/meets quality standards, score 0); Class B (good/lightly polluted, score -1 to -10); Class C (moderate/lightly polluted, score -11 to -30); Class D (bad/heavily polluted, score ≤ - 31).

Table 2. Score each type of parameter in the Storet method.

Total of sample	value	Parameters		
		Physical	Chemical	Biological
<10	Minimum	-1	-2	-3
	Maximum	-1	-2	-3
	Average	-3	-6	-9
>10	Minimum	-2	-4	-6
	Maximum	-2	-4	-6
	Average	-6	-12	-18

Results

The data used comparatively for measurements using the STORET method is >10 parameters, combining all physical, chemical and biological parameters. The variability of water quality parameter data from measurements in the Bone River (mean values, minimum and maximum range) is presented in Table 3.

Overall, the values for temperature, TSS, DO pH, nitrate, and water heavy metal concentrations for Pb and Cd still meet class II water quality standards. Both temperature, pH, DO, Pb and Cd at all observation stations still meet class I quality standards.

The results of measuring the water quality of the Bone River based on the STORET Index show that the STORET Index scoring ranges from -96 to 0 (see Table 4). Based on the STORET Index classification, this scoring means that some of the waters of the Bone River are categorized as Class A or good, and others are categorized as Class D or poor, so they are classified as heavily polluted.

Table 3. Mean and min-max range of water quality parameters (2021-2023) in the Bone River.

Parameter	Stations											
	1	2	3	4	5	6	7	8	9	10	11	12
	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average	Min-Max Average
Temperature (°C)	23.2-24.4 23.7	23.3-24.7 23.9	22.8-24.6 23.7	23.5-24.8 24.04	24.1-27.4 26.03	24.6-30.2 27.7	24.3-31.4 28.4	24.2-31.7 28.6	24.3-30.1 27.9	24.2-31.8 28.9	24.2-32.5 29.6	25.3-32.2 30.0
TSS (mg/L)	3.89-11.0 7.7	4.92-12.0 8.71	8.24-14.0 10.32	8.63-22.0 15.3	8.36-37.5 23.35	9.89-38.73 25.77	37.9-45.9 41.8	21.46-47.8 38.52	31.9-49.9 43.3	32.77-45.1 39.87	33.67-46.15 40.4	32.7-42.9 37.98
DO (mg/L)	7.8-8.6 8.1	7.8-8.5 8.1	7.7-8.1 7.9	7.3-7.8 7.7	6.3-7.9 7.4	7.5-8.1 7.7	7.4-8.5 7.8	7.4-8.0 7.7	7.5-8.1 7.7	7.2-8.6 7.8	7.4-8.5 7.8	7.0-8.5 7.6
pH	6.0-6.7 6.2	6.0-6.7 6.2	6.1-6.6 6.2	6.0-6.6 6.3	6.4-8.3 7.3	6.7-8.3 7.5	6.1-8.4 7.3	6.3-8.3 7.4	6.2-8.3 7.3	6.2-7.9 7.3	6.2-8.2 7.4	6.3-8.2 7.3
COD (mg/L)	9.26-10.76 9.78	9.12-10.76 9.96	10.48-14.36 12.12	13.59-14.91 14.4	41.46-54.0 46.86	39.87-47.42 43.54	36.72-44.75 40.31	35.57-44.0 38.38	36.28-42.0 38.5	37.54-45.0 41.6	35.14-46.29 40.65	36.22-44.88 41.72
BOD (mg/L)	2.24-2.81 2.54	2.34-2.84 2.67	2.45-2.89 2.72	2.75-3.98 3.23	5.21-6.42 5.78	6.72-8.81 7.98	5.9-9.88 7.86	7.77-12.3 9.24	7.94-9.2 8.56	7.94-13.4 9.6	7.72-9.89 8.56	7.12-13.4 9.19
Nitrate (mg/L)	n/a	n/a	n/a	n/a	2.32-3.32 2.67	2.27-2.97 2.51	2.42-3.29 2.73	1.86-3.38 2.37	1.25-3.13 1.91	1.23-2.98 1.85	1.25-2.73 1.78	1.69-3.16 2.21
Phospate (mg/L)	n/a	n/a	n/a	n/a	0.81-3.66 2.0	0.56-3.97 2.12	0.13-0.8 0.43	0.52-1.06 0.79	0.46-2.34 1.9	0.54-1.1 0.81	0.3-0.78 0.56	0.62-3.5 1.68
Ammonia (mg/L)	0.01-0.05 0.027	0.06-0.08 0.07	0.06-0.09 0.08	0.05-0.1 0.07	0.14-0.16 0.15	0.07-0.12 0.09	0.05-0.06 0.06	0.18-0.4 0.26	0.14-0.17 0.15	0.11-0.13 0.12	0.07-0.09 0.08	0.17-0.14 0.15
Pb (ppm)	0.0027-0.0025 0.01	n/a	n/a	n/a	n/a	n/a	0.0039-0.0046 0.0042	0.0043-0.0051 0.0047	n/a	0.0034-0.0039 0.0037	0.0028-0.0034 0.0031	n/a
Cd (ppm)	0.0012-0.0015 0.0013	n/a	n/a	n/a	n/a	n/a	0.0015-0.0018 0.0017	0.0026-0.0029 0.0028	n/a	0.0021-0.0025 0.0023	0.0024-0.0027 0.0025	n/a
Hg (ppm)	0.0022-0.0025 0.0012	n/a	n/a	n/a	n/a	n/a	0.0032-0.0035 0.0034	0.0028-0.0035 0.0032	n/a	0.0026-0.003 0.0028	0.0026-0.0029 0.0027	n/a

