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Regional Case Study

Sustainable Strategies to Reduce Water Pollution from Domestic Wastewater Discharge

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Abstract

Urban rivers are increasingly threatened by pollution from domestic and industrial waste, leading to water quality degradation. The Pampang River in Makassar, an essential water source for residential, agricultural, and industrial use, faces growing pressure from untreated wastewater discharge. This study evaluates the current water quality status of the Pampang River by analyzing BOD, COD, pH, and temperature, and projects future pollution trends using predictive modeling. Water samples were collected from six strategic locations along the river to represent various pollution sources. BOD and COD were analyzed according to SNI 6989.72:2009 and SNI 6989.02:2019, while pH and temperature were measured in situ. A time series regression model predicted pollution levels over the next five years. Results indicate BOD (4.426–6.439 mg/L) and COD (34.1594–43.4827 mg/L) remain within regulatory standards but show an upward trend, potentially exceeding acceptable limits in 3–4 years. pH (7.39–8.08) and temperature (31.9°C–34.4°C) reflect the impact of detergents and urban runoff, threatening biodiversity and oxygen levels. Without intervention, the river's pollution will escalate, posing ecological and health risks. Sustainable strategies, including better wastewater treatment, stricter industrial regulations, and community-based wastewater management, are essential for long-term water quality sustainability.

Keywords: BOD; COD; domestic wastewater; sustainable water management; urban rivers; water pollution

1. Introduction

Water pollution, especially in rapidly urbanising regions, poses a significant threat to river ecosystems and human health (Rashid et al., 2018; Giri, 2021; Akhtar et al., 2021; Lin et al., 2022). Water quality degradation due to anthropogenic activities, such as domestic and industrial wastewater discharge, has been well documented in various river systems around the world. These activities cause significant changes in physicochemical properties, including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, and temperature-parameters that are important indicators of water quality and ecological health (Djoharam et al., 2018; Choi et al., 2021; Lacalamita et al., 2024). The impact of urbanisation on river pollution is evident in many case studies, such as the Minjiang River in China, where a strong correlation between rapid urbanisation and increased pollution levels has been established (Zhao et al., 2024). Similarly, heavy metals, including cadmium and arsenic, have been identified as major contaminants in various river systems, highlighting the ecological risks posed by industrial activities (Syafri et al., 2020; Zhang et al., 2021).

Figure 1. Pollution Condition of Pampang River

The Pampang River, located in Makassar City, is a prime example of a river that faces severe pollution threats due to unregulated domestic and industrial wastewater discharges. Urban runoff and wastewater discharges have contributed to significant water quality degradation, likely introducing heavy metals and hazardous pollutants into the aquatic ecosystem. Understanding the relationship between domestic wastewater and river pollution is critical in assessing urban water quality dynamics (Giri et al., 2021; Syafri et al., 2020; Custadio et al., 2021; Anh et al., 2023). Studies show that domestic sources often contribute more to the overall pollution load of rivers than industrial sources (Xu et al., 2022; Rifai et al., 2023; Kumar et al., 2024). In the case of the Pampang River, the continuous discharge of untreated domestic wastewater has led to elevated levels of BOD and COD, indicating organic pollution that significantly impacts aquatic life and public health (Hanif et al., 2020; Maddah, 2022; Mangkoedihardjo, 2023). In addition, rainfall and stormwater runoff exacerbate pollution levels by transporting household and industrial wastewater directly into the river (Akhtar et al., 2021; Zeng et al., 2022; Prayoga et al., 2023; Sun et al., 2024).

Industrial effluents not only generate organic and inorganic pollutants, but also disrupt microbial communities important for nutrient cycling, thereby affecting the self-purification capacity of rivers (Zhang et al., 2021; Chakraborty & Chakraborty, 2021; Fan et al., 2024). Such disturbances can trigger cascading ecological effects, including loss of biodiversity, shifts in trophic interactions and collapse of aquatic ecosystems. In addition, poor water quality poses a direct risk to human populations by acting as a vector for waterborne diseases and other health problems (Hanif et al., 2020; Ali et al., 2021; Nooreen et al., 2022; Yeboah et al., 2024). Given the role of river water as a resource for irrigation, fisheries and domestic consumption, pollution control is urgent.

