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Evaluation of River Water Pollution Level in Yogyakarta City Using CCME Method and Biodegradability Index

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ABSTRACT
River water quality in urban areas, particularly in Yogyakarta, has declined due to pollution from domestic, industrial, and agricultural activities. Communal wastewater treatment plants (CWWTPs) were established to address this issue; however, they have not been operating optimally, limiting their impact on improving water quality. Therefore, this study aims to 1) analyze the condition of water quality temporally and spatially in river sections in Yogyakarta City, 2) determine river water quality index temporally and spatially using Canadian Council of Ministers of the Environmental (CCME) method and Biodegradability Index (BI), 3) evaluate the level of water pollution between CCME method and BI, and 4) analyze water quality parameters influencing the pollution level. The study procedures were carried out using the institutional survey method, and data were obtained from temporal water quality monitoring by Yogyakarta City Environmental Service. Water quality assessment was based on standards according to Governor Regulation No. 20 of 2008. Evaluation of pollution levels was carried out using water quality index with CCME method and BI. The influence of dominant parameters was statistically tested using Principal Component Analysis (PCA). The results showed that water quality in Yogyakarta City based on CCME method and BI was dominated by the poor and non-biodegradable categories. Between 2020 and 2023, the CCME and BI index values of rivers showed an increasing trend, indicating a reduction in pollution. The primary factors affecting water quality include NO_2, TDS, temperature, DO, NO_3, and total phosphate, originating from domestic and agricultural activities. In contrast, Cu, Zn, and Cd are primarily sourced from industrial activities.

INTRODUCTION

Yogyakarta City is one of the administrative areas in the Special Region of Yogyakarta, which has experienced rapid development compared to other districts. The population of Yogyakarta City in 2023 was 375,700 people, with a population density reaching 11,447 people/Km² (BPS, 2024). Several studies have shown that the increasing human activity and diverse lifestyles of urban communities around different rivers have put pressure on the sustainability of their functions as viewed from the water quality (Mahyudin et al., 2015). Consequently, a study on urban river water quality is essential. It can be used as a basis for determining river management by dividing segments based on water quality problems that arise (Pohan et al., 2016).

Rivers in urban areas often experience a lot of degradation, mainly caused by domestic waste and the increasing population (Chen et al., 2022; Widyarani et al., 2022). There was a correlation between water quality and anthropogenic activities occurring in a River Basin Area (Huang et al., 2021). Domestic and industrial activities produce waste that causes an increase in pollutant loads and contamination (Xu et al., 2022). A total of 4 rivers have been reported to cross Yogyakarta City, including the Code River, Winongo River, Belik River, and

Gajahwong River. A previous study using various methods for determining quality status showed that these rivers had experienced degradation.

8 out of 12 IPAL outlets in the Code River have a higher COD content than the inlet wastewater channel (Widodo et al., 2013). Furthermore, according to Widyastuti et al. (2021), several metal and non-metal parameters do not meet water quality standards. While domestic waste significantly impacts river water quality, the concentrations of these parameters are also influenced by the river's flow type. This shows that despite management efforts, waste still leaves residue and has not completely disappeared (Suprayogi et al., 2022).

To overcome the waste issues, this current study applies the Canadian Council of Ministers of the Environmental (CCME) method, which is considered very detailed and sensitive compared to others (Bilgin, 2018; Tyagi et al., 2020). Additionally, the CCME method facilitates the analysis of spatial and temporal changes, making it widely used in policymaking for water resource management and protection (Punja et al., 2024). CCME method is to be paired with the Biodegradability Index (BI), a simple and relatively fast method for identifying the level of organic pollution from wastewater. This index is highly sensitive to domestic waste, making it a reference in chemical procedures for wastewater treatment (Ghanbari et al., 2021). The results can be used to determine the trend of water pollution levels temporally and spatially and the government's management performance. Therefore, this study aims to (1) analyze water quality conditions temporally and spatially in river sections of Yogyakarta City, (2) determine water quality index temporally and spatially using CCME method and BI, (3) evaluate the level of pollution between CCME method and BI, and (4) assess water quality parameters influencing the level of pollution.

RESEARCH METHOD

This study was conducted in 4 rivers in the administrative area of Yogyakarta City (Fig. 2): Code, Winongo, Belik or Manunggal, and Gajahwong River. These rivers were monitoring points for Yogyakarta City Environmental Service, and they were monitored periodically from year to year. The selection of locations also considered the year of data and parameters that were monitored consistently, reflecting domestic waste characteristics. Data was collected in 2020-2023 at different monitoring point locations. This study applied a very detailed and simple method; however, both could be compared or juxtaposed for rapid evaluation of pollution levels.