Table 4. STORET index scores.

Stations (St)	Coordinate of Location	Score	Status
1	Upstream (0°29'48.07"N 123°27'30.57"E)	0	very good / meets quality standards
2	Upstream (0°29'50.00"N 123°26'25.62"E)	0	very good / meets quality standards
3	Upstream (0°29'54.15"N 123°26'6.19"E)	0	very good / meets quality standards
4	Upstream (0°29'35.93"N 123°25'46.72"E)	-16	moderate/medium polluted
5	Midstream (0°29'58.34"N 123°16'11.21"E)	-60	poor / heavily polluted
6	Midstream (0°30'38.60"N 123°15'29.70"E)	-60	poor / heavily polluted
7	Midstream (0°31'0.25"N 123°11'46.59"E)	-76	poor / heavily polluted
8	Midstream (0°32'0.99"N 123°10'20.59"E)	-96	poor / heavily polluted
9	Midstream (0°31'33.52"N 123° 9'15.12"E)	-62	poor / heavily polluted
10	Midstream (0°31'37.63"N 123° 7'38.89"E)	-80	poor / heavily polluted
11	Downstream (0°31'48.83"N 123° 6'33.66"E)	-80	poor / heavily polluted
12	Downstream (0°31'57.95"N 123° 4'34.61"E)	-60	poor / heavily polluted

Discussion

As we previously mentioned above, the measured values for temperature, TSS, DO pH, nitrate, phosphate, and water heavy metal concentrations for Pb and Cd generally still meet quality standards. Temperature itself is closely related to the amount of dissolved oxygen and photosynthesis. Temperature changes can be influenced by climate, changes in vegetation, pollutants from waste or pesticides, and anthropogenic activities (Obade & Moore, 2018). The greater the DO value in water, the more it indicates that the water has good quality. On the other hand, if the DO value is low, it can be seen that the water is polluted (Denindya *et al*., 2023). Human activities, such as agriculture and waste disposal, cause a decrease in dissolved oxygen concentrations (Anhwange *et al*., 2012). The pH value is an important factor that influences water productivity or water quality, which can experience changes due to factors such as temperature, concentration of organic and inorganic compounds, carbonate and bicarbonate concentrations, and CO_2 concentration in water.

The TSS value is closely related to the characteristics and influence of river tides, which cause the process of stirring up the bottom sediment of the waters. TSS consists of mud and fine sand as well as microorganisms, which are caused by soil erosion or soil erosion carried into water bodies (Effendi, 2003). In this research, it was

Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Volume 13, Number 3, Page 427-433

recorded that TSS experienced an increase in concentration from 2021 to 2022, where the measured concentration values at St8 to St11 exceeded the quality standards for class I.

The high rate of land conversion into built-up/residential areas around the watershed can cause soil solids entering the river flow through runoff to increase. The high TSS value will have a significant effect on fisheries interests, which require a TSS value between 25 - 80 mg/l (Hariyadi & Effendi, 2016).