Various studies have shown that river pollution is often indicated by elevated levels of BOD and COD, indicating the presence of organic and chemical contaminants (Haq & Kalamdhad, 2021; Setiawan, 2024; Contieri et al., 2024). BOD serves as the primary metric for biodegradable organic matter in water, while COD measures the total oxygen required to oxidise both biodegradable and non-biodegradable substances (Djoharam et al., 2018; Choi et al., 2021; Lacalamita et al., 2024). Increased levels of these parameters lead to reduced dissolved oxygen (DO), which negatively impacts aquatic sustainability. High levels of BOD and COD are correlated with reduced oxygen saturation, resulting in hypoxia and fish mortality (Braz-Mota & Almeida-Val, 2021; Joshi et al., 2022; Anifowoshe et al., 2022). In many urban rivers, untreated wastewater significantly increases pollution levels, making the water unusable for irrigation, drinking and recreational activities (Tyagi & Sarma, 2021; Hamzah et al., 2024). The presence of organic and inorganic compounds from both domestic and industrial sources further underscores the need for robust water quality monitoring systems to track pollution levels and enforce environmental regulations (Kruszelnicka et al., 2019; Surya et al., 2020; Mohanty et al., 2024). In addition to BOD and COD, fluctuations in pH and temperature can alter chemical reaction rates and biological activity, further impacting water quality and biodiversity (Pinheiro et al., 2021; Zaman et al., 2024). Hasan et al. (2016) observed that temperature variations significantly affected BOD and COD levels, thereby affecting the overall health of aquatic ecosystems (Syerin et al., 2023). The interactions between these physico-chemical parameters highlight the complexity of river ecosystem management, especially in urban areas where pollution sources are diverse and widespread (Islam et al., 2023).

The Pampang River plays an important role in providing water for irrigation, fisheries and domestic consumption. However, its strategic location in a densely populated and industrialised area makes it highly vulnerable to pollution. The river has been the site of extensive wastewater discharges from residential, commercial, and industrial sources, leading to marked degradation of water quality, including turbidity, foul odour, and excessive wastewater build-up (Miah et al., 2023; Setyawan et al., 2024). A similar case has been documented in the Ciliwung River in Jakarta, where dense urbanisation resulted in severe water quality degradation due to household discharges and wastewater (Tyassari et al., 2024). Observations in the Pampang River mirror these findings, as untreated sewage and urban runoff continue to be major contributors to pollution (Khan et al., 2021).

In addition, weak enforcement of water pollution regulations remains a major challenge. Despite the existence of legal frameworks designed to protect water quality, compliance and enforcement are inadequate, allowing for continued degradation of river ecosystems (Akhtar et al., 2021; Odume et al., 2022; Setyono et al., 2024). The case of the Gomti River in India is an example of this problem, where the discharge of untreated domestic wastewater has caused severe pollution (Khan et al., 2021). Similarly, the Pampang River faces regulatory challenges that exacerbate the environmental crisis. The physicochemical characteristics of the river, including BOD, COD, pH, and temperature, are important indicators of its pollution status. Elevated levels of BOD and COD are usually associated with organic pollution, which can adversely affect aquatic life and human health (Singer et al., 2019; Islam et al., 2023; Singh et al., 2024). In addition, heavy metals and other contaminants from industrial discharges further complicate water quality dynamics, posing risks to ecosystems and communities that depend on rivers for livelihoods (Makwana, 2020; Giri et al., 2021; Kumar et al., 2024).

Given the challenges facing the Pampang River, this study aims to assess the level of pollution by analysing BOD, COD, pH, and temperature and compare them with established water quality standards (Ministry of Environment and Forestry Decree No. 155/2003). In addition, the study will also evaluate future pollution trends using predictive modelling and propose sustainable strategies to reduce pollution and improve long-term water management. Previous research has mainly focussed on short-term pollution assessment, leaving gaps in long-term projections and mitigation strategies (Chakraborty et al., 2021). To address this gap, this research integrates a sustainability perspective, providing a quantitative assessment of pollution trends while identifying long-term mitigation strategies (Hua & Gani, 2022). Sustainable solutions, such as upgrading wastewater treatment facilities, enforcing stricter discharge regulations, and promoting green infrastructure (e.g., wetlands and vegetative buffers), have been recognised as effective measures to control river pollution (Achmad et al., 2024; Shrestha et al., 2023). The findings of this study are expected to provide valuable insights to policy makers, environmental agencies, and local communities, enabling the development of an effective water resources management framework that is aligned with Sustainable Development Goal (SDGs) 6-Clean Water and Sanitation.

2. Methods

2.1 Research Location

The location of this study is in Pampang River, a tributary of Tallo River in Makassar, South Sulawesi, with coordinates of 119°26'40.56"E longitude and 5°8'21.31"S latitude. The river stretches for about 3.5 km, flowing through densely populated and industrial areas, making it highly vulnerable to domestic and industrial wastewater pollution. Six selected sampling locations were distributed along the river to represent various levels of pollution, taking into account residential, commercial, and industrial areas. The sampling locations included upstream, middle, and downstream areas to ensure a comprehensive assessment of pollution trends.