The study data was in the form of secondary data collected from related agencies, which included the Yogyakarta BBI Map sheet on a scale of 1:25,000, river water quality monitoring series data, and river discharge in 2020-2022. Water quality data was collected from Yogyakarta City Environmental Service at all four river monitoring points of 4 rivers. Parameter kualitas air meliputi Suhu, TSS, TDS, pH, DO, BOD, COD, Fenol, Deterjen, Cl, SO_4, F, H_2S, Sianida, Cl_2, TP sebagai P, NO_3 sebagai N, NO_2 sebagai N, Cu, Cd, Pb, Cr^{6+}, Zn, Fecal coliform, dan Total coliform. The parameters used are numerous and varied, emphasizing quality to enhance the comprehensiveness of the data results (Saraswati et al., 2014). The data was from the 2020-2023 series.

The analysis of this study was conducted using quantitative descriptive methods. River water quality data analysis using standard quality was referenced according to Governor Regulation No. 20 of 2008 class 2. Water quality conditions were analyzed using the CCME water quality index method and BI. In addition, the analysis was carried out using Principal Component Analysis (PCA) to determine the most dominant parameters affecting water quality index value. The research framework employed to evaluate river water quality in Yogyakarta City using the Canadian Council of Ministers of the Environment (CCME) method and the Biochemical Oxygen Demand (BOD) index is depicted in Figure 1.

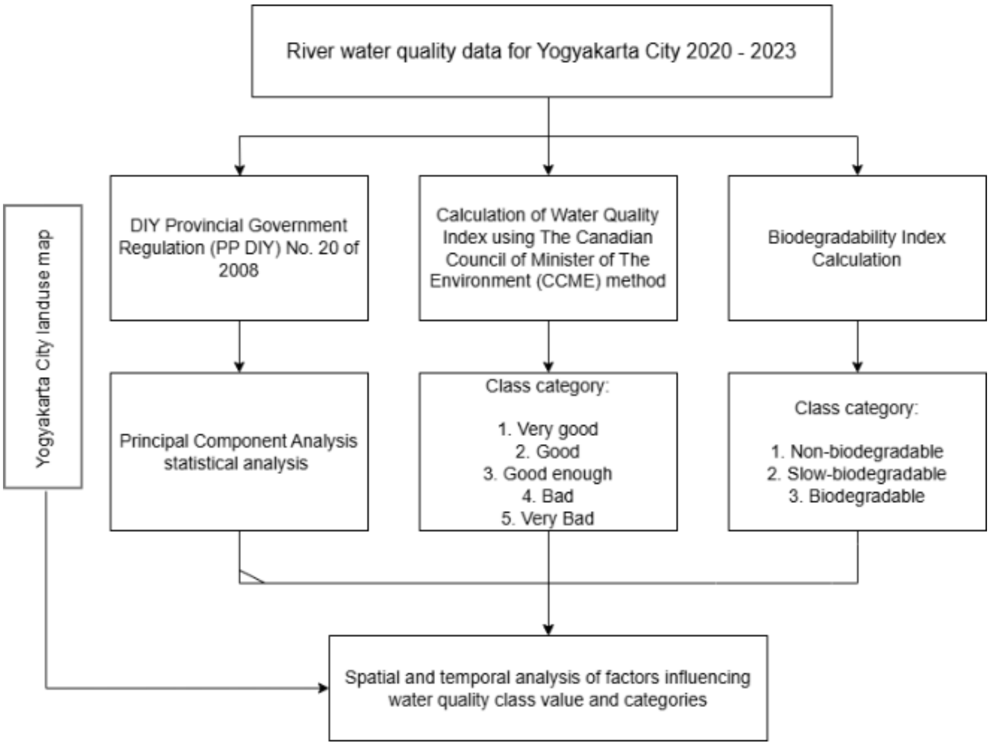


Figure 1. The Research Framework (Source: Result Analysis, 2024)

