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Trend Analysis on Water Quality of Cimahi City's Major Rivers

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Abstract

Trends in water quality of three major Cimahi City rivers (Cibeureum, Cimahi, and Cisangkan) were evaluated using Mann–Kendall and Seasonal Mann–Kendall tests with Sen's slope estimation for 12 parameters (TDS, TSS, BOD, COD, NO_2, NO_3, NH_3, T-P, Oil & Fat, Detergent, Fecal Coliform, Total Coliform) and two indices (Pollutant Index, PI and Indonesian Water Quality Index, WQI-INA) over 2017–2022. WQI-INA values remained in the "poor" to "very poor" categories for all rivers, with non-significant monotonic trends; only Cibeureum River exhibited a positive Sen's slope of 2.22 units/year. Basic trend analysis revealed significant decreases in NH_3 concentrations across all sites (Sen's slope range: –0.04 to –0.13 mg/L per season) and significant increases in NO_2 at all Cimahi River sites (0.005–0.017 mg/L per season). Seasonal trend tests identified four significant trends: decreasing PI at Cimahi downstream (z = –2.34), decreasing PI (z = –2.34) and T-P at Cibeureum midstream (z = –2.21), and decreasing COD at Cibeureum downstream (z = –2.01). Seasonal trend tests also found that dry-season improvements exceeded wet-season gains, indicating dominant groundwater baseflow dilution. Variability assessed via coefficient of variation highlighted the highest fluctuations in NH_3 (CV = 1.99), Fecal Coliform (CV = 1.92), and Total Coliform (CV = 1.53), versus lowest in TDS (CV = 0.47), NO_3 (CV = 0.75), and T-P (CV = 0.86). The variation also found that spatially, Cimahi upstream showed greatest variability, Cibeureum downstream the least. These patterns underscore active nitrification processes, laundry-effluent inputs, and seasonal hydrodynamics as key drivers. Enhanced monitoring frequency—particularly for microbiological and carbonaceous parameters—and refined seasonal sampling are recommended to improve trend detection and inform targeted management strategies.

Keywords: Cimahi, River pollution, Trend analysis, Water quality index.

1. Introduction

Water quality is a critical factor in maintaining the ecological balance and ensuring the availability of clean water for various purposes, such as drinking, agriculture, and industrial use. As a developing country, Indonesia always face challenges in managing water quality, especially in the municipalities with increasing number of industries and populations. The Indonesian national water quality status from the year 2015 to 2023 was always at a "moderate" level which failed the national target most of the time (Indonesian Ministry of Environment and Forestry, 2023).

One of municipalities which having the concern of water quality pollution is the city of Cimahi, located just beside the capital of West Java, the city of Bandung. The water quality of Cimahi City (based on WQI-INA) in 2017–2023 was always indicated as "very poor", except in 2022, which was indicated as "poor" (Government of Cimahi City, 2024). While having as many as 53 textile industries in 2023 (BPS-Statistics of Cimahi Municipality, 2024), Cimahi City is also a place of residence for many workers in Bandung City, making the city of Cimahi an important industrial and residential area in West Java. With annual population growth rate of 0.6% in 2021–2022 (BPS-Statistics of Cimahi Municipality, 2023) and 1.4% in 2022–2023 (BPS-Statistics of Cimahi

Municipality, 2024), Cimahi City is always having an increasing risk of heightened water pollution which lower the quality of life in the city. Therefore, the assessment of river water quality in Cimahi City is of significant importance.

There are many parameters to indicate water quality, such as biochemical oxygen demand (BOD), total suspended solids (TSS), nitrogenous compounds, total phosphate, and coliform. The "polluted" status is given for a parameter if its concentration has not satisfied the standard value in the regulation. However, it would be confusing if the results for each parameter differed. Therefore, to determine the pollution status of a river, a water quality index (WQI), a single value representing the overall water quality, is required (Chidiac et al., 2023).

A few studies have been conducted to assess the water quality index of rivers in Cimahi, West Java, Indonesia: Cisangkan River by Rosmeiliyana and Wardhani (2021); Cibaligo River by Anggraini and Wardhani (2021), Cibeureum River by Hermawan and Wardhani (2021), and Cimahi River by Rafianto and Wardhani (2021). These studies have provided a snapshot of the water quality index of rivers for 2019 using the Pollution Index (PI) method, which is also noted in the Decree of Minister of Environment Number 115 of 2003 (Indonesian Ministry of Environment, 2003) as a method to determine the status of the inland water quality. The PI method is originally based on the water quality index developed by Nemerow (1974) and — under the name of the Nemerow Pollution Index (NPI) — has been widely implemented in many studies (Su et al., 2022; Tri & Than, 2021; Sulthonuddin et al., 2020).

Many WQI methods have been developed over the last 50 years (Chidiac et al., 2023) as tools to determine water quality, such as the National Sanitation Foundation Water Quality Index (NSFWQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI). In Indonesia, most of studies were using only PI and STORET methods due to two methods is referenced in the Decree of the Minister of Environment Number 115 of 2003 (Indonesian Ministry of Environment, 2003).

In the latest decade, Ratnaningsih et al. (2016, 2018, 2020), from the Environmental Laboratory Quality Research and Development Center, have developed the water quality index of Indonesia (WQI-INA) based on the NSFWQI. The comparison of the WQI-INA method to the PI, STORET, and CCME methods by Damayanti et al. (2021) concluded the WQI-INA gives more suitable results while also being easy to use. Moreover, Kurniawan (n. d.), from the Indonesian Ministry of Environment and Forestry, also argued that WQI-INA is more suitable for representing the condition of the Indonesian river than the CCME method. Ultimately, the WQI-INA method is currently listed in the Regulation of the Minister of Environment and Forestry Number Number 27 of 2021 (Indonesian Ministry of Environment and Forestry, 2021).