2.2 Research Design

This study uses a quantitative research approach using field sampling, laboratory analysis, and predictive modelling. The study follows a cross-sectional study design, with water samples collected from six different points along the Pampang River to assess physicochemical characteristics. Data collection and analysis refer to Indonesian National Standards (SNI 6989.72:2009 and SNI 6989.02:2019), to ensure compliance with national water quality guidelines. The main physicochemical parameters analysed include: (1) Biochemical Oxygen Demand (BOD): Measures the amount of oxygen required by microorganisms to break down organic matter; (2) Chemical Oxygen Demand (COD): Represents the oxygen required to chemically oxidise biodegradable and non-biodegradable organic matter; (3) pH (Acidity): Indicates the alkalinity or acidity of river water, which affects chemical stability and biological processes; and (4) Temperature: Affects oxygen solubility, microbial activity, and the rate of chemical reactions in aquatic environments.

2.3 Sampling and Data Collection

Water samples were collected from six main points along the Pampang River, selected based on anthropogenic activity, pollution sources, and river flow dynamics. Sampling locations include: (1) Tallo River Bridge, (2) Racing Centre Bridge, (3) Unibos Campus Side, (4) Behind Ibnu Sina Hospital , (5) Pampang Bridge, (6) Near the Pampang Regulation Reservoir.

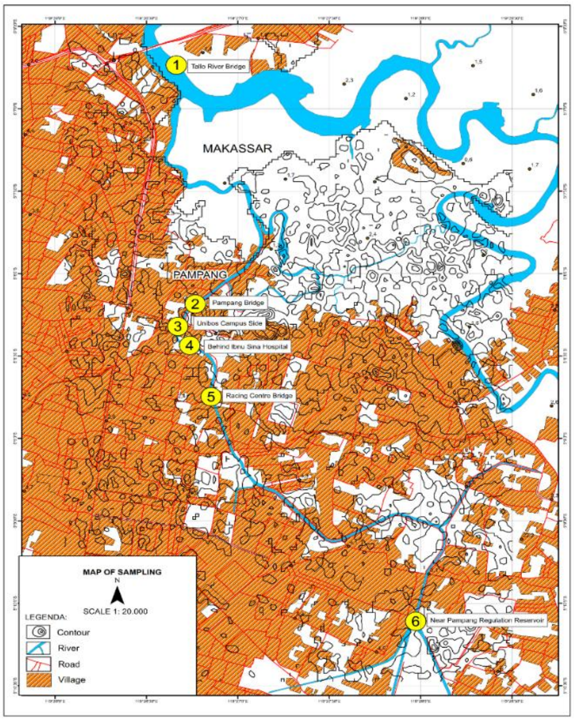

Figure 2. Research Location

Water samples were collected following standard sampling techniques. Sterile polyethylene bottles (1000 mL) were used to collect samples at a depth of 20-30 cm from the water surface, to ensure accurate representation of pollution levels. All samples were preserved at 4°C during transport to the laboratory to prevent degradation. Sampling is carried out during the dry and rainy seasons to determine seasonal variations in pollution levels (Kruszelnicka et al., 2019).

2.4 Laboratory Testing

Laboratory tests include Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH measurement, and temperature measurement. BOD is determined based on SNI 6989.72:2009 by incubation method for 5 days at a temperature of 20°C, where the concentration of dissolved oxygen (DO) is measured before and after incubation, with the difference indicating the oxygen consumed by microbial activity. COD is measured based on SNI 6989.02:2019 using the closed reflux titrimetry method with potassium dichromate ($K_2Cr_2O_7$) as the oxidant, where the amount of reduced dichromate is used to calculate the COD concentration (mg/L). The pH measurement was carried out in situ using a portable pH meter to ensure real-time recording of the acidity level. Meanwhile, the water temperature was recorded in situ using a digital water quality meter that recorded temperature variations along six sampling locations.

2.5 Data Analysis

The collected data is analysed using descriptive analysis. The results are compared with Indonesian water quality standards (Ministry of Environment and Forestry Decree No. 155/2003) to assess the severity of the pollution. To estimate long-term pollution trends, a time series projection model is applied to forecast BOD and COD variations over the next five years. This model uses linear regression analysis, assuming a consistent increase in pollution over time. The general equation used is Stock, James H and Mark W. Watson, (2015)

$$Y_T = \alpha + \beta X_t + \varepsilon_t \quad (1)$$

The model for estimating the level of pollution at a given time (Y_T) is formulated as a function of several variables, where Yt represents the estimated level of pollution at time (t), measured in BOD or COD concentration. The parameter α acts as an intercept reflecting the initial level of pollution, while β indicates the rate of increase in pollution per year. The variable Xt represents the time of year, while ε_t is the error term that accommodates unexplained variations in the model. The model is validated using historical water quality data and statistical tests to assess its accuracy and reliability (Setyawan et al., 2024).