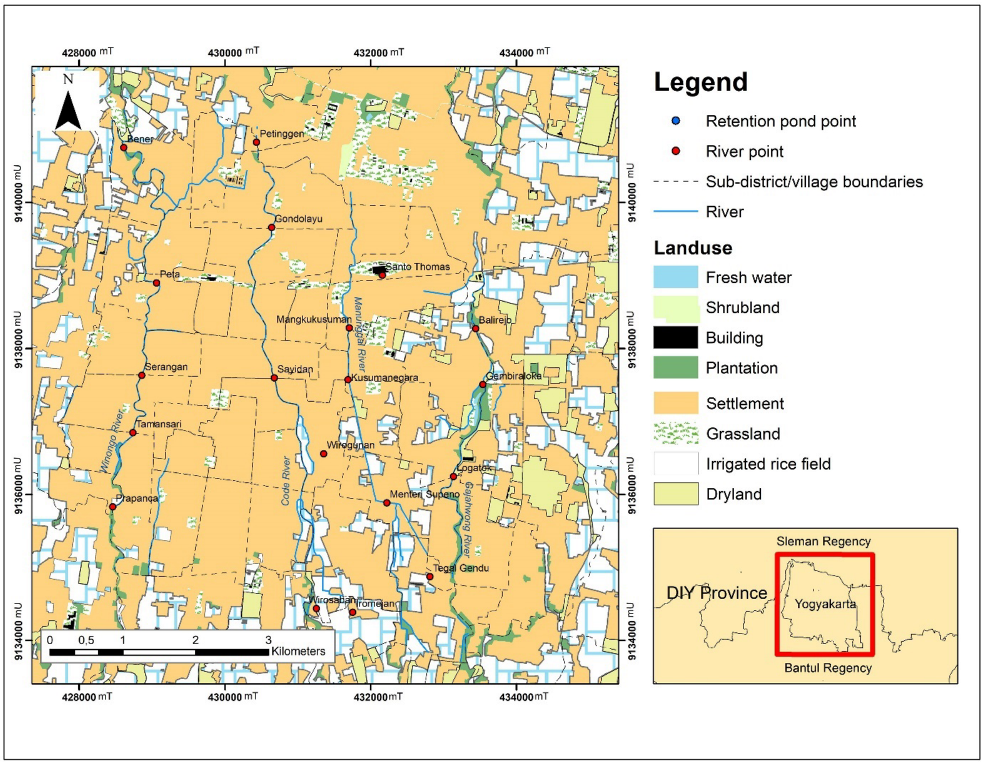


Figure 2. Research Location Map (Source: Result Analysis, 2024)

The calculation of the CCME water quality index method consisted of three stages: scope (F1), frequency (F2), and amplitude (F3) (CCME, 2012; Chidiac et al., 2023; Gikas et al., 2020; Noori, 2020; Tanjung et al., 2022).

1) F1 showed the percentage of parameters that failed to meet the quality standard at least once in a certain period or that failed relative to the total number of parameters measured (formula 1)

$$F_1 = \frac{Number\ of\ failed\ parameter}{Total\ number\ of\ parameters} \times 100 \quad \text{. . (1)}$$

2) F2 showed the percentage of individual tests that did not meet the target or failed tests relative to the total number of tests (formula 2).

$$F_2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \times 100 \quad \text{. . . (2)}$$

3) F3 showed the amplitude of the deviation of the number of tests that failed to meet their respective targets with the following calculation stages.

a) Calculation *excursions*

i. for parameters that had the concept that the higher the content, the better the quality, for example DO (formula 3)

$$excursion_i = \frac{Objective_i}{Failed\ test\ value_i} - 1 \quad \text{(3)}$$

ii. for parameters that had the concept that the higher the content, the worse the water quality, for example, COD parameter (formula 4)

$$excursion_i = \frac{Failed\ test\ value_i}{Objective_i} - 1 \quad \text{. . . (4)}$$

b) Calculate nse to define all excursions' normal sum (formula 5).

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ of\ tests} \times 100 \quad \text{. . .(5)}$$

c) Calculating amplitude (formula 6).

$$F_3 = \frac{nse}{0{,}01nse + 0{,}01} \quad \text{. . .(6)}$$

4) Calculating CCME Index (formula 7)

$$CCME\text{-}WQI = 100 - \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \quad \text{. . . (7)}$$

Classification of quality status based on CCME Index values can be seen in Table 1 the BI method was calculated by comparing BOD and COD (formula 8).

Biodegradability Index = BOD: COD . . . (8)

BI Classification used the classification in Table 2. PCA calculation began with the Bartlett Sphericity and Kaiser-Meyer-Olkin (KMO) tests. The feasibility of the data was determined based on the final KMO results; when the value was less than 0.5, the data was not feasible. PCA test results produced a percentage value from the 2-factor test, and the percentage showed the representative value of the entire data; the greater the percentage value, the better (Agustien et al., 2024). The PCA test also produced eigenvalues, and the parameters with the largest eigenvalues were the most influential.

Table 1. CCME Index Classification

No	WQI Value	Classification
1	95-100	Excellent
2	80-94	Good
3	60-79	Fair
4	45-59	Marginal
5	0-44	Poor

(Source: CCME, 2012)

Table 2. Biodegradability Index (BI) Value Classification

No	BI Value	Classification	Description
1	>0,6	*Biodegradable*	Existing wastewater can be decomposed biologically.
2	0,3 – 0,6	*Slow-Biodegradable*	Wastewater must be seeded in biological processing but the process is slow.
3	<0,3	*Non-Biodegradable*	Biodegradation or biological decomposition process cannot work hence other treatments are needed to treat existing wastewater.

(Source: Dhanke & Wagh, 2020)

RESULT AND DISCUSSION

River Water Quality in Yogyakarta City

The Code, Winongo, Manunggal, and Gajahwong Rivers in Yogyakarta exhibit similar water quality issues. Parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrite (NO_2), nitrate (NO_3), total phosphate, fecal coliform, total coliform, and chlorine often exceed water quality standards, primarily due to domestic wastewater discharge. Notably, microbiological parameters like total and fecal coliform levels in the Code River are significantly above acceptable limits. A temporal analysis indicates that these exceedances were markedly higher during 2022–2023 compared to 2020–2021, correlating with the resumption of industrial and tourism activities post-COVID-19 restrictions.