However, since the implementation of the Regulation of the Minister of Environment and Forestry Number 27 of 2021, the use of WQI-INA is still lacking, despite its versatility. Meanwhile, the increasing water pollution risk in Cimahi City (as explained in the beginning of introduction) would continuously demanding an urgent management. Formulating a water quality management strategy is necessary to ensure ecological reserves and improve the environmental carrying capacity of Cimahi City rivers. A good management strategy requires an understanding of temporal trends and changes in water quality. While several studies (Hermawan & Wardhani, 2021; Nurhayati et al., 2021; Rosmeiliyana & Wardhani, 2021; Wardhani & Primalaksono, 2022) have been conducted using the water quality index to analyze the water quality of Cimahi rivers, no study used WQI-INA and aimed for the temporal trends yet.

Therefore, this study aims to perform a water quality temporal analysis for three major rivers in Cimahi City: the Cibeureum River, Cimahi River, and Cisangkan River using trend analysis of their WQI-INA, PI, and water quality parameters. The analysis is not only conducted on the WQI-INA in order to obtain further insightful results. The results of this study can provide valuable insights into the trends and patterns of water quality of the rivers in Cimahi City, which can inform policy-making and management strategies to address water pollution issues in Cimahi City.

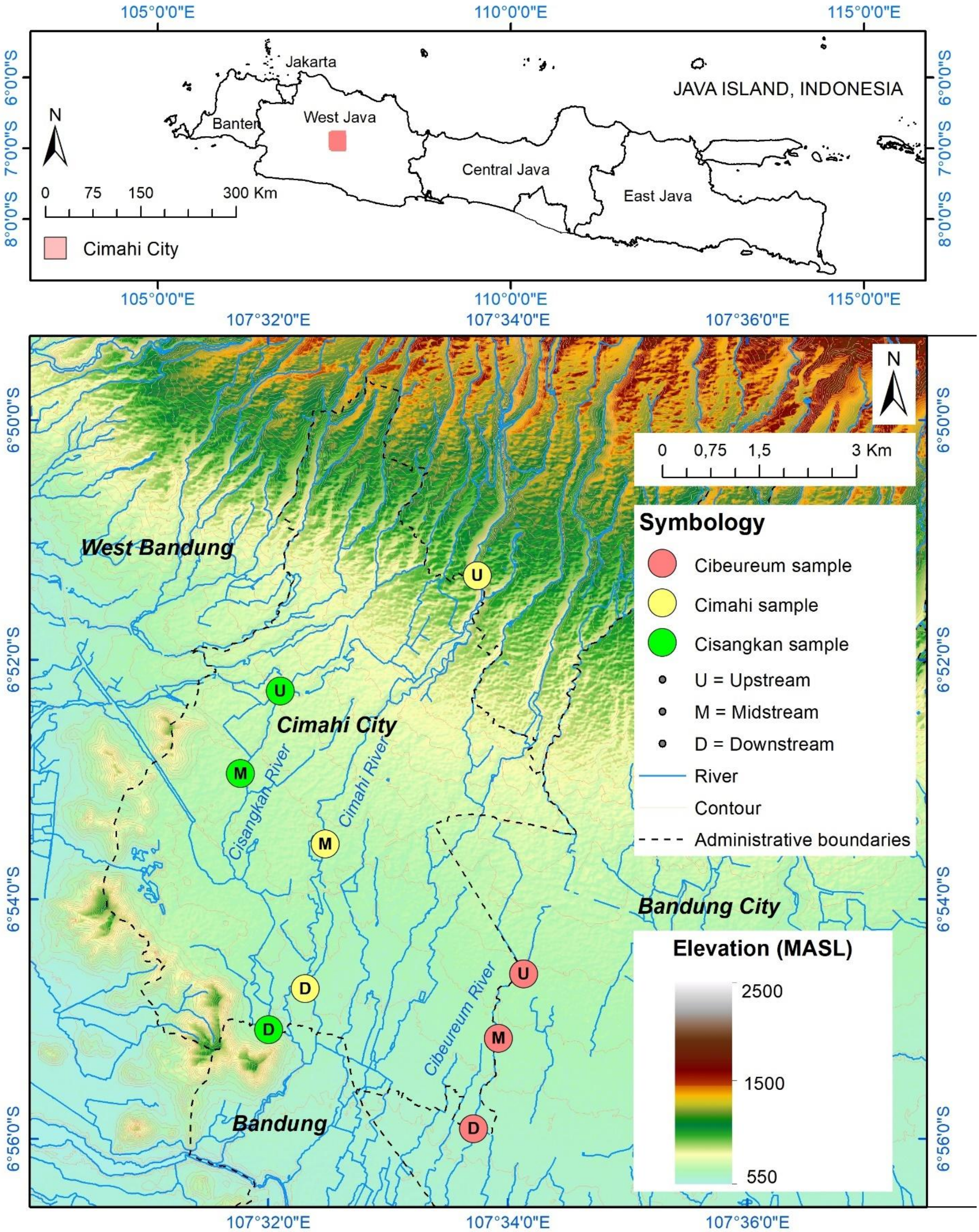

Figure 1. Location of the sampling points of the Cimahi, Cibeureum, and Cisangkan Rivers

2. Methods

2.1 Datasets

This study analyzed water quality data from three major rivers in Cimahi City: Cimahi River, Cibeureum River, and Cisangkan River. River water quality data for the period 2017–2022 were obtained from the Document of Environmental Management Performance (Government of Cimahi City, 2018–2023). The water quality parameters used in this study included total dissolved solids

(TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), total phosphate (TP), oil and fat, detergent, fecal coliform, and total coliform.

Data used in this study was based on the purposive selection of available monitoring data that met completeness and temporal consistency criteria across rivers and sampling points. Each river has three sampling points representing upstream, midstream, and downstream areas (Figure 1). The data for each sampling point were selected and arranged to ensure a consistent time frame across all time-series data. After cleaning the raw data, it then decided to use data from 2017 (September and November), 2018 (July), 2019 (April, July, November), 2020 (February, July, October), 2021 (March, June, September), and 2022 (March, June, September). Therefore, the total number of data would be 45 for each river and 15 for each sampling point (Table 1).

Due to irregular monitoring intervals, trends are interpreted at a seasonal rather than monthly or annual scale. The months are also inconsistent except for the last two years (2021 and 2022). Therefore, a seasonal trend analysis was also conducted in this study. The seasonal trend analysis requires data to be categorized into multiple categories, which this study translates into seasonal categories. From the available data, the seasons were divided into wet season (December to April), dry season (August to November), and transitional season (May to July).