3. Result and Discussion

3.1 Biochemical Oxygen Demand (BOD) Analysis

Biochemical Oxygen Demand (BOD) is an important parameter that measures the amount of oxygen needed by microorganisms to break down organic matter in water. Table 1 presents the BOD levels recorded at six different sampling sites along the Pampang River.

Table 1. Biochemical oxygen demand levels in the pampang river

Point	Sample Point	BOD (mg/L)	Testing Method
1	Tallo River Bridge	6.439	SNI 6989.72:2009
2	Pampang Bridge	5.634	
3	Unibos Campus Side	4.829	
4	Behind Ibnu Sina Hospital	5.467	

Point	Sample Point	BOD (mg/L)	Testing Method
5	Racing Centre Bridge	4.426	
6	Near Pampang Regulation Reservoir	5.471	

Source: Laboratory Analysis by BBSP JIHPMM, 2024

The highest BOD concentration was recorded at Point 1 (Tallo River Bridge) at 6.439 mg/L, while the lowest was at Point 5 (Racing Centre Bridge) at 4.426 mg/L. The highest BOD value at Point 1 indicates a significant accumulation of organic matter, most likely originating from the upstream flow of the river. However, according to Setiawan et al. (2019), high BOD levels should be interpreted carefully, as they do not always directly indicate pollution without considering other supporting water quality parameters. Determination of pollution status must consider other water quality parameters, such as COD, pH, and temperature. Meanwhile, the lowest BOD value was recorded at Point 5 (Racing Centre Bridge) at 4.426 mg/L, which may be influenced by stronger river currents and natural dilution processes, as commonly observed in river segments with higher flow velocity and lower pollutant input (Setiawan et al., 2019). Overall, the results of the analysis show that the BOD values at all sampling points are still within the standard water quality limits as stipulated in the Minister of Environment Regulation No. 155 of 2003.

Based on Figure 2, modelling of the BOD trend in the Pampang River shows a progressive increase over the next five years. It is estimated that in the 4th year, the BOD value will exceed the required quality standard, indicating a significant increase in the organic pollution load. Bezsenyi et al. (2021) mention that the BOD value can be used as an indicator of organic pollution in water, because the higher the BOD value, the greater the amount of oxygen consumed by microorganisms to break down organic matter. This increase risks lowering the level of dissolved oxygen (DO) in the water, which in turn can disrupt the balance of the aquatic ecosystem and endanger aquatic life. Therefore, immediate mitigation measures are needed to control pollution and maintain the long-term water quality of the Pampang River.

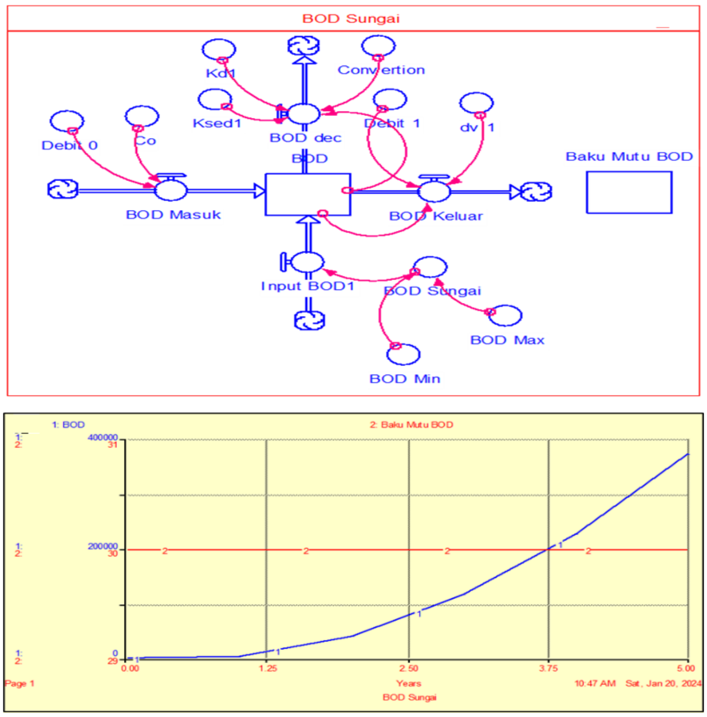

Figure 3. Projected BOD Trend in the Pampang River (2024-2028)

3.2 Chemical Oxygen Demand (COD) Analysis

Chemical Oxygen Demand (COD) is a broader indicator of water pollution that includes both biodegradable and non-biodegradable pollutants. The COD levels recorded at various sampling locations are summarised in Table 2.