These conditions are further substantiated by the Government of Yogyakarta's (2023) report. which indicates a significant increase in tourist arrivals during 2022. Research by Pasciucco et al. (2023) highlights that the volume of tourists influences both the characteristics and the load of pollutants. Additionally, land use along riverbanks is highly varied, contributing to the complexity of managing water quality in the region.

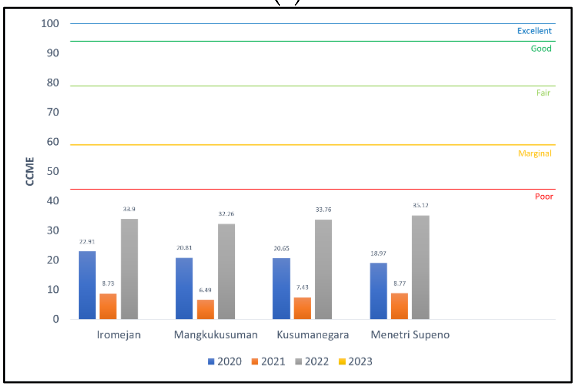
Analysis using satellite imagery indicates that the proximity between river bodies and anthropogenic land use areas is relatively close. This proximity correlates with higher pollutant concentrations entering the river (Zhao et al., 2020, Astuti et al., 2017).

River Water Quality Index in Yogyakarta City

Water quality conditions reviewed from CCME method showed that all points in the 4 rivers were in the "bad" category because the value was below 45 (Fig. 3). CCME value in 2021 showed the lowest value compared to previous and subsequent years. This was because 2021 was a transitional year for the decline in Covid-19 cases. This caused an increase in the number of tourists to Yogyakarta City. According to BPS (2024), the number of tourists in 2020 - 2021 increased by 41.55%. The high number of tourists had an impact on water quality conditions, and these conditions were related to land use and activities around the river. Land use around Gajahwong River was quite diverse, including settlements, hotels, and zoos. The more built-up land and anthropogenic activities, the more waste could be produced (Zhang et al., 2022). These conditions caused poor CCME values in Gajahwong River.

(a)

(b)



(c)

(d)

Figure 3. CCME Water Quality Index Values included (a) Code River, (b) Winongo River, (c) Manunggal River, and (d) Gajahwong River (Source: Result Analysis, 2024).

River Water Biodegradability Index in Yogyakarta City

In terms of BI, all monitoring points in the 4 rivers in 2020-2023 were included in the value <0,3, which meant it could not be biodegraded, except for the Manunggal River. All monitoring points in Manunggal River in 2020-2022 were included in the value >0,3, which meant it was slow to decompose and could be biodegraded, except for the Kusumanegara monitoring point in 2020, the index value of which was included in the non-biodegradable group with a value of 0,24 (Fig. 4).

The level of river water pollution in Yogyakarta City, both temporally and spatially, using CCME method showed similarities, namely that almost all monitoring points were in the bad category. The same pattern occurred in BI method, namely that almost all monitoring points in the Code River, Winongo River, and Gajahwong River were in the non-biodegradable category, except for Manunggal River, where several points were in the slow biodegradable and biodegradable categories.

The same condition showed that the water quality in almost all rivers in Yogyakarta City had poor water quality when viewed from CCME and BI methods. However, Manunggal River had differences in the results of BI method data processing due to the COD concentration factor which did not exceed the quality standard. BI value was also dominated by non-biodegradable conditions, except at several points in Manunggal River.

The increasing trend in BI value for 4 years indicated the potential for environmental conditions in river water in Yogyakarta City to improve water quality in terms of decomposing organic pollution. The decrease in slum areas was one indicator of increasing BOD and COD levels in river water, except for the amount of coliform and phosphate which could still worsen when there were still untreated septic tanks (Rohmadi et al., 2022).