Table 1. Sets of water quality monitoring data used in this study

Rivers	Sampling Points	Periods	Month	Number of Data for each River each Period
Cisangkan River, Cibeureum River, Cimahi River	Upstream, Midstream, Downstream	2017	09, 11	6
		2018	07	3
		2019	04, 07, 11	9
		2020	02, 07, 10	9
		2021	03, 06, 09	9
		2022	03, 06, 09	9
		2017–2022	2017-09 until 2022-09	45

2.2 Determination of WQI-INA

The water quality index is calculated using the WQI-INA method from the Ministry of Environment and Forestry Regulation No. 27 of 2021, based on the following steps.

1.) Determine the water quality class based on Indonesian Government Regulation Number 22 of 2021 (Indonesian Government, 2021). The class of the three rivers of this study was not determined yet by the government at the time of this study. Therefore, based on the Indonesian Government Regulation Number 82 of 2001 article 55 (Indonesian Government, 2001), the water quality standard for class II (Table 2) was used.

2.) Calculate the Pollution Index by comparing each parameter value to the the water class II standard value and then calculating their aggregate value as shown in the equation below.

$$PI = \sqrt{\frac{(C_i/L_i)^2{}_M + (C_i/L_i)^2{}_R}{2}}$$

Where C_i is the water quality value for the parameter i, L_i is the water quality standard for the parameter i, M denotes the maximum value, and R denotes the average value.

3.) Determine the pollution status for each sampling point in a particular month using the calculated index in the previous step, based on the Table 3.

4.) Calculate the percentage of each pollution status in Table 3 for each year in each river.

5.) Multiply the percentage of each pollution status with each respective weight (Table 3).

6.) Sum up the total calculation results of all pollution statuses in the previous step.

7.) Determine the status level of WQI-INA based on the result value in the previous step for each year, according to Table 4. This study covered six years (2017–2022) for each river.

Table 2. Water quality standards for class II rivers based on Indonesian Government Regulation No. 22 of 2021 (only parameters used in this study)

Parameter	Unit	Maximum Value
TDS	mg/L	1000
TSS	mg/L	50
BOD	mg/L	3
COD	mg/L	25
NO_2	mg/L	0.06
NO_3	µg/L	10
NH_3	mg/L	0.2
T-P	mg/L	0.2
Oil & Fat	mg/L	1
Detergent	mg/L	0.2
Fecal Coli	/100mL	1000
Total Coli	/100mL	5000

Table 3. Pollution Index classification and corresponding WQI-INA weights based on Regulation of Indonesian Ministry of Environment and Forestry Number 27/2021

Criteria	Status	Weight for WQI-INA
$0 \leq PI \leq 1$	Good	70
$1 < PI \leq 5$	Lightly Polluted	50
$5 < PI \leq 10$	Moderately Polluted	30
$PI > 10$	Heavily Polluted	10

Table 4. WQI-INA status by the index values based on Regulation of Indonesian Ministry of Environment and Forestry Number 27/2021

WQI-INA Value	Category
$90 \leq x \leq 100$	Very Good
$70 \leq x < 90$	Good
$50 \leq x < 70$	Moderate
$25 \leq x < 50$	Poor
$0 \leq x < 25$	Very Poor

2.3 Trend Analysis

The Mann-Kendall test (Mann, 1945; Kendall, 1975; Gilbert, 1987) is employed to assess temporal trends in this study. This nonparametric test has been widely used to detect monotonic trends in a dataset without requiring the data to follow a normal distribution. The Mann-Kendall test provides a statistical indication of the presence of a trend in a time-series dataset. The existence of a trend in a dataset is shown by the Kendall tau (τ). A positive τ means a positive (increasing) trend; a negative τ means a negative (decreasing) trend, while a zero value of τ means no clear monotonic trend exists (Kendall, 1975).

To complement to the Mann-Kendall test, Sen's slope estimation was also performed to determine the rate of change of the existing trend in time series data. Sen's slope is the median of all pairwise slopes between data points which indicates the magnitude of the trend in the data (Sen, 1968). Sen's Slope value means the magnitude of trend or rate of change (Sen, 1968). For example, a 100 units/year Sen's slope of COD parameter indicates that COD concentration increased by 100 mg/L per year.

This study used monthly-based datasets with an abrupt change in the time step. The time step cannot be claimed as monthly nor annually due to the sampling time not being routinely conducted every month. However, the sampling was based on the seasonal timing: rainy season, transition season, and dry season. Therefore, the trend test is also performed using the Seasonal Mann-Kendall Trend Test or also known as the Hirsch-Slack Test (Hirsch et al., 1984; Hirsch and Slack, 1984), an extension of the Mann-Kendall test.

The functions of the 'trend' package (Pohlert, 2023) in R programming (R Core Team, 2025) were employed for conducting the Mann-Kendall Test, Seasonal Mann-Kendall Test, and Sen's slope estimation. The basic Mann-Kendall trend analysis was conducted to obtain the trend of the WQI-INA, pollution index (PI), and water quality parameters over the period of 2017–2022. However, due to the incomplete data of the earlier years, the seasonal trend test used only four years of data from 2019–2022 to understand the PI and water quality parameters seasonal trend.

2.4 Variability Analysis

Determining variability in a parameter gives insight into its fluctuation so it can be evaluated fairly in a temporal analysis. Variability is determined by the values of the coefficient of variation (CV), which is calculated by dividing the standard deviation by the mean. A higher CV value indicates a higher variability of a parameter.

Higher variability gives noise to the result of trend analysis by causing a wider confidence interval in the trend estimation, resulting in lower confidence in the statistical power of the trend test. Cobb et al. (1992) developed a Monte Carlo simulation showing that the statistical power to detect a nonzero slope in a regression (and by extension in nonparametric tests) falls off as the CV increases. Feng et al. (2020) also found that the Mann-Kendall test power decreases as sample variance grows.

