EVOJES
EcoVision: Journal of Environmental Solutions
EVOJES 2(1): 1–14
ISSN 3046-8434

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Analysis of heavy metal (Cd, Hg, Fe) contamination in canal water as an environmental challenge

Fani Suma[1], Chairunnisah J. Lamangantjo[1,*], Regina Valentina Aydalina[1], Zuliyanto Zakaria[1], Syam S. Kumaji[1]

[1] *Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Bone Bolango, Gorontalo 96119, Indonesia.*

*Correspondence: chairunnisah@ung.ac.id

Received Date: January 19, 2025 Revised Date: February 28, 2025 Accepted Date: February 28, 2025

ABSTRACT

Background: This study aims to determine the quality of water channels close to rice fields and houses that produce domestic and agricultural waste based on heavy metal contamination. **Method:** Water sampling was carried out directly at the research location and tested at the UPTD Regional Health Laboratory of Gorontalo Province. The sampling points amounted to three points, namely station I, station II, and station III. The water quality parameters analyzed included heavy metals (Cd, Hg, Fe), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and temperature. **Results:** The results of Cd heavy metal concentrations at each point were station I (0 mg/L), station II (0 mg/L), and station III (0 mg/L). Heavy metal Hg was recorded at station I (0.0038 mg/L), station II (0.00185 mg/L), and station III (0 mg/L). Fe heavy metal concentrations were station I (1.20685 mg/L), station II (1.0082 mg/L), and station III (0.4 mg/L). The pH value in Tamalate canal water remained stable at around 7, with station I (7.3), station II (7.4), and station III (7.3). The DO values were station I (82.7 mg/L), station II (85.1 mg/L), and station III (81.7 mg/L). The BOD values were station I (55.35 mg/L), station II (51.85 mg/L), and station III (57.05 mg/L). The COD values were station I (110.5 mg/L), station II (109.5 mg/L), and station III (119.5 mg/L). The temperature measurements were station I (30.95°C), station II (29.35°C), and station III (30.2°C). **Conclusion:** The distribution of heavy metals in canal water is quite varied due to the influence of environmental conditions and activities around the Tamalate canal, resulting in uneven distribution. **Novelty/Originality of this article:** This study provides a detailed assessment of heavy metal contamination using multiple water quality indicators. It highlights the influence of surrounding land use, including domestic and agricultural activities, on metal distribution and overall water quality.

KEYWORDS: water quality; tamalate canal; heavy metals; physics; chemistry.

1. Introduction

Water quality is a crucial factor that determines the health of aquatic ecosystems and human welfare. As stated by Pramaningsih et al. (2023), water is an essential environmental element for sustaining life, and the availability of water resources in both quantity and quality is vital for supporting environmental sustainability. Polluted water can threaten the survival of living organisms, reduce ecosystem productivity, and indirectly impact human health. This aligns with the findings of Farhan et al. (2023), who stated that water pollution has serious consequences, including harming biodiversity and damaging aquatic ecosystems such as seas, lakes, and canals that flow into rivers. One of the water sources frequently affected by human activities is canals, which function as reservoirs during the

Cite This Article:
Suma, F., Lamangantjo, C. J., Aydalina, R. V., Zakaria, Z., & Kumaji, S. S. (2025). Analysis of heavy metal (Cd, Hg, Fe) contamination in canal water as an environmental challenge. *EcoVision: Journal of Environmental Solutions, 2*(1), 1-14. https://doi.org/10.61511/evojes.v2i1.2025.1722

rainy season to prevent overflow and flooding. Canals are part of river systems that have been expanded or deepened in specific areas and are constructed by humans to meet various needs. In Bone Bolango district, one of the most important canals is the Tamalate Canal, which serves as a source of agricultural irrigation and a disposal site for agricultural and household waste. Agricultural and household waste act as pollutants that can contaminate the canal (Lamangantjo et al., 2023).

Pollution in the Tamalate Canal primarily originates from domestic waste, including detergents, household garbage, and agricultural activities that involve the use of pesticides and chemical fertilizers, contributing to the decline in water quality. This is consistent with the findings of Junaedi & Hasanah (2014), who stated that harmful substances mainly come from household waste, including used laundry water (soap and detergent), fertilizers, and pesticides. Residual fertilizers and pesticides can pollute water in agricultural environments. The impact of such pollution disrupts the balance of aquatic ecosystems; therefore, assessing water quality in the Tamalate Canal is essential. To evaluate its water quality, an analysis using physical and chemical parameters is required, including measurements of heavy metals (Cd, Hg, Fe), DO, BOD, COD, temperature, and pH.

Water quality, particularly in areas adjacent to agricultural land, is often threatened by various pollutants. Hazardous pollutants commonly found include Cd, Hg, and Fe. Heavy metals originate from the use of fertilizers and pesticides in agricultural activities. During rainfall, accumulated heavy metals in the soil are carried by runoff water into the water system. The accumulation of heavy metals in aquatic organisms can disrupt biological processes and damage aquatic ecosystems. This is in line with the findings of Sutrisno & Kuntyastuti (2015), who stated that heavy metal pollution in agricultural land also results from the use of pesticides and inorganic fertilizers. The continuous and prolonged use of these substances leads to increased contamination of agricultural land.

Physical parameters such as water temperature and pH provide insights into the physical condition of water, which affects life around the Tamalate Canal (Ernawati & Restu, 2021). An approach that integrates chemical and physical parameters yields a more comprehensive analysis of water conditions, as these factors are interrelated and influence each other. Therefore, research on the analysis of water quality in the Tamalate Canal is crucial, combining these two factors to provide a more thorough assessment of water quality. This is particularly important as the canal is frequently used as a disposal site for various types of waste. This aligns with the findings of Yusal & Hasyim (2022), who stated that physico-chemical parameters significantly impact life in and around aquatic environments.

2. Methods

This research was conducted in the Tamalate Canal, Bone Bolango Regency, Gorontalo Province, from November 2024 to January 2025.