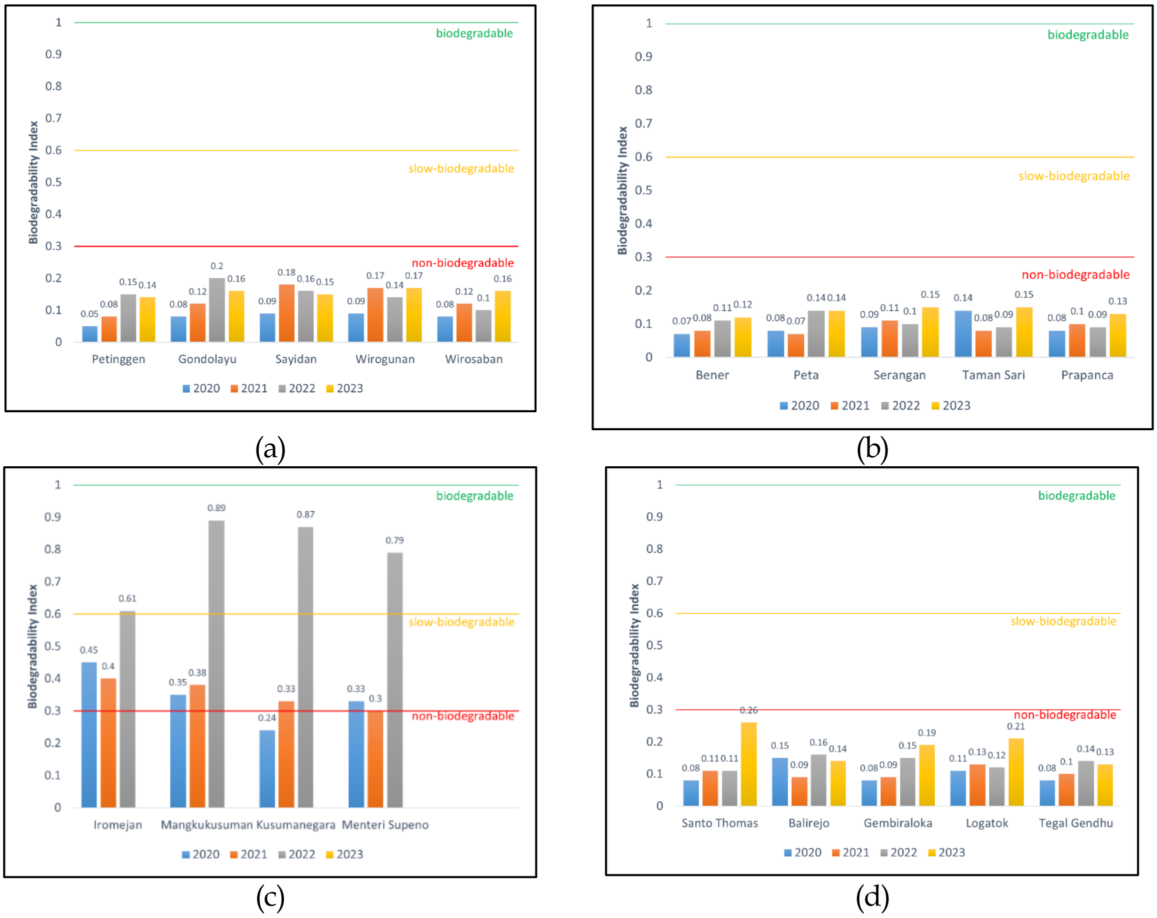


Figure 4. BI Values included (a) Code River, (b) Winongo River, (c) Manunggal River, and (d) Gajahwong River (Source: Result Analysis, 2024).

Dominant Factors Influencing River Water Quality

Based on the result (Fig. 5), the percentage of PCA representation of the Code River data from 2020 - 2023 was in the range of 43.71 - 53.43%, and the parameters with the highest score values in each F1 also varied. In 2020, the parameters with the highest scores were NO_2, total phosphate, and temperature, and in 2021, each was NO_2, BOD, and total phosphate. In 2022, each was TDS, DHL, NO_3, and phenol, DO, and total phosphate. Based on all parameters from 2020 - 2023, the sources were almost the same, namely due to domestic activities, however, in 2023 there was a phenol parameter. Phenol in rivers primarily originates from industrial discharges, including those from paper and dye factories (Arifiati et al., 2023). More specifically, the waste that caused high levels of phenol in river water was coal, plastic, and oil. Meanwhile, agricultural activities also produced phenols in smaller amounts.

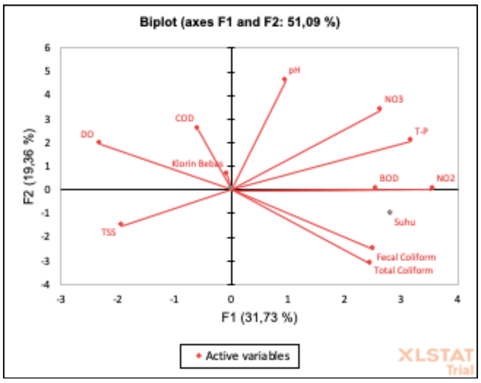
The percentage of water quality parameter data representation in Winongo River was in the range of 44.09 - 54.40%. The parameters with the highest score values in F1 in 2020 were NO_2, NO_3, and total phosphate. In 2021, the parameters were NO_2, NO_3, and total phosphate. In 2022, each was DHL, sulfate, and chloride. In 2023, chlorine, dissolved Cu, and dissolved Zn were also included. The parameters in 2020 and 2021 could be categorized as coming from domestic and agricultural waste. However, in 2022 and 2023, all were different. According to Hong et al. (2023), chloride came from the pharmaceutical, textile, food, and other industries, and Cu and Zn were included in the heavy metal category.