3. Results and Discussion

3.1 WQI-INA Trend

WQI-INA results for the three rivers are shown in the Table 5 and Figure 2. The three rivers have the values of WQI-INA ranges between 16.7 to 33.3 for the Cisangkan River, 10.0 to 43.3 for the Cibeureum River, and 23.3 to 36.7 for the Cimahi River. Based on Figure 2, it can be concluded that Cisangkan River had the worst quality due to its "Very Poor" status along 2018 to 2021, while Cimahi River had "Very Poor" status only on 2020 and Cibeureum River leveled-up from "Very Poor" to "Poor" since 2021. The WQI-INA calculated using aggregated six years of data (2017–2022) showed that Cisangkan River was the only river among the three that got the "Very Poor" status, while the other two rivers were both "Poor". Therefore, the overall water quality of the three rivers was still poor, especially the Cisangkan River.

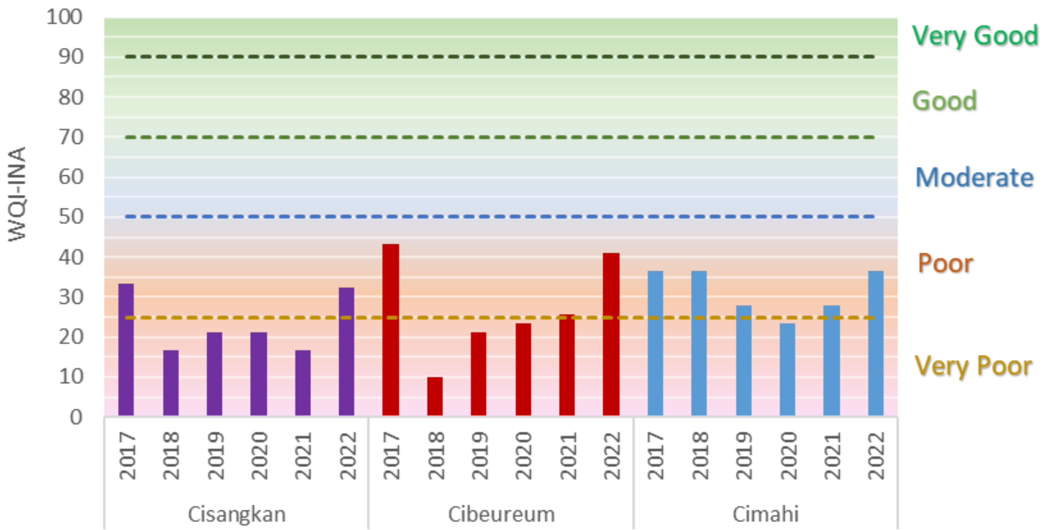

Figure 2. Water quality index (WQI-INA) of the three Cimahi City's rivers on 2017–2022.

Table 5. Results of trend analysis of WQI-INA values.

River	τ (tau)	τ p-value (α = 0.05)	Sen's Slope
Cibeureum	0.751	0.452 (not significant)	2.22
Cimahi	-0.411	0.681 (not significant)	0
Cisangkan	0	1 (not significant)	0

The values of Kendall tau calculated from WQI-INA from 2017 to 2022 (Table 5) indicate the water quality of river were improved in Cibeureum River, worsened in Cimahi River, and remained consistent in Cisangkan River. However, all results of the Kendall trend test resulted in p-values ≥ 0.05, indicating that these results are not significant. This was expected because of the lack of WQI-INA values for each river.

Interestingly, among the three rivers, only Cibeureum River obtained the value of Sen's Slope (slope = 2.22). The slope indicates that the Cibeureum River has an increasing WQI-INA of as many as 2.22 units per year. Suppose the slope is assumed to constantly remain at the same value. In that case, it can be forecasted that in 2026 (four years after the latest data available), Cibeureum River will be able to graduate from Poor quality to Moderate quality.

3.2 Water Quality Parameters Trend

The WQI values have only six data sets; thus the power to conclude the study is lacking. Therefore, trend analysis for each water quality parameter and pollution index are also conducted. There are 15 data for each set of parameters at each sampling point, representing seasonal time steps over the 2017 to 2022 periods. The results of the Mann-Kendall trend analysis for those datasets on nine different sampling points (3 points × 3 rivers) are shown in Figure 3. Further, using all nine sampling sites, Figure 4 and Table 6 summarize the overall trend for each parameter. Finally, Figure 5 displayed the trend boxplots for each river parameter to show the spatial difference (or similarity) trends.