Table 2. Chemical oxygen demand levels in the pampang river

Point	Sample Point	BOD (mg/L)	Testing Method
1	Tallo River Bridge	43.4827	SNI 6989.02:2019
2	Pampang Bridge	34.1594	
3	Unibos Campus Side	37.0853	
4	Behind Ibnu Sina Hospital	39.4657	
5	Racing Centre Bridge	39.7137	
6	Near Pampang Regulation Reservoir	36.0439	

Source: Laboratory Analysis by BBSP JIHPMM, 2024

Based on the results presented in Table 2, the analysis of Chemical Oxygen Demand (COD) shows that all sampling points still meet the established water quality standards. However, spatial variations in COD values indicate differing levels of organic and chemical pollution along the Pampang River. The fluctuations observed may be influenced by upstream pollutant input, river flow dynamics, and natural processes such as dilution and sedimentation, particularly near reservoir areas.

The high levels of COD at Point 1 have a similar pattern to the BOD results, which shows that this area has accumulated organic matter and pollutants. However, not all substances in COD can be broken down biologically, so non-biodegradable organic compounds continue to degrade water quality. Djoharam et al. (2018), revealed that bacteria can oxidise organic substances into CO_2 and H_2O, which results in a higher COD value than BOD for the same water sample. This explains why the COD value is always greater than the BOD, because COD also includes chemical compounds that are difficult to biodegrade. Therefore, high COD values can be a major indicator of more complex organic and chemical pollution in the Pampang River.

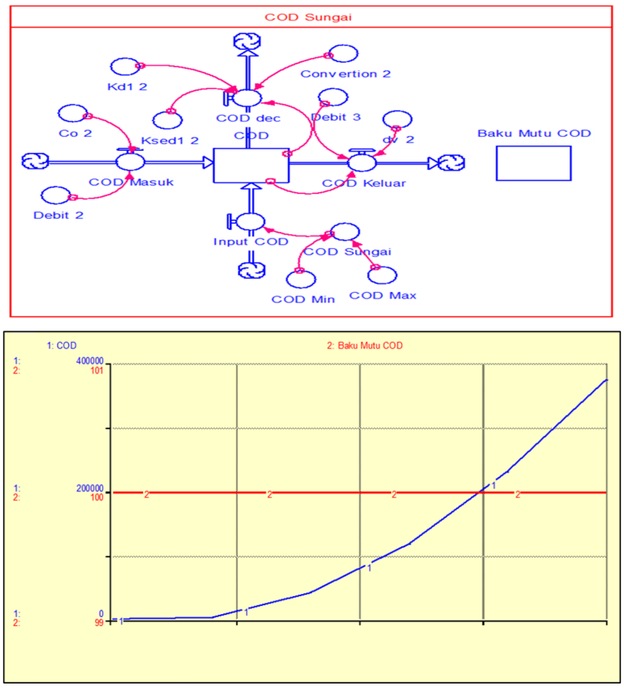

Figure 4. Projected COD Trends in the Pampang River (2024-2028)

Based on Figure 3, the modelling of the COD trend shows that in the next five years, the COD value is expected to continue to increase, with the peak of pollution occurring in the 3rd year, where the COD level exceeds the required quality threshold. This was also revealed by Lacalamita et al (2024), who stated that a higher COD value compared to BOD indicates the presence of non-biodegradable materials, such as heavy metals, detergents, and chemical compounds from industrial and household wastewater. Thus, without effective mitigation efforts, water pollution in the Pampang River could reach levels that endanger the aquatic ecosystem and the health of the people who depend on these water resources.

3.3 pH and Temperature Analysis

pH and temperature significantly affect the chemical stability and biological processes in aquatic ecosystems. Table 3 summarises the pH and temperature values recorded at six sampling sites.