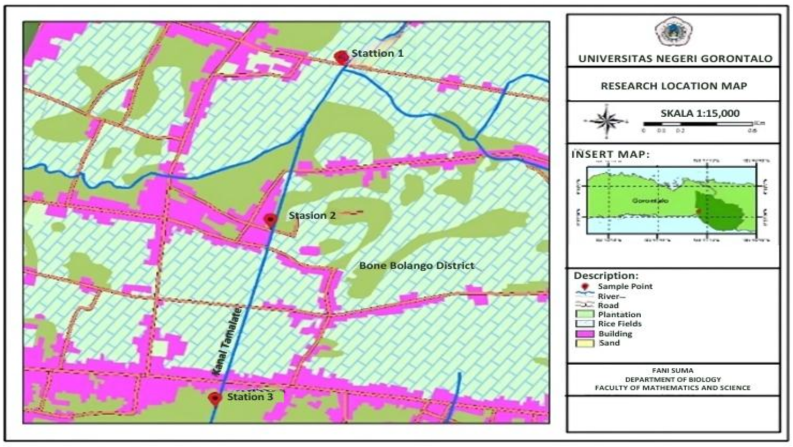

Fig. 1. Map of the Tamalate Canal

This study employed a quantitative descriptive method with a survey approach. This method was chosen to provide a comprehensive overview of the Tamalate Canal's water quality based on physico-chemical parameters, particularly focusing on heavy metal contamination (Cd, Hg, and Fe).

2.1 Data collection technique

Water sampling was conducted directly at the research site (in situ) at several locations considered representative along the Tamalate Canal, along with the measurement of physical and environmental parameters. The sampling points were determined based on locations adjacent to agricultural activities, residential areas, and representative locations upstream, midstream, and downstream of the canal. Three sample points were identified: Station I in West Poowo Village, Station II in North Oluhuta Village, and Station III in Oluhuta Main Village. The coordinates of these points were mapped using GPS (Global Positioning System). Water samples from the Tamalate Canal were collected at each observation station by first rinsing the sample bottles, followed by the collection of water samples, which were subsequently analyzed at the UPTD Regional Health Laboratory of Gorontalo Province. Additionally, measurement activities at the research location were recorded and documented, and environmental parameters such as pH and ambient temperature were measured.

2.2 Data analysis

Descriptive analysis of heavy metals involves calculating the mean, standard deviation, and concentration range (minimum and maximum values) for each sample type. This analysis aims to provide an overview of the concentration levels of heavy metals in the Tamalate Canal. Comparison analysis with quality standards involves comparing the measured concentrations of each heavy metal (Cd, Hg, and Fe) with the water quality standards based on Government Regulation No. 22 of 2021, Class III, on the Implementation of Environmental Protection and Management. This analysis determines whether the concentration of heavy metals in the Tamalate Canal has exceeded the allowable limits and has the potential to cause negative impacts on the environment and human health. Correlation analysis of heavy metals is conducted to determine the relationship between the concentration of each heavy metal (Cd, Hg, and Fe) and other water quality parameters, such as temperature, water color, turbidity, pH, DO, COD, and BOD. This analysis aims to identify factors that may affect the concentration of heavy metals in the Tamalate Canal and to assess whether there is a relationship between heavy metal concentrations and the condition of the aquatic environment.

3. Results and Discussion

This research was conducted in the Tamalate Canal located in Bone Bolango Regency, Gorontalo Province, which stretches for 2.5 km with a width of 25 m and a depth of 1.5 m. The Tamalate Canal functions as a flood control channel and holds excess water during the rainy season, which empties into the Bone River. Based on the results of the research, the results of the physico-metallic parameter measurements were found in.

Table 1. Physical-chemical factors of tamalate canal at 3 observation stations

No.	Physical and chemical factors	Optimum value of good water quality	Location		
			I	II	III
1	Temperature	Dev 3	30.95°C	29.35°C	30.2°C
2	Water color	-	Brownish	Yellowish-brown	Brown
3	pH	6-9	7.3	7.4	7.3
4	Turbidity	-	38.84	90.905	80.88

 https://doi.org/10.61511/evojes.v2i1.2025.1722

5	Dissolved Oxygen (DO)	Minimum limit 3 mg/L	82.7 mg/L	85.1 mg/L	81.7 mg/L
6	Biological Oxygen Demand (BOD)	Minimum limit 6 mg/L	55.35	51.85	57.05
7	Chemical Oxygen Demand (COD)	Minimum limit 40 mg/L	110.5 mg/L	109.5 mg/L	119.5 mg/L
8	Cadmium (Cd)	Minimum limit 0,01 mg/L	0	0	0
9	Mercury (Hg)	Minimum limit 0,002 mg/L	0.0038 mg/L	0.00185 mg/L	0 mg/L
10	Iron (Fe)	Minimum limit - mg/L	1.20685 mg/L	1.0082 mg/L	0.04 mg/L

The results of water temperature measurements at Station I reached 30.95°C. The water temperature at Station I of the Tamalate Canal is categorized as Class III according to the river water quality standards outlined in Government Regulation No. 22 of 2021. The temperature at Station I shows a fairly good range, as supported by Dawes (1981) and Putriningtias et al. (2021), who stated that the normal range for tolerable temperatures is between 27-30°C. The same range is cited by Wulandari et al. (2015) and Putriningtias et al. (2021), which is 28-30°C. The water temperature remains relatively stable without any significant increase. This condition can be attributed to the high sun exposure in the Tamalate Canal, which causes a very bright environment. The fluctuations in temperature measured can be influenced by several factors, such as weather conditions, the location of sampling points, and the time of sampling (Zainuri et al., 2023).

The pH value at Station I is 7.3, which, based on the quality standards of Government Regulation No. 22 of 2021, still meets the water quality standards for Class III river water. This class can be used for freshwater fish farming, animal husbandry, and crop irrigation. The pH value remains within the optimal range, with a minimum limit of 6-9 for Class III river water. A very low pH can increase the solubility of metals in water, making them toxic, while a high pH can elevate ammonia concentrations in water, which is also toxic.

The turbidity measurement result was 38.84, indicating that the water is turbid with a brownish color, similar to what Munfiah & Setiani (2013) and Sari et al. (2019) described. The color of the water can be caused by the presence of organic matter, inorganic materials, metal ions such as Fe, and other substances. High concentrations of Fe in water can cause discoloration, turning it from clear to yellow or brown. High turbidity causes light to be scattered and absorbed rather than passing through the water in a straight line. Turbidity leads to water becoming foggy, reducing its transparency. The direction of the emitted light beam will change when it collides with particles in the water (Kurniawati et al., 2023).

The concentration of dissolved oxygen (DO) at Station I is around 82.7 mg/L. According to the river water quality standards of Government Regulation No. 22 of 2021, this DO value meets the standards for Class III water, which is suitable for freshwater fish farming, animal husbandry, and crop irrigation, with a minimum limit of 3 mg/L. This indicates that the dissolved oxygen at Station I of the Tamalate Canal is quite high. As Alfatihah et al. (2022) stated, the high DO value is due to the photosynthesis process by aquatic plants that produce oxygen in the water. Additionally, Pasongli & Dirawan (2015) noted that dissolved oxygen levels are strongly influenced by temperature, salinity, and water level. As temperature and water level increase, dissolved oxygen tends to decrease. Biological factors such as photosynthesis and respiration also affect the amount of dissolved oxygen in the water.