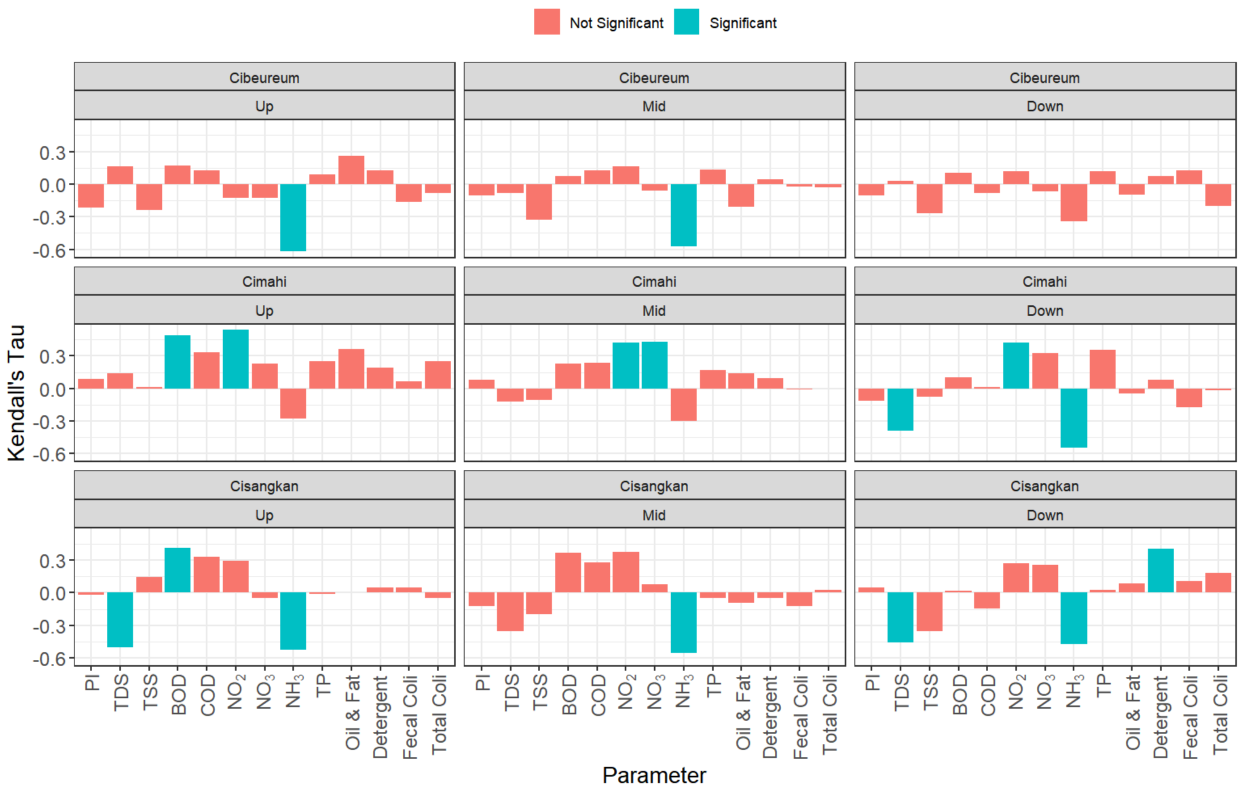

Figure 3. Results of trend analysis for Cibeureum, Cimahi, and Cisangkan Rivers. A positive (negative) Kendall's tau value indicates an increasing (decreasing) trend.

Table 6. Summarized trend analysis results of water quality parameters based on Kendall's τ

Parameter	Number of Sampling Points			τ Range	Trend Conclusion
	Increasing	No Trend	Decreasing		
Pollution Index (PI)	3	0	6	−1.09 to 0.40	Mostly decreasing
TDS	3	0	6 (3 significant)	−2.57 to 0.79	Mostly decreasing
TSS	1	1	7	−1.78 to 0.69	Decreasing
BOD	9 (2 significant)	0	0	0.05 to 2.48	Increasing
COD	6	0	2	−0.69 to 1.68	Mostly increasing
NO_2	8 (3 significant)	0	1	−0.60 to 2.66	Increasing
NO_3	5 (1 significant)	0	4	−0.59 to 2.18	Mostly increasing
NH_3	0	0	9 (6 significant)	−3.04 to −1.32	Decreasing
T-P	7	1	1	−0.20 to 1.78	Increasing
Oil and Fat	4	1	4	−1.04 to 1.79	Cannot be concluded
Detergent	8 (1 significant)	1	1	−0.20 to 2.04	Increasing
Fecal Coliform	4	1	4	−0.84 to 0.59	Cannot be concluded
Total Coliform	3	1	5	−0.99 to 1.24	Cannot be concluded

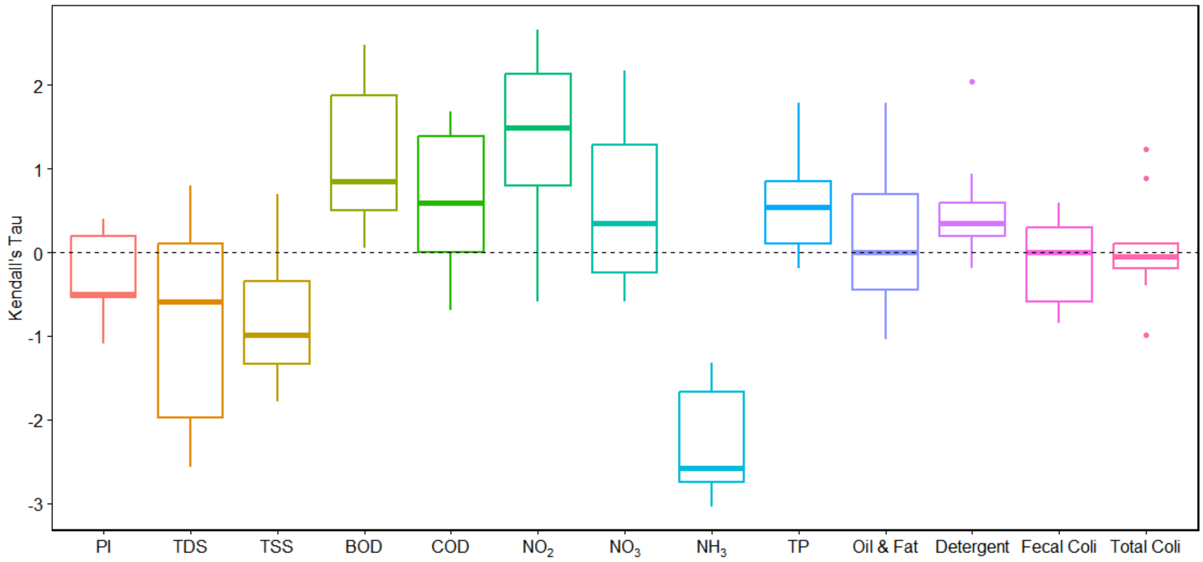

Figure 4. Boxplots of Kendall's τ for all water quality parameters using all rivers data. Positive τ = increasing trend. Negative τ = decreasing trend.