Based on the measurement results, it is known that several parameters directly exceed river water quality standards for both class I and class II categories at several observation stations, such as BOD, COD, Phosphate and Hg parameters. Only the COD concentration in St1 meets class I quality standards, while St5 to St12 exceed class II quality standards. Meanwhile, for BOD, concentrations at all observation stations have exceeded class I quality standards and only stations in the upstream area (Stations 1-4) meet class II quality standards. The threshold value for phosphate concentration for classes I and II is 0.2 mg/l. It was recorded that phosphate concentrations at all observation stations exceeded quality standards and tended to increase yearly.

The measured ammonia concentrations at all observation stations met class II quality standards during the sampling period, except for St8 in the first sampling period of 2021, when the concentration reached 0.4 mg/l (exceeding class II quality standards). It was recorded that during the sampling period, the ammonia concentration value at Stations 5, 8, 9, and 12 was consistently at a value of >0.1 mg/l or exceeded the quality standard for class I. The Hg concentration at all observation stations had exceeded the quality standard for class I, and only St 1 (upstream part) still meets class II quality standards.

Temperature, pH, DO, BOD, and COD were relatively measured during sampling in 2021-2023. Generally, BOD and COD concentrations in the middle to downstream parts of the Bone River tend to increase yearly. This condition is thought to be influenced by the decomposition of organic waste originating from agricultural and residential activities. The condition of the Bone River water quality during the three years, represented by the BOD and COD parameters, is shown in Figure 2.

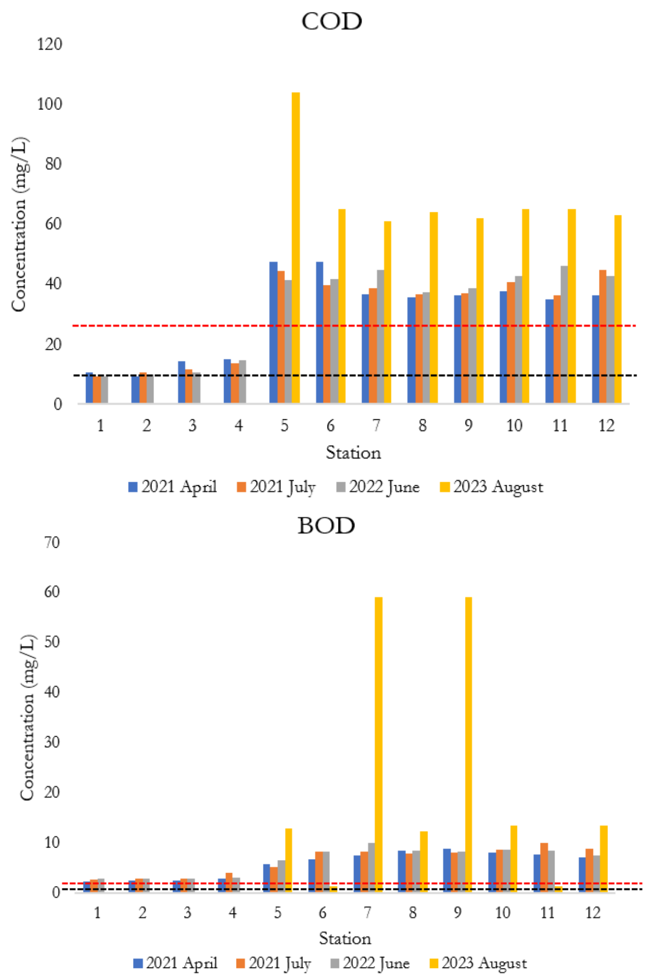

Figure 2. The Bone River BOD and COD parameters during the three years (------ = standard for Class I; ------ standard for Class II).

A high COD concentration indicates a greater level of pollution occurring (Pasisingi *et al*., 2014). The COD value in unpolluted waters is usually less than 20 mg/l, while in polluted waters, it can be more than 200 mg/l (Effendi, 2003). BOD is the amount of oxygen used to decompose organic material, while COD is the oxygen requirement to oxidize organic material chemically. The high and low values of BOD and COD in a body of water describe the activity of organisms in breaking down organic material input in that water, and fluctuations in the values of these two parameters are influenced by domestic and agricultural waste (Masykur *et al*., 2018). The higher the BOD concentration in a body of water indicates that the water is polluted (Kadim *et al*., 2022).