Table 3. pH and temperature levels in the pampang river

Point	Sample Point	pH	Temperature (°C)
1	Tallo River Bridge	7.79	33.1
2	Pampang Bridge	7.39	34.4
3	Unibos Campus Side	8.08	33.1
4	Behind Ibnu Sina Hospital	7.41	31.9
5	Racing Centre Bridge	7.67	32.9
6	Near Pampang Regulation Reservoir	8.01	32.7

Source: Laboratory Analysis by BBSP JIHPMM, 2024

Table 3 presents the pH and temperature levels at six sampling points along the Pampang River. The pH ranged from 7.39 to 8.08, indicating neutral to slightly alkaline conditions. Temperature varied between 31.9°C and 34.4°C, with the highest recorded at Point 2. All values remain within acceptable limits for river water quality. The results of this analysis show that the temperature variation along the Pampang River is relatively small, indicating the presence of environmental factors that influence temperature fluctuations in different locations. Furthermore, Boyd & Boyd (2020) state that an increase in water temperature can reduce the level of dissolved oxygen (DO) due to the diffusion process between water and the atmosphere, as well as being influenced by photosynthetic activity in aquatic ecosystems. However, based on the Minister of Environment Regulation No. 155 of 2003, the water temperature in the Pampang River is still within the water quality threshold, so it still supports fish farming activities with a floating net pond system around the Pampang Watershed. Temperature fluctuations between measurement points are influenced by several factors, including sunlight intensity, water depth, and the geographical conditions of each location (Tian et al., 2019; Vohsen & Herrera, 2024). According to Secchi et al. (2011), temperature differences in a body of water can be caused by exposure to sunlight, heat exchange between water and ambient air, topographic elevation, and the degree of vegetation cover along the stream. This is very relevant to the condition of the Pampang River, where at several points aquatic vegetation such as water hyacinth and other plants are found, which play a role in retaining heat and affecting water temperature locally.

In addition to temperature, measurements of the pH of the water at each point show values ranging from 7.39 to 8.08. Point 1 (Tallo River Bridge) has a pH of 7.79, while Point 2 (Pampang Bridge) shows a decrease to 7.39. At Point 3 (next to Unibos Campus), the pH increased to 8.08, then decreased at Point 4 (7.41), then rose again at Point 5 (7.67) and Point 6 (8.01). When compared to the water quality standard according to the Minister of Environment Regulation No. 115 of 2003, where the normal pH range for waters is 6.5–9.0, all pH values obtained are still within safe limits for aquatic ecosystems. The high pH value at Point 3 (8.08) can be attributed to the influence of domestic wastewater disposal and household activities in the surrounding area. This point is close to the confluence of drainage canals, which receive household wastewater from residential areas, especially wastewater containing detergents and chemicals from washing and bathing. According to Purba (2022), waters with a normal pH allow microorganisms and aquatic plants such as water hyacinth to play a role in the decomposition and oxidation of pollutants. However, the difference in pH between sampling points shows that organic and inorganic wastewater discharged into rivers contributes to variations in the acidity of the water. This is strongly correlated with the environmental conditions around the Pampang watershed, where domestic and industrial activities have a direct influence on the dynamics of pH and overall water quality.

Figure 5. The meeting point of the canal with the Pampang River

3.4 Water Quality Trend Analysis

Time series projections were made to estimate future pollution trends in the Pampang River. BOD and COD trends show this: (1) BOD levels will exceed the set threshold within 4 years, leading to increased oxygen depletion and risk to aquatic life; (2) The COD level will exceed acceptable limits within 3 years, indicating the accumulation of non-biodegradable pollutants such as plastics, industrial chemicals, and heavy metals; and (3) Trends in pH and temperature indicate that urban runoff and wastewater discharge can continue to impact water chemistry, with potential ecological consequences. Projected increases in BOD and COD are in line with the findings of Buraerah et al. (2023), who emphasise that the accumulation of organic wastewater is a major driver of river degradation. Higher COD values compared to BOD indicate the presence of non-biodegradable contaminants, which require better wastewater treatment strategies (Djoharam et al., 2018).

3.5 Trends in Water Quality and Sources of Pollution

The findings of this study show a strong correlation between anthropogenic activity and the increasing level of organic and chemical pollution in the Pampang River. The highest concentrations of Biochemical Oxygen Demand (BOD) (6,439 mg/L) and Chemical Oxygen Demand (COD) (43,4827 mg/L) recorded at the Tallo River Bridge indicate a significant accumulation of pollutants in the upstream area. This trend is in line with research in other urban rivers in Indonesia, such as the Ciliwung River, where high BOD and COD levels are caused by inadequate wastewater treatment infrastructure and uncontrolled wastewater disposal (Rajagukguk & Pranoto, 2023; Juwana et al., 2023). Similarly, in densely populated areas along the Ciliwung River, domestic sewage has been identified as a major contributor to declining water quality (Juwana et al., 2023).