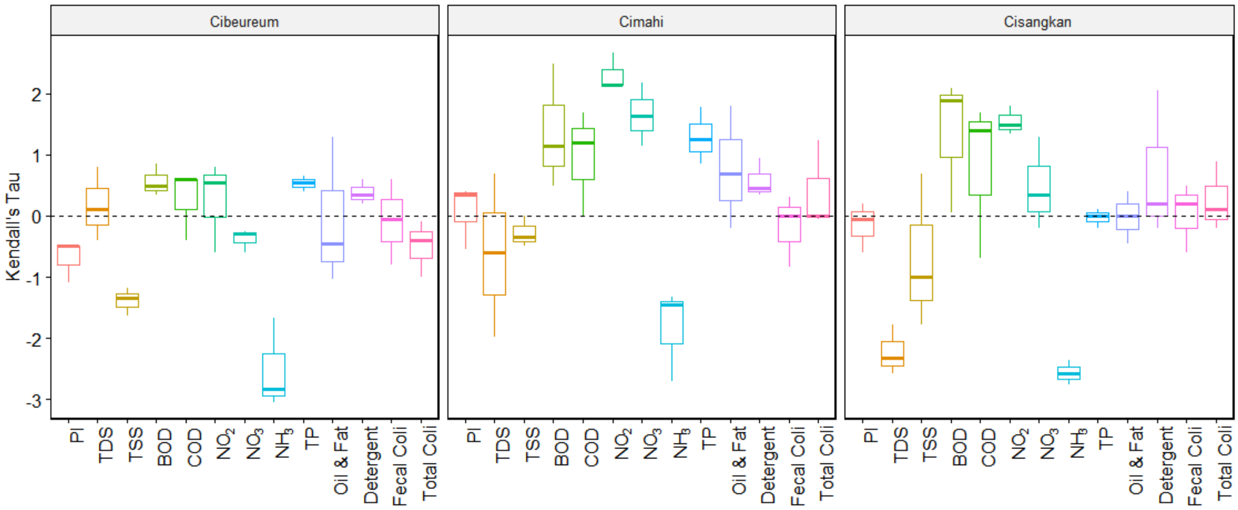

Figure 5. Boxplots of Kendall's τ for all water quality parameters using each river data. Positive τ = increasing trend. Negative τ = decreasing trend.

Figure 3 clearly shows that NH_3 concentrations at all sampling points of the three rivers had a decreasing trend. The decreasing trend of NH_3 concentration was statistically significant at the following sampling points: Cibeureum upstream, Cibeureum midstream, Cimahi downstream, and all Cisangkan points. These six significant trending sites make NH_3 the most significant trendy parameter among all parameters in this study. Other parameters that were also significantly trending are NO_2 (increasing at Cimahi upstream, midstream, and downstream), TDS (decreasing at Cimahi downstream, Cisangkan upstream, and Cisangkan downstream), BOD (increasing at Cimahi upstream and Cisangkan upstream), NO_3 (increasing at Cimahi midstream), and detergent (increasing at Cisangkan downstream). Sen's slopes of all significant trending parameter points are shown in Table 7 to show the change rate of the trend.

Table 7. Sen's slope value for parameters that have significant trend.

Parameter	Cibeureum River			Cimahi River			Cisangkan		
	Up	**Mid**	**Down**	**Up**	**Mid**	**Down**	**Up**	**Mid**	**Down**
TDS	-	-	-	-	-	−42	−9.11	-	−28.44
BOD	-	-	-	1.03	-	-	4.08	-	-
NO_2	-	-	-	0.005	0.017	0.014	-	-	-
NO_3	-	-	-	-	0.17	-	-	-	-
NH_3	−0.13	−0.11	-	-	-	−0.12	−0.04	−0.13	−0.13
Detergent	-	-	-	-	-	-	-	-	0.05

Interestingly, there are no contradicting trends among all significant points. The contradicting trends is defined as when a parameter obtains an equal or almost equal number between the increasing and decreasing trend points. The contradicting trends occured in these parameters: Oil and Fat, Fecal Coliform, and Total Coliform. Meanwhile, NO_3, with five increasing trend points and four decreasing trend points, is concluded as "mostly increasing" because NO_3 has one significant increasing point.

Moreover, NO_2 clearly had an increasing trend with eight (three were significant) out of nine points have increasing trends. It agrees with the process of nitrification in which NH_3 (ammonia) oxidized into NO_2 (nitrite) and then oxidized again into NO_3 (nitrate) (Bernhard, 2010). When the concentration of ammonia goes down while the concentration of nitrite and nitrate goes up in a place, the nitrification process occurs most of the time. The nitrification process requires oxygen to oxidize ammonia. More occurence of nitrification means more oxygen to oxidize ammonia into nitrite and nitrate. Therefore, the oxygen to oxidize or degrade the biochemical organic matter would be limited, increasing the concentration of BOD and COD.

Trends for BOD and COD are increasing with an average rate of 1.51 mg/L and 4.40 mg/L per season, consecutively. The highest increase rate of both BOD and COD occurred in the Cisangkan River, at the upstream (4.08 mg/L for BOD; 10.62 mg/L for COD) and the midstream (5.4 mg/L for BOD; 6.63 mg/L for COD).

The parameters TDS and TSS are concluded as having "mostly decreasing" trends, with six (three were significant) out of nine points having a decreasing trend on TDS and seven out of nine points having a decreasing trend on TSS. The average decreasing rate of TDS was −15.50 mg/L per season, while the average decreasing rate of TSS was −2.74 mg/L per season. The highest decreasing rate occurred downstream of the Cimahi River for TDS (−42 mg/L per season) and at the midstream Cibeureum River for TSS (−5.25 mg/L per season). From the overall site aspect, Cisangkan River had the strongest decreasing TDS and TSS trends among the three rivers (Figure 5).

Total Phosphate (T-P) and Detergent both have increasing trends on seven and eight sampling points, consecutively. The average increasing rate of T-P and Detergent was 0.012 mg/L and 0.017 mg/L per season. The highest increasing rate occurred consecutively downstream of the Cimahi River for T-P (0.029 mg/L per season) and downstream of the Cisangkan River for Detergent (0.051 mg/L per season). These increases hint at the increasing laundry wastewater at the three rivers since the parameters T-P and Detergent are the key points of laundry wastewater (Omolara & Zainab, 2018).

The overall trend of Oil and Fat cannot be concluded due to the contradicting trends with four increases, four decreases, and one no trend (Table 6). The position of the Oil and Fat boxplot in Figure 4 also supports this statement. However, Figure 5 shows that the Oil and Fat parameter is increasing, mainly in the Cimahi River. The calculation of Sen's slope showed that Oil and Fat at the upstream and midstream of Cimahi River have an average increasing rate of as low as 0.067 mg/L. Meanwhile, the highest Oil and Fat increase occurred upstream of the Cibeureum River, at 0.175 mg/L.