The BOD measurements at Station I of the Tamalate Canal were 55.35 mg/L, which, according to the river water quality standards in Government Regulation No. 22 of 2021 for Class III water, is above the minimum limit of 6 mg/L. This shows that the organic pollution level in the Tamalate Canal is high. According to Hatta (2014) and Murjani et al. (2024), high BOD values are correlated with an increase in organic matter in the water. Conversely, lower BOD values are associated with lower organic matter content. In line with Daroini & Arisandi (2020), the high organic matter content in the water increases the demand for dissolved oxygen (BOD). Therefore, the higher the organic matter in the water, the higher the BOD value. BOD is an essential chemical parameter for determining water quality, and in the case of the Tamalate Canal, the high BOD content indicates a lack of dissolved oxygen in the water.

The concentration of COD at Station I of the Tamalate Canal is around 110.5 mg/L, which, based on the river water quality standards in PP No. 22 of 2021 for Class III, exceeds the minimum limit of 40 mg/L. The high COD levels at Station I are caused by significant pollution in the Tamalate Canal, and the proximity of the canal to sources of agricultural and residential waste. The existence of unplanned settlements leads to improper household waste disposal, such as bathroom/toilet and kitchen waste entering the canal directly without proper coordination (Purwati, 2015). COD is required to break down both easily and difficultly decomposable organic matter in water, and thus, the COD value reflects the total amount of organic matter present in the water (Simbolon, 2016). COD and BOD values determine the extent of water pollution. The concentration of COD increases as the amount of organic matter in the water rises. High concentrations of BOD and COD indicate low dissolved oxygen levels in the water, a result of high organic matter content (Mayagitha & Rudiyanti, 2014).

At Station I, cadmium levels were found to be 0, and based on the river water quality standards in PP No. 22 of 2021 for Class III, which has a minimum limit of 0.01 mg/L, the cadmium pollution level in the Tamalate Canal is considered negligible. The release of cadmium (Cd) into the water occurs naturally through rock weathering, which releases Cd into the soil and water. It is suspected that the source of Cd in the Tamalate Canal comes from fertilizers and pesticides used by farmers in the surrounding areas, which are carried into the canal with rainwater. As Purbalisa et al. (2017) stated, the excessive use of inorganic fertilizers can increase the cadmium content in soil and plants. The cadmium content in fertilizers ranges from 0.1 to 170 ppm (Wangge et al., 2022). Fluctuations in Cd concentrations in sediments at Station I are influenced by river currents. Hutagalung et al. (1997) and Emilia et al. (2013) found that areas with calmer currents have higher concentrations of heavy metals that settle on the waterbed compared to areas with stronger currents.

At Station I, mercury (Hg) levels were found to be approximately 0.0038 mg/L. Based on the river water quality standards in PP No. 22 of 2021 for Class III, with a minimum limit of 0.002 mg/L, this indicates that mercury pollution in the Tamalate Canal exceeds the minimum threshold. The Hg heavy metal compounds in the Tamalate Canal come from various sources, including household activities such as bathroom/toilet and kitchen waste entering the canal, as well as agricultural activities in the surrounding area, carried into the canal with rainwater. According to Apdy (2016), environmental contamination due to mercury arises from various sources, including agricultural activities such as fertilizer and fungicide use. Common sources of mercury in the environment include household detergents and cleaners. Gholizadeh et al. (2016) also argue that mercury contamination in aquatic environments poses a higher risk to human health and aquatic organisms since water acts as a long-term repository for heavy metals. Water quality analysis is the process of determining the chemical, physical, biological, and other characteristics of water bodies to identify potential pollution sources that could degrade water quality. A decrease in water quality can be caused by the discharge of waste, pesticides, heavy metals, and sediments. Sources of heavy metals in soil also come from the soil-forming parent material, such as Hg in sand sedimentary rocks (0.29 ppm). Mercury in the soil originates not only from soil-forming materials but also from insecticides used in agricultural commodity production. Intensive use of insecticides and fertilizers in rice fields leads to the highest levels of mercury in the soil compared to other sources (Juhriah & Alam, 2016). The use of Urea and Phonska fertilizers by farmers around the Tamalate Canal also contributes to high mercury levels, as these fertilizers contain essential nutrients and secondary elements like Ca, Mg, and microelements, including heavy metals such as Cd, Cr, Pb, Cu, and Hg in varying amounts, thus elevating mercury levels at Station I of the Tamalate Canal beyond the permissible limit (Purbalisa & Mulyadi, 2018). Similarly, Barokah et al. (2019) suggested that the high mercury levels at a location are likely caused by mercury-containing waste from nearby housing that enters the Tamalate Canal. According to Purnawan et al. (2013)

and Nuraini et al. (2017), mercury in aquatic environments can result from various human activities, such as household waste and agriculture, which contribute to increasing mercury concentrations in aquatic environments.

At Station I, iron (Fe) levels were found to be around 1.20685 mg/L. The high iron content in the Tamalate Canal water is due to various factors, including waste disposal into water bodies. Iron is carried by canal water currents, which eventually flow toward the river mouth (Syukriah et al., 2024). The increase in iron levels is influenced by temperature, with temperature measurements at Station I showing around 30.95°C, which is still relatively high. Febriana & Efendy (2020) stated that temperature supports the high solubility of iron in water, and an increase in temperature can affect the solubility of iron, thus explaining the elevated Fe levels in Tamalate Canal water. Iron is an essential metal needed by living organisms in certain amounts, but excessive levels can be toxic. High levels of iron can impact human health, causing poisoning (vomiting), intestinal damage, premature aging, sudden death, arthritis, birth defects, bleeding gums, cancer, kidney cirrhosis, constipation, diabetes, diarrhea, dizziness, fatigue, hepatitis, hypertension, and insomnia (Supriyantini & Endrawati, 2015).