The STORET Index is an instrument for measuring the quality of pollution in a water body by using comparative data between water quality data and water quality standards to determine the water quality status according to its intended use. The Indonesian government issued this instrument

Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Volume 13, Number 3, Page 427-433

as regulated in the Decree of the Minister of Environment, No. 115 (2003), concerning Guidelines for Determining Water Quality Status.

Based on the data presented in Table 4, it is known that there is a decrease in the Storet score from upstream to downstream of the Bone River. Stations 1, 2, and 3, which are in the upstream area of the river, are still in the Class A category or very good because all the measured parameters still meet the water quality standards for Class II, resulting in a STORET score of 0. The remaining STORET scores are for St 4 (upstream), then St 5 to St 12 (middle to downstream) < 0, which indicates pollution has occurred. The STORET Index measurement of Bone River water quality shows moderate and heavy pollution caused by parameters that exceed the permitted quality standards.

The increase in the value score is correlated with the increase in pollutant parameter values at each monitoring point, and this is correlated with the increase in population, which is also indicated by the dominant pollutant source from the household sector, which predominantly contributes to COD and BOD parameters. Station 4, in the upstream part of the Bone River, received the moderately polluted category with a STORET score of -14. This score is influenced by the measured BOD value, which exceeds the quality standard. This station is the only station in the upstream area close to residential areas, so it is estimated that this factor is the cause of the high BOD concentration compared to other stations located upstream of the Bone River.

The results of data analysis using the STORET method show that the pollution level in the Bone River is dominated by organic waste originating from agricultural and domestic household activities. This is shown by the results of dominant pollutant load analysis calculations from several stations, which show BOD and COD parameters. Because the concentration value consistently exceeds the quality standard in all data from St 5 to St 12. These two parameters are enough to significantly cause worsening water quality status based on the STORET method with a total score contribution of -40, which means it is in the heavily polluted category. Other parameters, namely phosphate, ammonia, and Hg, whose concentrations also exceed the quality standards at St5 to St12 (middle to downstream), also influence the STORET score so that the scores at these stations range from -60 to -96. Station 8 was recorded as the observation location with the highest score (-96) because all the parameters that caused the high STORET score in this study (BOD, COD, phosphate, ammonia, and Hg) had exceeded the quality standards. A high score at St8 indicates that the intensity of input from anthropogenic activities at that station is high, originating from around the station or from stations above it, is high. The sampling point at St8 is also close to the dam, so there is a possibility of a buildup of pollutants due to the blocking of river water flow.

The STORET method has the flexibility to determine the number and type of significant parameters used to calculate the index (Arnop *et al*., 2019; Kadim *et al*., 2017). The STORET index is quite sensitive in responding to the dynamics of the water quality index at each location with a few or many parameters. The more water quality parameters are measured, the more it is observed that the parameters do not meet the quality standards (from the maximum and minimum parameter values), and the more often the parameters do not meet the threshold, the worse the water quality status will be (Saraswati *et al*., 2014). The positive thing about the Storet method is that this water quality index does not reflect instant water quality data (short-term effects), the water quality status is calculated/concluded from a series of data resulting from several water quality specimens being taken (long-term effects) (Romdania *et al*., 2018).

If this condition is not handled, in the future, it will have the potential to harm the quality of the waters and the biota in them, as a result, the balance of the waters in the Bone River will be increasingly disturbed. As we previously stated in the introduction, the Bone River is the habitat of the adult Nike fish, an economically important fish for the people of Gorontalo. Deteriorating water conditions will threaten the life of these biota, even dying and becoming extinct. This river also flows into Gorontalo Bay, which is part of the waters of Tomini Bay and can threaten the ecosystem and the economic and social aspects of society in the long term.

Conclusion

The water quality of the Bone River, especially in the midstream to downstream parts during this research period, was categorized as heavily polluted and did not meet the quality standards for water use, both Class I and Class II. This pollution level is dominated by organic waste from agricultural and domestic household activities. The concentration value consistently exceeds the quality standard in all data from St 5 to St 12. These two parameters are enough to significantly cause worsening water quality status based on the STORET method with a total score contribution of -40, which means it is in the heavily polluted category. BOD and COD parameters contribute the most to the Bone River's pollution level.

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