There is little to say about the overall Fecal Coliform and Total Coliform trend. While the trend results of the Fecal Coliform cannot be concluded at all, something can be said for the Total Coliform. The increasing trend of Total Coliform only happens at the Cisangkan River's midstream (3369 /100 mL increases per season) and downstream (40950 /100 mL increases per season), along with the Cimahi River's upstream (1223 /100 mL increases per season). The large data disparity between the two coliform parameters might be one reason why it was harder to achieve a clear outcome.

Finally, the Pollution Index (PI) trend concluded as "mostly decreasing". Although insignificant, six of nine sampling points showed decreasing trends (Figure 6). The most evident trend of PI was in the Cibeureum River. All three sampling points in the Cibeureum River have decreasing trends with the highest rate of the trend obtained at its upstream (−0.19 per season). It indicates that the three rivers' water pollution tended to be worsened, especially for the Cibeureum River. Also, it should be noted that the upper Cibeureum River had an uncommonly high rate of increasing pollution among the three rivers (Figure 6).

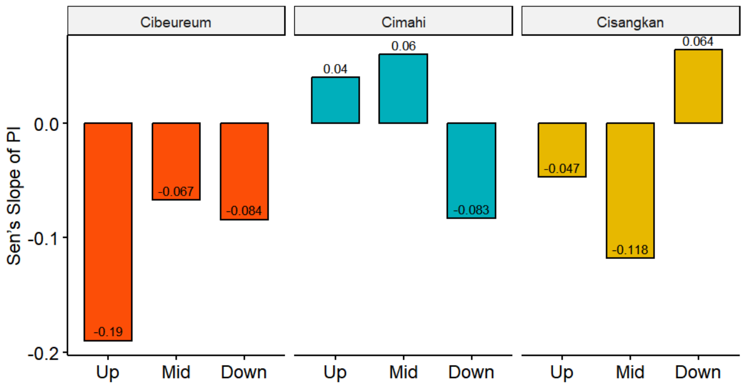

Figure 6. Sen's slope for the Pollution Index (PI) of the three rivers trend over 2017–2022.

3.3 Seasonal Trend

The seasonal trend means that the trend is calculated from the sample's unique seasonal sampling. The timing of data sampling in this study was divided into three seasons: wet season (December to April), dry season (August to November), and transitional season (May to July). The results of the Seasonal Mann-Kendall Test are shown using z statistics in Figure 7. Out of 117 samples, 4 showed statistically significant trends at $\alpha = 0.05$, which are Cibeureum River midstream PI ($z = -2.34$) and COD ($z = -2.01$), Cibeureum River downstream T-P ($z = 2.21$), and Cimahi River downstream PI ($z = -2.34$). The seasonal Sen's Slope estimates of the four significant samples in all three seasons are shown in Table 8.

Apparently, the seasonal trend of the top trending parameters in the basic Mann-Kendall trend test before was nonexistent, especially for NH_3 and NO_2. It shows that the wet and dry seasons significantly affected the concentrations of those parameters. Their concentrations in each season did not really change over the same season. The previous decreasing trend of NH_3 and increasing trend of NO_2 were indicated to be changed gradually over time because of the changing climate conditions of the seasons over the years. NH_3 and NO_2 lost their annual trends when stratified by season, which might also be driven by the inter-annual rainfall variability that may mask monotonic change within each season. It is suggested that the dataset be augmented with higher‑frequency sampling to capture intra-seasonal variability better.

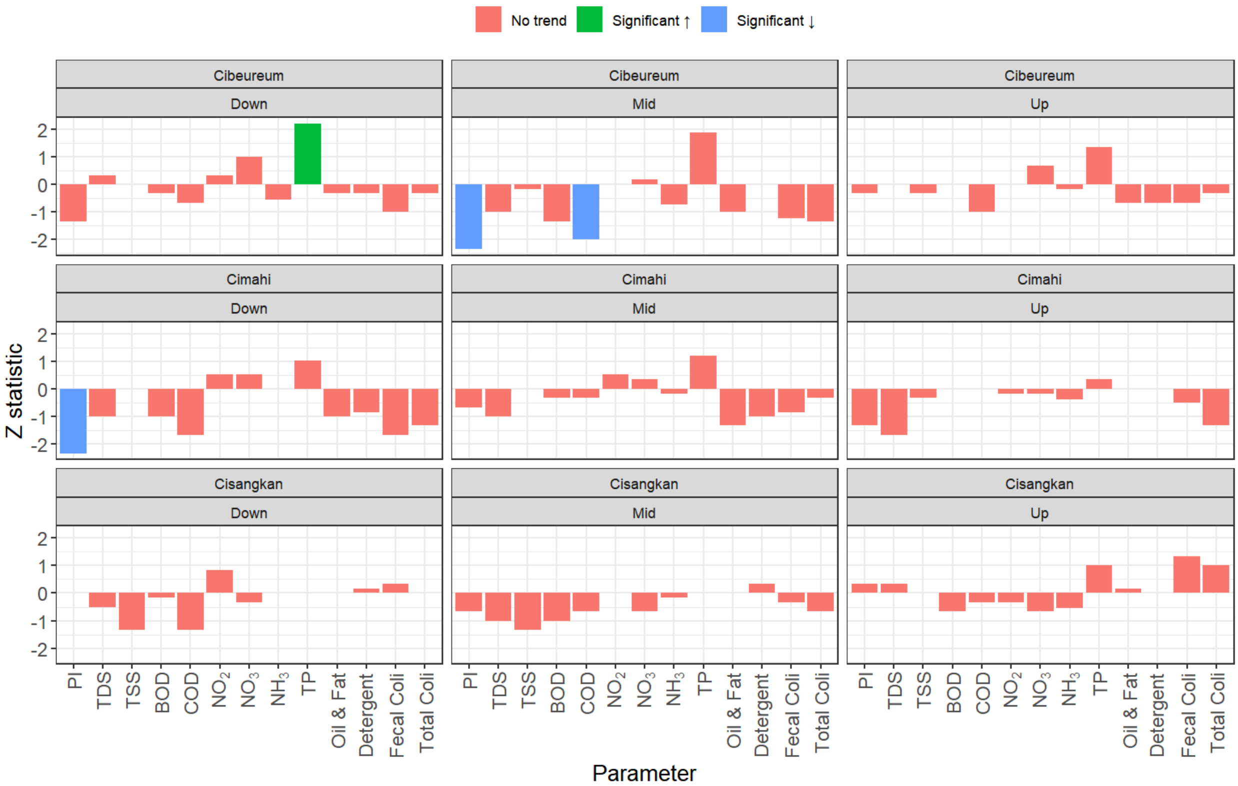

Figure 7. Seasonal Mann-Kendall's test result for all water quality parameters among the rivers.