Temperature measurements at Station II were around 29.35°C, differing from Station I. Asrini et al. (2017) argued that temperature plays a crucial role in controlling aquatic ecosystems. An increase in temperature accelerates the decomposition of organic matter by microbes. The temperature difference between the stations in the Tamalate Canal, from upstream to downstream, is caused by varying human activities that contribute to pollution, such as settlements and agriculture. According to Samsundari & Wirawan (2013), temperature affects oxygen solubility in water and influences interactions between various water quality factors. Water at Station II appeared brownish-yellow with a turbidity value of 90.905, a result of organic and inorganic materials in the water, which can affect the water's color, as noted by Harianti & Nurasia (2016). Water color can be caused by the presence of organic and inorganic materials, including metal ions. Turbidity measures the amount of suspended substances in water. The higher the light scattering caused by suspended particles, the higher the turbidity. Substances causing turbidity include sediment (mud), organic and inorganic particles, and dissolved organic color mixtures (Samarinda, 2017). According to Usman et al. (2024), the high turbidity and color values are linked to humic and fulvic compounds. The pH value at Station II was 7.4, which is still within the neutral range, in line with Fadillah et al. (2023), who stated that pH values between 6 and 9 typically indicate neutral to slightly alkaline conditions.

The results of dissolved oxygen (DO) measurements at Station II ranged from 85.1 mg/L, which is quite high compared to the river water quality standards in PP No. 22 of 2021 for Class III, with a minimum limit of 3 mg/L. The BOD concentration at Station II ranged from 51.85 mg/L, and the COD value ranged from 109.5 mg/L, both of which are classified as high according to the river water quality standards in PP No. 22 of 2021 for Class III, with minimum limits of BOD 6 mg/L and COD 40 mg/L. This indicates that organic matter pollution at Station II is considerably high, as Sara et al. (2018) mentioned that BOD and COD are commonly used as water pollution parameters due to their role in estimating organic matter contamination. In line with Santoso's (2018) view, BOD measures the amount of oxygen used by microbial populations in response to degradable organic matter entering water. Some researchers add that BOD also reflects the amount of biodegradable organic matter in the water.

At station II, the cadmium level was found to be 0, and based on the quality standards for river water and similar bodies in PP No. 22 of 2021, class III, with a minimum limit of 0.01 mg/L, it indicates that the cadmium pollution level at this station is virtually absent. The suspected source of cadmium in the Tamalate canal waters is the adjacent agricultural land, where cadmium contamination primarily originates from fertilizers. The cadmium content in fertilizers ranges from 30-60 mg/kg. Consequently, wastewater from rice fields could flow into water bodies, potentially polluting the canal. Additionally, the Tamalate canal serves as an irrigation source, and the irrigation water is then used to irrigate rice fields. The cadmium metal is subsequently deposited into the soil and enters the water body along with rainwater (Syachroni, 2017). In line with the opinion of Septiani et al. (2020), it was suggested that cadmium (Cd) in rice fields comes from irrigation systems that act as drains for household waste, and from the use of chemical fertilizers by farmers (Suriani, 2016). According to Wihardjaka & Harsanti (2018), the intensive use of fertilizers in rice cultivation in a continuous manner leads to high fertilizer deposition, thus increasing cadmium metal availability. It is also noted that farmers near the Tamalate canal use various types of fertilizers to enhance soil fertility, such as urea and NPK fertilizers. Based on research by Sukarjo et al. (2018), the highest cadmium content is found in NPK fertilizer at approximately 4.49 ppm, and urea fertilizer contains about 2.14 ppm.

At station II, mercury (Hg) levels were recorded at 0.00185 mg/L, which, according to the quality standards for river water in PP No. 22 of 2021, class III, with a minimum limit of 0.002 mg/L, still falls within the average quality standard. Several factors influence mercury levels in water, such as temperature and pH. Variations in water temperature significantly correlate with water salinity, affecting mercury, which tends to bind easily with salt. Low mercury levels in a water body can lead to deficiencies in various organisms (Selayar et al., 2015). In terms of chemical parameters, Tamalate canal water is of good quality and does not contain toxic chemicals or heavy metals that exceed the water quality standards stipulated by PP No. 22 of 2021, class III. If a water body contains heavy metals above the threshold, it results in pollution that harms the surrounding environment. Common heavy metals found in water, such as iron (Fe), mercury (Hg), and cadmium (Cd), are often used as indicators of water quality (Anwar et al., 2019; Syuzita et al., 2022). The presence of heavy metals in water is influenced by both natural factors, such as erosion of surrounding mineral stones, and human activities, such as waste disposal from industrial, domestic, and agricultural sources, as well as excessive use of chemical fertilizers (Widyaningrum; Khoiroh et al., 2020; Syuzita et al., 2020).

Mercury is a non-essential heavy metal, and its presence in the body is not known to have any beneficial effects, and it can even be toxic. Mercury is the only metal that is liquid at normal temperatures. In natural fresh waters, mercury levels range from 10-100 nm/L (Moore, 1991), while at station II, mercury levels were found to be 0.00185 mg/L. Mercury exists in nature in the form of metals, inorganic salts, and organic salts. Inorganic mercury salts can cause liver and kidney damage, as the highest mercury deposits are found in these organs (Palar, 1994; Supriharyono, 2000; Effendi, 2000). Accumulation of mercury in the body can result in symptoms such as thermor, parkinsonism, gray eye lens disorders, nerve disorders, and, ultimately, death (Linder, 2010; Wijayanti, 2017). At station II, the iron (Fe) content was measured at 1.0082 mg/L. While the presence of iron in water is necessary for living organisms in certain amounts, excessive iron can become toxic to the body (Murraya et al., 2018). The iron content at station II is due to agricultural runoff entering the water body. Local farmers often use chemical fertilizers containing iron, and during rainfall or excessive irrigation, this runoff flows into the canal, raising the iron levels, in line with the opinion of Viana et al. (2021), who suggest that iron levels can result from runoff from agricultural practices, such as fertilizer application and pesticide spraying.

Temperature measurements at station III ranged from 30.2°C, which is within the optimal range, as stated by Tatangindatu et al. (2013) and Pratiwi (2022), where the optimal temperature is 28-32°C. High and low temperatures can be influenced by various factors, including sunlight and wind. Sunlight plays a key role in determining the amount of heat absorbed by the surface of the water, while wind affects the temperature by moving hot and cold air, bringing heat to colder areas and raising temperatures accordingly (Pasongli & Dirawan, 2015). As stated by Syuzita et al. (2022), temperature changes can be caused by external factors such as wind, humidity, and weather conditions. pH measurements at station III ranged from 7.3, indicating that the water is neutral. Based on PP No. 22 of 2021, this still meets the class III water quality standards, with a minimum limit of 6.9.