Figure 6. Urban runoff and untreated wastewater discharge in the Pampang River

A similar phenomenon is likely to occur in the Pampang River, where urban runoff and untreated domestic wastewater discharge are major contributors to increasing BOD and COD levels. The observed decrease in BOD and COD levels downstream can be attributed to natural dilution and self-purification processes. However, predictive modelling shows that without effective mitigation measures, BOD and COD levels will exceed regulatory thresholds within three to four years, leading to severe ecological consequences. Previous research has emphasised that increased concentrations of organic wastewater in water bodies result in decreased levels of dissolved oxygen (DO), ultimately causing long-term ecological degradation (Ratnaningsih et al., 2019; Shil et al., 2019). In addition, the cumulative impact of industrial discharges, urban runoff, and untreated domestic wastewater has been shown to disrupt the structure of microbial communities, further exacerbating the imbalance of river ecosystems (Zhang et al., 2021; Liu et al., 2021).

Improving the water quality of the Pampang River requires a multi-faceted approach that addresses both domestic and industrial sources of wastewater. Strengthening wastewater management, enforcing stricter industrial wastewater regulations, and promoting community-based wastewater management programmes will be crucial in reducing pollution. The results of the study highlight that anthropogenic activities, especially unregulated wastewater discharge, are the main drivers of the deterioration of water conditions. Therefore, sustainable pollution control strategies and strong regulatory interventions are essential to maintain ecological balance and protect public health.

3.6 Biochemical Oxygen Demand (BOD) and its Implications for River Sustainability

BOD analysis shows significant levels of organic pollution in the Pampang River, with the highest values recorded at the Tallo River Bridge (6,439 mg/L) and behind Ibnu Sina Hospital (5,467 mg/L). These values reflect the oxygen requirements of microorganisms to break down organic matter, which serves as a key indicator of water quality and pollution levels (Zulfikar et al., 2022). Although these values are still within the limits set by the WHO (1985) (50 mg/L for wastewater before discharge into water bodies), the trend of increasing BOD raises concerns about long-term oxygen depletion (Oladeji, 2020). High BOD levels correlate with a decrease in dissolved oxygen (DO) levels, which leads to hypoxic conditions that damage aquatic habitats and reduce biodiversity (Prokkola et al., 2022).

The increase in BOD levels in the Pampang River is mainly caused by untreated household wastewater and runoff from residential areas. A similar trend also occurs in the Ciliwung River, where household wastewater and inadequate drainage systems are the main contributors to the increase in BOD levels (Vigiak et al., 2019). The continuous discharge of untreated domestic wastewater not only increases BOD levels but also disrupts the natural self-purification process, especially in urban areas with limited flow regulation and ecosystem recovery capacity (Ghahrchi et al., 2020). The accumulation of organic waste stimulates the activity of heterotrophic bacteria, which consume large amounts of oxygen, accelerating the deterioration of water quality and negatively impacting aquatic organisms that depend on a balanced ecosystem. To mitigate the adverse effects of high BOD levels, effective wastewater management strategies must be implemented, including structured household wastewater treatment systems and community awareness programmes on sustainable wastewater disposal. Previous research has shown that biological and chemical treatment methods can significantly reduce BOD levels in wastewater before it is discharged into natural water bodies (Dhinesh et al., 2024). For example, natural coagulants have been shown to improve the efficiency of wastewater treatment, offering an environmentally friendly solution to reduce organic pollution (Wulansarie et al., 2024). In addition, ecosystem-based approaches, such as constructed riparian buffer zones and wetlands, can enhance natural water purification processes and help stabilise water quality in the long term.

3.7 Chemical Oxygen Demand (COD) and Non-Biodegradable Pollutants

COD analysis shows concentrations ranging from 34.1594 to 43.4827 mg/L, consistently higher than BOD levels, indicating significant chemical pollution from industrial and domestic sources. The highest COD concentration, recorded at Tallo River Bridge (43.4827 mg/L), indicates a substantial accumulation of chemical pollutants in the upstream area, where domestic and industrial wastewater is concentrated. This is in line with the findings of Xu et al. (2020), which emphasises the strong impact of anthropogenic activity on the chemical oxygen demand in river systems.

The higher COD to BOD ratio further indicates the presence of non-biodegradable contaminants, such as detergents and industrial solvents, which are more resistant to natural decomposition (Hashim et al., 2024). Despite a slight decrease in COD levels downstream - possibly due to the dilution and sedimentation process - predictive modelling shows that without intervention, COD levels will exceed regulatory limits within three years. This reflects trends in the Gomti River in India, where persistent chemical pollution from industrial wastewater and heavy metals has led to high levels of COD over a long period of time (Khan et al., 2021).