The results of Fadlillah et al. (2022), stated that Cu in the rivers of Yogyakarta

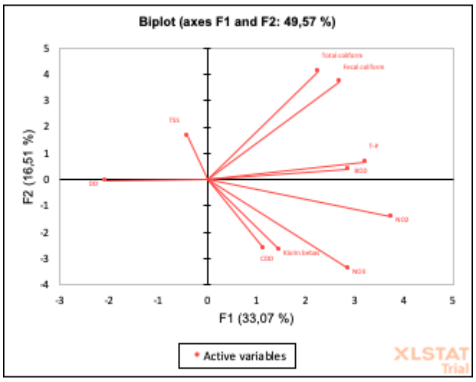
City had a high value. Zn and Cu that entered the river came from industries that used chemicals. The comparison between 2020 and 2021 with 2022 and 2023 could show that industrial activities affected the condition of river waters because in 2020 - 2021 there was Covid-19 which caused many industries to stop operating however the dominant parameters that influenced only came from domestic and agricultural sources.

The percentage of water quality parameter data representation in Manunggal River was in the range of 44.18 - 48.98%. The parameters with the highest score values in F1 in 2020 were total phosphate, total coliform, and fecal coliform. In 2021, the parameters were NO_2, DO, and TSS, and in 2022, it was TDS, dissolved chloride, and DO. The parameters in 2020 - 2022 generally came from domestic and agricultural waste, except for chloride in 2022 which came from industry. Temporally, industrial activities in 2022 had started operating again, while in 2020 - 2021 it was hampered by Covid-19.

The percentage of water quality parameter data representation in Gajahwong River was in the range of 43.62 - 52.81%. The parameters with the highest score values in F1 in 2020 were NO_2, TDS, and temperature. In 2021, total phosphate, NO_2, and NO_3, and in 2022, TDS, DHL, and NO_3. However, in 2023, it was dissolved Cu, Zn, and Cd. The parameters that described the overall condition of Gajahwong River in 2020 - 2022, namely NO_2, TDS, temperature, DHL, NO_3, and phosphate came from domestic and agricultural activities. The parameter that described the overall condition of the river was the type of heavy metal. Dissolved Cu, Zn, and Cd were types of heavy metals whose sources could come from industry. A study by Mokarram et al. (2020) on Gajahwong River proved that sugar and paper factories caused high Cd values in the river which also passed through the silver craft area. The study results of Udzkhiyati & Widyastuti (2024) also stated that the value of heavy metal silver increased after passing through Kotagede area.



(a)



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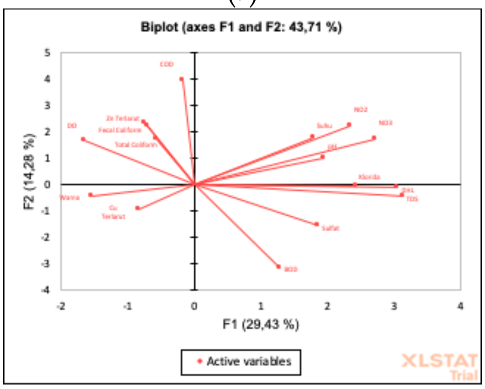

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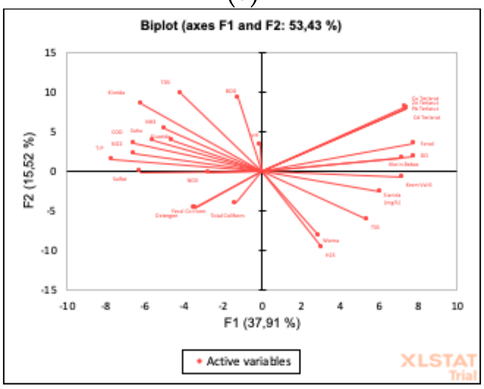

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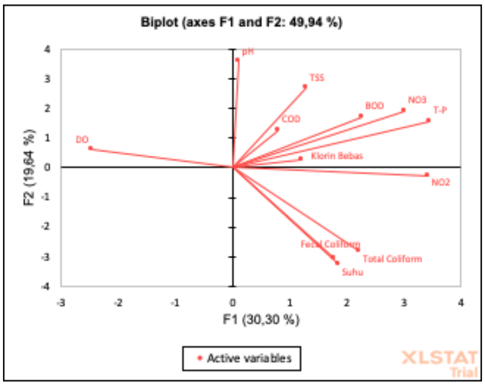
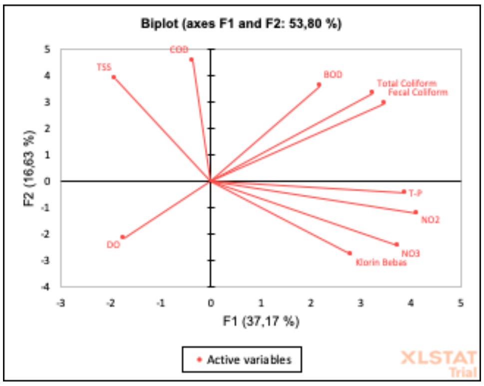
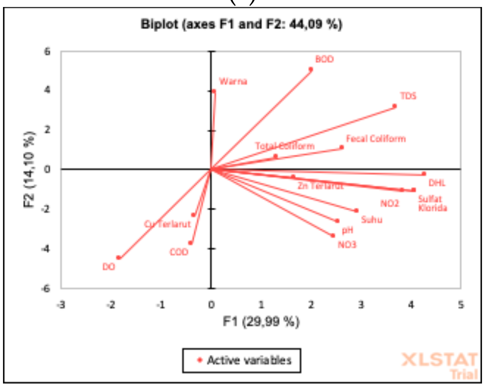