The dissolved oxygen concentration was measured at approximately 81.7 mg/L, classified as relatively high based on the quality standards for river water in PP No. 22 of 2021. This indicates that dissolved oxygen at station III exceeds the minimum limit of class

III water quality standards intended for freshwater fish cultivation, animal husbandry, and irrigation, with a minimum limit of 3 mg/L. Water temperature influences the solubility of oxygen in water, with higher temperatures reducing the oxygen solubility, and vice versa (Pasongli & Dirawan, 2015). Turbidity levels at station III were recorded at 80.88 mg/L, which is classified as high. This high turbidity is likely due to sediment accumulation from surface runoff during rainfall, particularly since station III is located at the downstream part of the canal. According to Siahaan et al. (2011), suspended solids from upstream flow downstream, causing increased turbidity. The water turbidity in the Tamalate canal is also influenced by agricultural activities near the canal, as runoff directly enters the water body, causing turbidity. Even slight turbidity can result in darker water (Prayoga, 2021).

The BOD value at station III is approximately 57.05 mg/L, indicating a decline in water quality due to pollution, as higher BOD levels reflect greater organic matter and pollution. As stated by Hindriani (2013), an increase in BOD indicates a decrease in water quality. The accumulation of BOD from polluting sources puts a burden on the canal's ability to recover. The COD concentration, which was recorded at 119.5 mg/L, represents a higher pollution load compared to BOD, highlighting activities that increase COD levels, such as detergent residue disposal, laundry water discharge, food waste disposal, and garbage dumping into the canal. According to Afwa et al. (2021), domestic waste directly discharged into water bodies results in decreased water quality. This is consistent with Setyowati's (2016) statement that high BOD and COD pollution levels stem from wastewater containing organic matter from settlements and agriculture. The findings suggest that the water quality of the Tamalate canal has decreased from upstream to downstream, primarily due to the presence of organic matter, and is classified as mildly polluted. The proximity of rice fields and the disposal of household waste in the area have contributed organic material, impacting water quality.

At station III, the cadmium level was found to be 0, indicating that cadmium pollution is virtually absent, similar to the levels at stations I and II. At station III, mercury levels were recorded as 0 mg/L, which is below the quality standard for river water, with a minimum limit of 0.002 mg/L. This suggests that mercury pollution at station III is not present or does not meet the quality standards. It is suspected that mercury contamination in the downstream part of the canal results from mercury carried by sediments from upstream areas, which accumulate in the estuary. Bernadus & Rorong (2021) state that mercury binds chemically to sediment particles, which are moved through water from rice fields to water bodies, and during the sedimentation process, mercury-bound particles are deposited along the canal flow. From the study, it is evident that the rice fields near the Tamalate canal, combined with fertilizer and pesticide use containing mercury, are major contributors to pollution in the canal waters.

Judging from the results of the study, the Hg levels have varying concentrations at each station. The results of Hg concentrations at station I ranged from 0.0038 mg/L, at station II 0.00185 mg/L, and at station III 0 mg/L, which illustrates that the Hg concentration at station I has exceeded the quality standard, the Hg concentration at station II is still within the average quality standard, and the Hg concentration at station III is below the quality standard and even considered absent. The further downstream the canal, the Hg concentration value decreases or even becomes absent, as explained by Hindratmo et al. (2019). This is because heavy metals entering the canal water environment undergo precipitation, dilution, and dispersion. Nasution (2024) stated that heavy metals have properties that easily bind and settle to the bottom of the water, merging with sediments. Therefore, heavy metal levels in sediments are higher than in water. Heavy metal precipitation in water occurs due to the presence of carbonate, hydroxyl, and chloride anions.

At station III, the Fe content is 0.04 mg/L, which is still in the low category. The low Fe metal content is thought to be due to dynamic water movement, influenced by several factors such as currents, which cause continuous dilution (Murraya et al., 2018). Similarly, Endrawati (2015); Syukriah et al. (2024) stated that high Fe content in water is caused by various factors, one of which is the many activities that dispose of waste into water bodies.

This heavy metal is carried by water currents and later heads toward the estuary. Additionally, the swift flow of the current also dilutes the polluting material, causing the level of water pollution to be very low, while the increase in Fe heavy metal content in water is caused by activities such as domestic waste disposal, including detergents and agricultural waste, as well as the influence of tides and river currents that distribute heavy metals downstream. This is evidenced by the environmental conditions at station III, which is far from or not adjacent to rice fields and residential areas, meaning the Fe levels obtained are likely from upstream contamination, carried by the current downstream of the canal (Firmansyaf et al., 2013).

Iron has many positive impacts if its levels do not exceed the predetermined threshold, but if iron levels in water exceed the threshold, the iron compound becomes toxic and causes damage due to free radicals. One factor contributing to high iron (Fe) content is bedrock weathering (Sudarningsih, 2021; Syuzita et al., 2022). The research data at station III shows that the heavy metal content of Fe in Tamalate canal water is still relatively low, so the water quality of the Tamalate canal from Fe contamination is still relatively good.

4. Conclusions

The water quality of the Tamalate canal showed variations in conditions measured at the three research stations, as observed from heavy metal contamination. The analysis of chemical parameters in the form of heavy metal content (Cd, Hg, and Fe) indicates that the water quality of the Tamalate canal is declining, with the concentration of pollution strengthening the assumption that heavy metals entering the aquatic environment will undergo precipitation, dilution, and dispersion, then be absorbed by organisms living in the Tamalate canal waters. This is supported by the values of BOD and COD concentrations, which have already exceeded the minimum limit set in PP No. 22 of 2021, class III. Cd heavy metal pollution in the Tamalate canal has a concentration value of 0 mg/L at all three observation stations.

Acknowledgments
Would like to express my deepest gratitude to Mrs. Chairunnisah J. Lamangantjo and Mrs. Regina Valentina Aydalina as my supervisors who always provided input during the preparation of this article, and I also express my deepest gratitude to Mr. Zulyanto Zakaria and Mr. Syam S. Kumaji as my examiners, thank you for your help and support as well as valuable motivation and constructive suggestions during the preparation of this article. I would also like to express my deepest gratitude to the Bone Bolango District government for granting me the necessary permits to conduct this research. Your support and cooperation were essential in enabling me to complete this research.

Author Contribution
All authors contributed equally to the conceptualization, methodology, analysis, and writing of this review. They collaboratively reviewed and approved the final manuscript for submission.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The authors declare no conflict of interest.