The increase in non-biodegradable pollutants in the Pampang River poses a major risk to aquatic biodiversity and human health. Studies show that long-term exposure to chemical pollutants can reduce the population of aquatic species and increase the risk of toxicity to humans through contamination of the food chain (Surya et al., 2020). In addition, continuous chemical pollution can degrade water quality for drinking, irrigation, and recreational activities (Yu et al., 2020). To overcome these challenges, stricter industrial wastewater regulations and advanced urban wastewater treatment infrastructure are needed to prevent further degradation. Real-time water quality monitoring and community-based pollution control initiatives can also help reduce chemical pollution and ensure sustainable water management systems.

3.8 Variation of pH and Temperature in Relation to Aquatic Ecosystems

The recorded pH level (7.39 to 8.08) shows that the Pampang River is still within the alkaline stability range, in accordance with the Minister of Environment Regulation No. 115/2003. The highest pH levels were observed near the Sukamaju Area (8.08) and Pampang Reservoir (8.01), indicating contamination from detergents and household cleaning products. This finding is in line with Andama et al. (2022), who reported that detergents significantly affect pH levels in urban rivers, which has the potential to disrupt water species that are sensitive to pH fluctuations. The highest temperature variation (31.9°C to 34.4°C) occurred at Pampang Bridge (34.4°C), which indicates the potential for thermal pollution from river runoff. Increased temperatures accelerate the rate of microbial respiration, increase BOD requirements and reduce the availability of dissolved oxygen (DO) (Da & Wang, 2024). As shown in studies of shallow river systems, higher temperatures can increase the solubility and mobility of pollutants, thus exacerbating chemical contamination (Jóźwiakowski et al., 2021). Therefore, stricter control measures are needed to reduce the entry of detergents and other pollutants into rivers, as well as strategies for managing water temperature to ensure the sustainability of the Pampang River ecosystem.

3.9 Sustainable Strategies for Water Pollution Control and Urban Water Resources Management

Increasing organic and chemical pollution in the Pampang River emphasises the need for an integrated water quality management approach to address the challenges of urban environmental sustainability. Without effective intervention, pollutant levels are projected to exceed regulatory limits in the coming years, which could lead to declining water quality, disruption of aquatic ecosystems, and increased public health risks (Syafri et al., 2020; Surya et al., 2020; Setiawan et al., 2024). Poor urban water management exacerbates the risk of flooding, groundwater contamination, and ecosystem degradation, requiring a holistic and sustainable approach to protect rivers and the communities that depend on them.

In addition to regulatory efforts, community involvement in domestic wastewater management is essential to reduce the pollution burden. Awareness campaigns and incentives for waste sorting and recycling programmes can help reduce the amount of waste entering urban waters (Molloy et al., 2022). The establishment of wastewater treatment cooperatives can also encourage active community participation in the collective management of water resources. Nature-based solutions, such as riparian buffer zones, green infrastructure, and constructed wetlands, have the potential to increase the natural purification capacity of rivers, while mitigating the impact of rainwater runoff carrying pollutants from urban areas (Kemba et al., 2019).

Sustainable water management in the Pampang River must be directed towards the integration of ecosystem-based solutions and increased regulatory capacity to ensure long-term protection of water quality. These steps are in line with Sustainable Development Goal (SDG) 6 – Clean Water and Sanitation, which emphasises the importance of integrated water resources management to ensure sustainable access for communities and maintain the ecological balance of rivers (Zhang et al., 2021). With the implementation of this strategy, the Pampang River has the potential to naturally restore its purification capacity, support biodiversity conservation, and improve the quality of life of the urban communities that depend on these water resources.

4. Conclusions

This study highlights the significant impact of domestic and industrial wastewater disposal on the water quality of the Pampang River, Makassar. The findings show that BOD and COD levels, although currently within regulatory limits, are projected to exceed the permissible threshold within 3-4 years, indicating an increasing trend in pollution. The highest BOD (6.439 mg/L) and COD (43.4827 mg/L) values were recorded at the Tallo River Bridge, an area heavily influenced by urban and industrial discharges. The high COD to BOD ratio further indicates the presence of non-biodegradable pollutants, most likely from detergents, industrial solvents, and chemical waste. The pH (7.39–8.08) and temperature (31.9°C–34.4°C) values remain within acceptable limits, but variations in these parameters indicate the influence of detergent pollution and urban runoff. These findings are in line with previous research on urban rivers, which emphasises the role of anthropogenic activity in the deterioration of water quality. Given the projected pollution trends, urgent mitigation measures are needed. Key recommendations include strengthening wastewater treatment infrastructure, enforcing stricter industrial effluent regulations, promoting community-based waste management programmes, and implementing green infrastructure solutions such as constructed wetlands and riparian buffer zones that ensure long-term water quality improvement and ecosystem sustainability in the Pampang River.

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