Biplot (axes F1 and F2: 49,94 %)
F2 (19,64 %)
F1 (30,30 %)
pH
TSS
COD
BOD
NO3
T-P
DO
Klorin Bebas
NO2
Fecal Coliform
Total Coliform
Suhu
Active variables

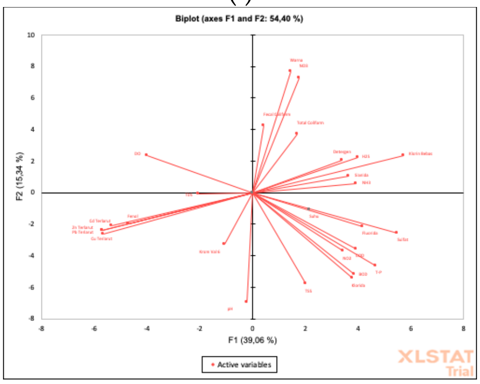
(e)


Biplot (axes F1 and F2: 53,80 %)
F2 (16,63 %)
F1 (37,17 %)
COD
TSS
BOD
Total Coliform
Fecal Coliform
T-P
NO2
NO3
Klorin Bebas
DO
Active variables

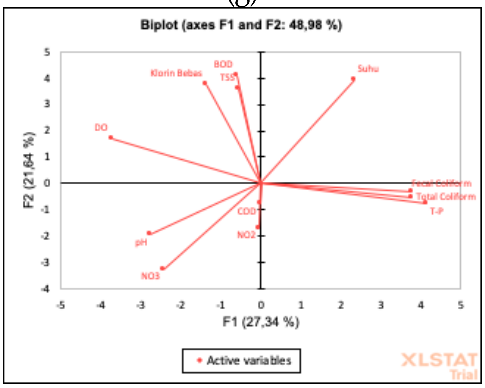
(f)


Biplot (axes F1 and F2: 44,09 %)
F2 (14,10 %)
F1 (29,99 %)
BOD
Warna
TDS
Fecal Coliform
Total Coliform
Zn Terlarut
DHL
NO2
Sulfat
Klorida
Suhu
pH
NO3
Cu Terlarut
COD
DO
Active variables

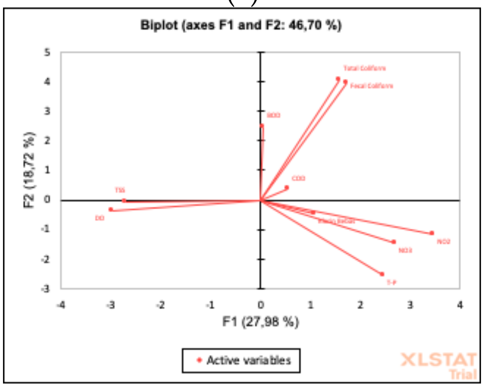
(g)


Biplot (axes F1 and F2: 54,40 %)
F1 (39,06 %)
Active variables

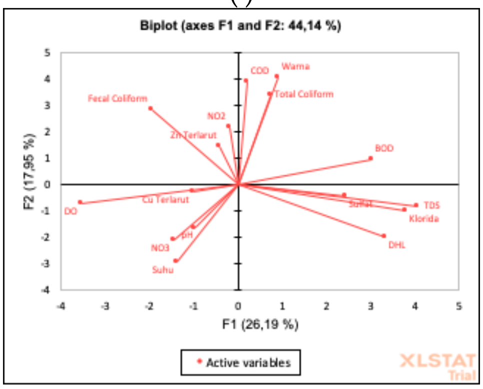
(h)


Biplot (axes F1 and F2: 48,98 %)
F2 (21,64 %)
F1 (27,34 %)
Klorin Bebas
BOD
TSS
Suhu
DO
Fecal Coliform
Total Coliform
T-P
COD
NO2
pH
NO3
Active variables

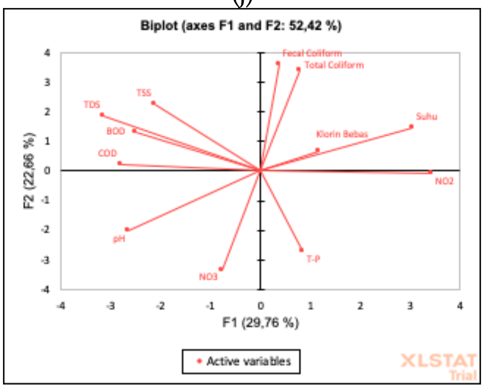
(i)