Open Access

References
Afwa, R. S., Muskananfola, M. R., Rahman, A., Suryanti, S., & Sabdaningsih, A. (2021). Analysis of the load and status of organic matter pollution in Beringin River Semarang. *Indonesian Journal of Chemical Science*, *10*(3), 168-178. https://doi.org/10.15294/ijcs.v10i3.50705

Alfatihah, A., Latuconsina, H., & Prasetyo, H. D. (2022). Analysis of Water Quality Based on Physical and Chemical Paremeters in Patrean River Waters, Sumenep Regency. *AQUACOASTMARINE: Journal of Aquatic and Fisheries Sciences*, *1*(2), 76-84. https://doi.org/10.32734/jafs.v1i2.9174

Anwar, M. C., Wardono, H. R. I., & Cahyono, T. (2019). Heavy Metal (Pb) Exposure in Sediments of the Final Disposal Site (Tpa) River Flow. *Journal of Health Research, 8*(1), 60-67 https://doi.org/10.31983/jrk.v8i1.4440

Apdy, A. R. A. R. (2016). *Levels of Heavy Metal Pollution of Lead (Pb), Mercury (Hg) and Zinc (Zn) in Soil around Losari Beach Flats in Makassar City*. Thesis. Universitas Islam Negeri Alauddin Makassar.

Asrini, N. K., Adnyana, I. W. S., & Rai, I. N. (2017). Study of water quality analysis in Pakerisan watershed, Bali Province. *Ecotrophic: Journal of Environmental Science, 11*(2), 101-107. https://doi.org/10.24843/EJES.2017.v11.i02.p01

Barokah, G. R., Dwiyitno, D., & Nugroho, I. (2019). Heavy metal contamination (Hg, Pb, and Cd) and safe consumption limits of green mussels (Perna virdis) from Jakarta Bay waters in the rainy season. *Journal of Marine and Fisheries Postharvest and Biotechnology, 14*(2), 95-106. http://dx.doi.org/10.15578/jpbkp.v14i2.611

Bernadus, G. E., & Rorong, J. A. (2021). The Impact of Mercury on the Aquatic Environment Around Mining Sites in Loloda District, West Halmahera Regency, North Maluku Province. *Agri-Socioeconomics, 17*(2 MDK), 599-610. https://doi.org/10.35791/agrsosek.17.2%20MDK.2021.35429

Daroini, T. A., & Arisandi, A. (2020). Analysis of BOD (Biological Oxygen Demand) in the Waters of Prancak Village, Sepulu District, Bangkalan. *Juvenil: Scientific Journal of Marine and Fisheries, 1*(4), 558-566. https://doi.org/10.21107/juvenil.v1i4.9037

Effendi, H. (2000). *Water Quality Assessment*. Bogor Agricultural Institute.

Emilia, I., Suheryanto, S., & Hanafiah, Z. (2013). Distribution of cadmium metal in water and sediment in Musi River Palembang City. *Journal of science research, 16*(2). https://doi.org/10.56064/jps.v16i2.73

Ernawati, N. M., & Restu, I. W. (2021). Condition of Physical and Chemical Parameters of Benoa Bay Waters, Bali. *Enggano Journal, 6*(1), 25-36. https://ejournal.unib.ac.id/jurnalenggano/article/view/12781

Fadillah, I., Ramadhani, T. S., & Tiftazani, Z. A. (2023). Estimating Temperature and Ph of

Freshwater Fish Farming Using Support Vector Regression (SVR*). Jurnal Khatulistiwa Informatika, 11*(2), 85-91. https://doi.org/10.31294/jki.v11i2.16177

Farhan, A., Lauren, C. C., & Fuzain, N. A. (2023). Analysis of Water Pollution Factors and the Impact of Community Consumption Patterns in Indonesia. *Journal of Law and Human Rights Wara Sains, 2*(12), 1095-1103. https://doi.org/10.58812/jhhws.v2i12.803

Firmansyaf, D., Yulianto, B., & Sedjati, S. (2013). Study of Iron (Fe) Heavy Metal Content in Water, Sediment and Soft Tissue of Blood Clams (Anadara granosa Linn) in Morosari River and Gonjol River, Sayung District, Demak Regency. *Journal of Marine Research, 2*(2), 45-54. https://doi.org/10.14710/jmr.v2i2.2350

Gholizadeh, M. H., Melesse, A. M., & Reddi, L. (2016). A comprehensive review on water quality parameters estimation using remote sensing techniques. *Sensors*, *16*(8), 1298. https://doi.org/10.3390/s16081298

Harianti, H., & Nurasia, N. (2016). Analysis of color, temperature, pH and salinity of borehole water in Palopo City. *Proceedings, 2*(1). https://core.ac.uk/reader/267087987

Hindratmo, B., Rita, R., Masitoh, S., Kusumardhani, M., & Junaedi, E. (2019). Mercury (Hg) Heavy Metal Content in Former Small-Scale Gold Mining (ASGM) Areas: Case Study in Gunung Botak, Buru Regency, Maluku Province. *Ecolab, 13*(2), 127-132. https://doi.org/10.20886/jklh.2019.13.2.124-129

Hindriani, H. (2013). *Ciujung River Pollution Control Based on Analysis of Total Maximum Daily Load* (Vol. 9). Bogor Agricultural University.

Juhriah, J., & Alam, M. (2016). Phytoremediation of Heavy Metal Mercury (Hg) in Soil with Celosia Plumosa (Voss) Burv. *Bioma: Makassar Journal of Biology, 1*(1). https://doi.org/10.20956/bioma.v1i1.1349

Junaedi, A. F., & Hasanah, U. A. (2014). Counseling on handling household waste. *Journal of Innovation and Entrepreneurship, 3*(2), 111-114.

Khoiroh, S. A., Firdasut, M., & Budiono, Z. (2020). The Relationship of Distance and Soil Permeability to Lead (Pb) and Cadmium (Cd) Levels in Residents' Well Water Around Kaliori Landfill, Kalibagor District, Banyumas Regency. *Buletin Keslingmas*, *39*(1), 23-30. https://doi.org/10.31983/keslingmas.v39i1.4696

Lamangantjo, C. J., Aydalina, R. V., Sarniati, R. R., & Ibrahim, M. (2023). Diversity and Abundance of Fish in The Bone Canal. *E3S Web of Conferences, 400*. https://doi.org/10.1051/e3sconf/202340002006

Linder, M. C. (2010). *Biochemistry of Nutrition and Metabolism: With Clinical Applications.* Appleton & Lange.

Mayagitha, K. A., & Rudiyanti, S. (2014). Water quality status of Bremi River, Pekalongan Regency in terms of TSS concentration, BOD5, COD and phytoplankton community structure. *Management of Aquatic Resources Journal (MAQUARES), 3*(1), 177-185. https://doi.org/10.14710/marj.v3i1.4435

Moore, H. P. (1991). *Marine Pollution by Heavy Metals: in Status of Marine Pollution in Indonesia and Monitoring Techniques*. P30-LIPI.

Murjani, A., Fatmawati & Siswanto. (2024). Water Quality Status and Pollution Control Strategy for the Kanibungan River, Sebuku Island, Kotabaru Regency. *Agroqua Journal: Agronomy and Aquaculture Information Media, 22*(1), 49-60. https://doi.org/10.32663/ja.v22i1.4411

Murraya, M., Taufiq-Spj, N., & Supriyantini, E. (2018). Iron (Fe) heavy metal content in water, sediment and green mussels (Perna viridis) in Trimulyo Waters, Semarang. *Journal of Marine Research, 7*(2), 133-140. https://doi.org/10.14710/jmr.v7i2.25902

Nasution, D. A. (2024). *Test of Remediation Effectiveness Using Coontail Plants (Ceratophyllum Demersum L.) in the Removal of Iron (Fe) Metal Levels in Artificial Waste.* Doctoral dissertation. UIN Ar-Raniry.

Nuraini, R. A. T., Endrawati, H., & Maulana, I. R. (2017). Analysis of chromium (Cr) heavy metal content in water, sediment, and green mussels (Perna viridis) in Trimulyo Semarang Waters. *Journal of Tropical Marine, 20*(1), 48-55. https://doi.org/10.14710/jkt.v20i1.1104

Palar, H. (1994). Heavy Metal Pollution and Toxicology. Rineka Cipta.

Pasongli, H., & Dirawan, G. D. (2015). Zoning of Pond Suitability for Vaname Shrimp (Penaeus Vannamei) Aquaculture Development on Water Quality Aspects in Todowongi Village, Jailolo District, West Halmahera Regency. *Journal of Bioeducation, 3*(2). https://doi.org/10.33387/bioedu.v3i2.70

Pramaningsih, V., Yuliawati, R., Sukisman, S., Hansen, H., Suhelmi, R., & Daramusseng, A. (2023). Water Quality Index and Impact on Public Health around Karang Mumus River, Samarinda. *Indonesian Journal of Environmental Health, 22*(3), 313-319. https://doi.org/10.14710/jkli.22.3.313-319

Pratiwi, N. (2022). *Water Quality Analysis in the Pucak River, Maros District, South Sulawesi Province Based on Physics-Chemical Parameters*. Doctoral dissertation. Hasanuddin University.

Prayoga, E (2021). *Analysis of the Impact of Domestic Waste on the Water Quality of Anak Sungai Asam*. Doctoral dissertation. Batanghari University.

Purbalisa, W., & Mulyadi, M. (2018). Pb and Cu in Water Bodies and Rice Field Soil of Solo Hilir Sub-basin, Lamongan Regency. *Agrologia, 2*(2). https://doi.org/10.30598/a.v2i2.266

Purnawan, S., Sikanna, R., & Prismawiryanti. (2013). Distribution of mercury metal in marine sediments around Poboya River Estuary. *Journal of Natural Science, 2*(1),18-24. https://doi.org/10.22487/25411969.2013.v2.i1.1580

Purwati, D, N. E. (2015). *Analysis of Bod and Cod Levels in River Water (Study in Jombang Regency River).* Doctoral dissertation. STIKes Insan Cendekia Medika Jombang.

Putriningtias, A., Bahri, S., Faisal, T. M., & Harahap, A. (2021). Water quality in the coastal area of Ujung Perling Island, Langsa City, Aceh. *Habitus Aquatica, 2*(2), 95-99. https://doi.org/10.29244/HAJ.2.1.95

Ramadhawati, D., Wahyono, H. D., & Santoso, A. D. (2021). Online monitoring of cisadane river water quality and quality status analysis using the storet method. *Journal of Environmental Science & Technology, 13*(2), 76-91. https://doi.org/10.20885/jstl.vol13.iss2.art1

Samarinda, E. B. (2017). Analysis of Water Quality Based on Parameters of Violence, TDS (Total Dissolved Solid), Ph and Organic Substances in Bukit Batu Putih Way, Samarinda, East Kalimantan. *Journal of Mineral Technology FT UNMUL, 5*(2), 1-4. https://e-journals.unmul.ac.id/index.php/TM/issue/view/140

Samsundari, S., & Wirawan, G. A. (2013). Analysis of biofilter application in recirculation system on water quality quality of eel fish (Anguilla bicolor) cultivation. *Journal of gamma, 8*(2). https://ejournal.umm.ac.id/index.php/gamma/article/view/2410

Santoso, A. D. (2018). Remonstration of DO, BOD and COD Values in a Former Coal Mine Lake. *Journal of Environmental Technology, 19*(1). http://dx.doi.org/10.29122/jtl.v19i1.2511

Sara, P. S., Astono, W., & Hendrawan, D. I. (2018, October). Water quality assessment in ciliwung river with BOD and COD parameters. In *Proceedings of the National Seminar of Scholars* (pp. 591-597). https://doi.org/10.25105/semnas.v0i0.3478

Selayar, N. A., Tumembouw, S., & Mondoringin, L. L. (2015). Analysis of Heavy Metal Content of Mercury (Hg) Around the Bay of Manado. *e-Journal of Aquaculture, 3*(1). https://doi.org/10.35800/bdp.3.1.2015.6947

Septiani, W., Khairuddin, K., & Yamin, M. (2022). The evidence of cadmium (Cd) heavy metal in south Asian apple snail (Pila ampullacea) on the Batu Kuta village Narmada district. *Journal of Tropical Biology, 22*(2), 339-344. https://doi.org/10.29303/jbt.v22i2.2586

Setyowati, R. D. N. (2016). Literature study on the effect of land use on water quality. *System: Journal of Engineering Sciences, 12*(1), 7-15. https://repository.uinsa.ac.id/id/eprint/1865/

Siahaan, R., A. Indrawan, D. Soedharma and Lilik B. Prasetyo. (2011). Water Quality of Cisadane River, West Java-Banten. *Scientific Journal of Science, 11*(2), 268-273. https://doi.org/10.35799/jis.11.2.2011.218

Simbolon, A. R. (2016). Status of Pollution in Cilincing Waters, Coastal DKI Jakarta. *Pro-Life Journal, 3*(3), 167-180. http://ejournal.uki.ac.id/index.php/prolife/article/view/29/0

Sudarningsih, S. (2021). Analysis of Heavy Metal Contents in Sediments from Martapura River, South Kalimantan Analysis of Heavy Metal Contents in Sediments from Martapura River, South Kalimantan. *Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat, 18*(1), 1-8. https://dx.doi.org/10.20527/flux.v17i2.7089

Sukarjo, S., Hidayah, A., & Zulaehah, I. (2018, May). Effect of Fertilizer on Accumulation and Translocation of Cadmium and Lead in Soil and Plants. In *Prosiding SNPBS (Seminar Nasional Pendidikan Biologi dan Saintek)* (pp. 205-211). https://proceedings.ums.ac.id/snpbs/article/view/573

Supriharyono. (2000). *Conservation and Utilization of Natural Resources in Tropical Coastal Areas*. Gramedia Pustaka Utama.