Biplot (axes F1 and F2: 46,70 %)
F2 (18,72 %)
F1 (27,98 %)
Total Coliform
Fecal Coliform
BOD
COD
TSS
DO
Klorin Bebas
NO2
NO3
T-P
Active variables

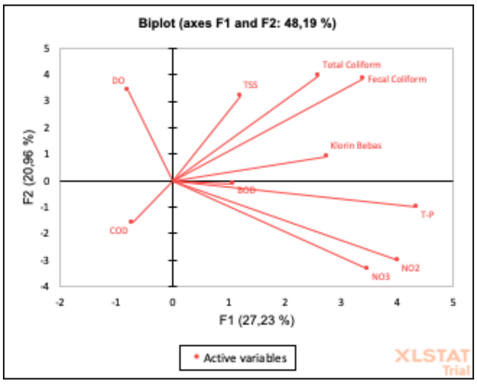
(j)


Biplot (axes F1 and F2: 44,14 %)
F2 (17,95 %)
F1 (26,19 %)
COD
Warna
Total Coliform
Fecal Coliform
NO2
Zn Terlarut
BOD
Cu Terlarut
Sulfat
TDS
Klorida
DHL
DO
pH
NO3
Suhu
Active variables

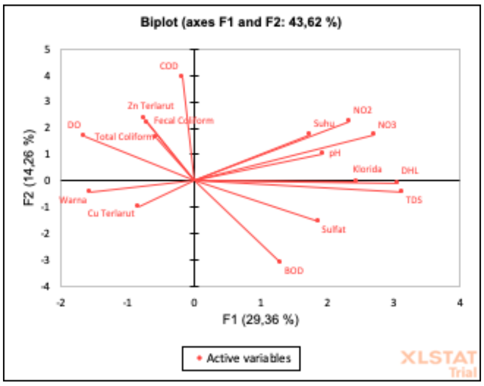
(k)


Biplot (axes F1 and F2: 52,42 %)
F2 (22,66 %)
F1 (29,76 %)
Fecal Coliform
Total Coliform
TDS
TSS
BOD
COD
Suhu
Klorin Bebas
NO2
pH
T-P
NO3
Active variables

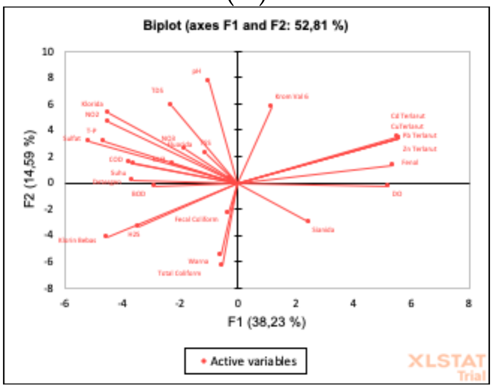
(l)



(m)



(n)



(o)

Figure 5. River PCA Test included (a) Code 2020, (b) Code 2021, (c) Code 2022, (d) Code 2023, (e) Winongo 2020, (f) Winongo 2021, (g) Winongo 2022, (h) Winongo 2023, (i) Manunggal 2020, (j) Manunggal 2021, (k) Manunggal 2022, (l) Gajahwong 2020, (m) Gajahwong 2021, (n) Gajahwong 2022, and (o) Gajahwong 2023

(Source: Result Analysis, 2024)

CONCLUSION

The water quality conditions of the Code, Winongo, Manunggal, and Gajahwong Rivers in Yogyakarta City exhibited overall similarities, with several parameters exceeding established water quality standards. These parameters included biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrite (NO_2), nitrate (NO_3), total phosphate, fecal coliform, total coliform, and chlorine.

Temporal analyses revealed that during the COVID-19 pandemic, water quality in these rivers was predominantly impacted by domestic waste. However, post-pandemic periods saw additional influences from industrial discharges and tourism-related activities, further affecting the rivers' water quality. Based on CCME Index, all monitoring points in the 4 rivers were in the poor category, and the results of BI calculation showed that the ability to decompose organic matter in the river tended to be poor or was dominated by the non-biodegradable category.

Analysis of the CCME and BI index values over time in the Code, Winongo, Manunggal, and Gajahwong Rivers indicates an upward trend, suggesting a reduction in pollution levels following mitigation efforts targeting informal settlements. The primary factors influencing water quality include nitrite (NO_2), total dissolved solids (TDS), temperature, electrical conductivity (EC), nitrate (NO_3), and total phosphate, which are mainly attributed to domestic and agricultural activities. In contrast, concentrations of copper (Cu), zinc (Zn), and cadmium (Cd) are primarily linked to industrial activities

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