Supriyantini, E., & Endrawati, H. (2015). Iron (Fe) heavy metal content in water, sediment, and green mussels (Perna viridis) in the waters of Tanjung Emas Semarang. *Journal of tropical marine, 18*(1). https://ejournal2.undip.ac.id/index.php/jkt/article/view/512

Suriani. (2016). *Analysis of Heavy Metal Content of Lead (Pb), Cadmium (Cd), and Zinc (Zn) in Paddy Field Soil in Paccinongan Village, Sombaopu District, Gowa.* Thesis. UIN Alauddin Makassar.

Sutrisno, S., & Kuntyastuti, H. (2015). Management of Cadmium Contamination in Agricultural Land in Indonesia. *Buletin Palawija*, *13*(1), 83-91. https://doi.org/10.21082/bul%20palawija.v13n1.2015.p83-91

Syachroni, S. H. (2017). Analysis of Cadmium (cd) Heavy Metal Content in Rice Field Soil in Palembang City. *Sylva Journal, 6*(1), 23-29. https://doi.org/10.32502/sylva.v6i1.893

Syukriah, S., Fauziansyah, H., & Amira, S. (2024). Study of Iron (Fe) Heavy Metal Content in Water and Fish in Medan Belawan Pond, North Sumatra. *Bioma: Scientific Periodical Biology, 26*(1), 16-26. https://doi.org/10.14710/bioma.2024.58929

Syuzita, A., Meiliyadi, L. A. D., & Bahtiar, B. (2022). Leachate pollution level in shallow groundwater around Kebon Kongok landfill using physical and chemical parameters. *Journal of Flux Physics: Scientific Journal of Physics FMIPA Lambung Mangkurat University, 19*(2), 126-134. https://dx.doi.org/10.20527/flux.v19i2.13030

Tatangindatu, F., Kalesaran, O., & Rompas, R. (2013). Study of physical parameters of water chemistry in fish farming areas in Lake Tondano, Paleloan Village, Minahasa Regency. *E-Journal of Aquaculture, 1*(2). https://doi.org/10.35800/bdp.1.2.2013.1911

Usman, T., Wahyuni, N., Ramadani, M. I., Nainggolan, D. D. J., & Astar, I. (2024). Continuous Adsorption of PDAM Water Color Using Metakaolin. *Journal of Environmental Science, 22*(6), 1554-1561. https://doi.org/10.14710/jil.22.6.1554-1561

Viana, L. F., Crispim, B. D. A., Sposito, J. C. V., Melo, M. P. D., Francisco, L. F. V., Nascimento, V. A. D., & Barufatti, A. (2021). High iron content in river waters: environmental risks for aquatic biota and human health. *Revista Ambiente & Água*, *16*, e2751. https://www.scielo.br/j/ambiagua/a/XMzr8VkNYGVsdcRjxNfk83F/?format=html

Wangge, E., Sito, E., & Mutiara, C. (2022). Testing the Heavy Metal Cadmium Contamination Levels in Soil and Rice (*Oryza sativa L.*) in Lape Village, Aesesa Sub-District, Nagekeo District. *Agrica, 14*(2), 152-157. https://doi.org/10.37478/agr.v14i2.1482

Wihardjaka, A & Harsanti, E. S. (2018). Cadmium (Cd) Concentration in Rice Grain and Rainfed Rice Field Soil Due to Routine Fertilizer Application. *Ecolab. 12*(1): 12-19. https://doi.org/10.20886/jklh.2018.12.1.12-19

Wijayanti, T. (2017). Profile of heavy metal pollution in waters of Grindulu Pacitan watershed. *Scientific Journal of Science,* 19-25. http://dx.doi.org/10.4067/S0718-58392022000100033

Wulandari, S. R., & Hutabarat, S., & Ruswahyuni. (2015). Influence of current and substrate on seaweed density distribution in Panjang Island Waters West and South. *Management of Aquatic Resources Journal (MAQUARES)*, *4*(3), 91-98. https://doi.org/10.14710/marj.v4i3.9324

Yusal, M. S., & Hasyim, A. (2022). Assessment of Water Quality Based on Meiofauna Diversity and Physics-Chemical Parameters in the Coastal Losari, Makassar. *Journal of Environmental Science, 20*(1), 45-57. https://doi.org/10.14710/jil.20.1.45-57

Zainuri, M., Indriyawati, N., Syafifah, W., & Fitriyah, A. (2023). Correlation of light intensity and temperature to phytoplankton abundance in the Ujung Piring Estuary Waters of Bangkalan. *Marina Oceanography Bulletin, 12*(1), 20-26. https://doi.org/10.14710/buloma.v12i1.44763

Biographies of Authors

Fani Suma, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Bone Bolango, Gorontalo 96119, Indonesia.

- Email: fansum13@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Chairunnisah J. Lamangantjo, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Bone Bolango, Gorontalo 96119, Indonesia.

- Email: chairunnisah@ung.ac.id
- ORCID: 0000-0001-9129-9834
- Web of Science ResearcherID: N/A
- Scopus Author ID: 57189302148
- Homepage: https://scholar.google.co.id/citations?user=uAPi72YAAAAJ&hl=id

Regina Valentina Aydalina, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Bone Bolango, Gorontalo 96119, Indonesia.

- Email: aydalinaregina@ung.ac.id
- ORCID: 0000-0002-7256-5591
- Web of Science ResearcherID: N/A
- Scopus Author ID: 58093433200
- Homepage: https://scholar.google.co.id/citations?user=Ia9XsHQAAAAJ&hl=en

Zuliyanto Zakaria, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Bone Bolango, Gorontalo 96119, Indonesia.

- Email: zuliyanto_zakaria@ung.ac.id
- ORCID: 0000-0003-1620-4086
- Web of Science ResearcherID: N/A
- Scopus Author ID: 57218530912
- Homepage: https://scholar.google.co.id/citations?user=xlFNK3MAAAAJ&hl=id

Syam S. Kumaji, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Bone Bolango, Gorontalo 96119, Indonesia.

- Email: syam_bio@ung.ac.id
- ORCID: 0000-0002-1835-8313
- Web of Science ResearcherID: N/A
- Scopus Author ID: 57220206486
- Homepage: https://scholar.google.co.id/citations?user=O-2t8HwAAAAJ&hl=id