In the midstream of the Cibeureum River and downstream of the Cimahi River, a relatively strong decreasing trend of PI showed that the river water quality is seasonal. The basic trend analysis (Figure 3) showed that the PI of the two sites had the same decreasing trends. Therefore, the seasonal effect is similar to the annual effect. The seasonal Sen's Slope estimates of the two sites (Table 8) showed that the water quality improved more in the dry season (-2.07 and -1.52) than in the wet season (-0.8 and -0.27). The possible driving forces of this phenomenon might be caused by the increased urban runoff transferring wastes from the city streets into the river during the wet season. Meanwhile, the reduced urban runoff during the dry season might generate more stable baseflows that dilute pollutant loads. Baseflows from groundwater are commonly known to have a pristine water quality that can dilute pollutants.

Table 8. Sen's slope value for parameters that have significant seasonal trend.

Sampling Points and Parameter	Season		
	Wet	Transition	Dry
Cimahi River Downstream PI	-0.8	-2.17	-2.07
Cibeureum River Midstream PI	-0.27	-0.81	-1.52
Cibeureum River Midstream T-P	-0.09	-0.09	-0.03
Cibeureum River Downstream COD	-5.42	2.61	222.18

3.4 Variability of Water Quality Parameters

The variability of each water quality parameter is shown as the coefficient of variation (CV) in Figure 8 and Table 9. The results show that the relatively high variability parameters were NH_3 at all three rivers, Fecal Coliform at the Cibeureum and the Cimahi Rivers, Total Coliform at the Cimahi River, and COD at the Cibeureum River. Interestingly, the significantly trending NH3 also becomes the most common parameter with a high variability at the midstream of the Cibeureum River, the midstream of the Cimahi River, and the upstream of the Cisangkan River. The top three parameters having the highest variability are NH_3 (average CV = 1.99), Fecal Coliform (average CV = 1.92), and Total Coliform (average CV = 1.53).

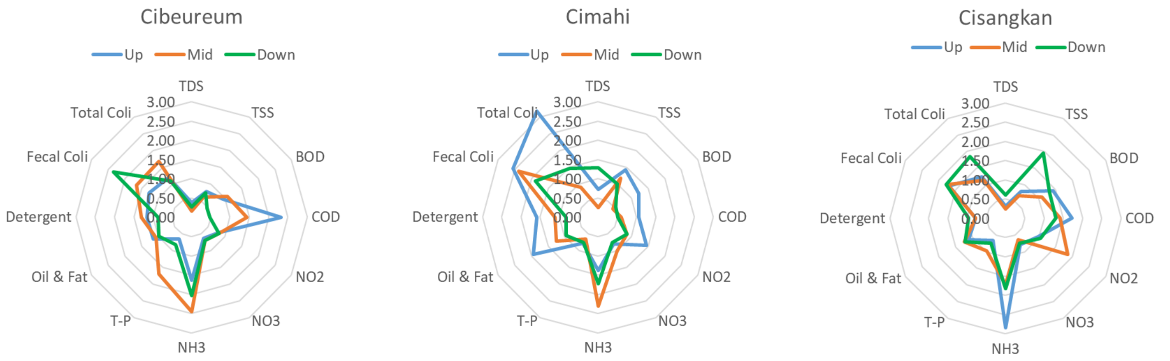

Figure 8. Radar spread of Coefficient of Variation (CV) for all water quality parameters.

Table 9. Coefficient of Variation (CV) values of all water quality parameters at each sites.

Parameter	Cibeureum			Cimahi			Cisangkan			Average
	Up	Mid	Down	Up	Mid	Down	Up	Mid	Down	
TDS	0.38	0.17	0.27	0.72	0.26	1.29	0.31	0.25	0.61	0.47
TSS	0.78	0.61	0.74	1.43	1.17	1.00	0.81	0.68	1.96	1.02
BOD	0.95	1.07	0.47	1.22	0.44	0.54	1.43	1.10	1.33	0.95
COD	2.33	1.44	0.48	1.06	0.60	0.52	1.72	1.41	1.30	1.21
NO_2	0.80	0.82	0.83	1.45	0.87	0.86	0.97	1.87	1.05	1.06
NO_3	0.62	0.70	0.70	0.80	1.00	0.75	0.78	0.65	0.74	0.75
NH_3	1.64	2.46	2.03	1.38	2.31	1.73	2.85	1.72	1.83	1.99
T-P	0.66	1.69	0.82	0.78	0.65	0.75	0.66	0.98	0.75	0.86
Oil & Fat	1.14	1.06	0.99	1.94	1.24	0.96	1.12	1.23	1.22	1.21
Detergent	1.16	1.30	0.87	1.59	1.11	0.82	0.78	0.78	0.96	1.04
Fecal Coli	1.28	1.65	2.34	2.55	2.39	1.88	1.70	1.74	1.77	1.92
Total Coli	1.20	1.68	1.09	3.18	0.89	1.46	1.25	1.13	1.86	1.53
Average	1.08	1.22	0.97	1.51	1.08	1.05	1.20	1.13	1.28	

The concentration of Total Coliform upstream of the Cimahi River had the highest variability among all the datasets, with a CV value of 3.18. It was also noted that Fecal Coliform at the same site also had a high CV value (2.55). This could hint at investigating the fluctuation of the microbiological pollution sources upstream of Cimahi River.

The top three of the overall highest average variability were NH_3 (CV = 1.99), Fecal Coliform (CV = 1.92), and Total Coliform (CV = 1.53). Despite a true underlying decreasing trend found in NH_3, its high variability masked the trend significance. A huge inter-annual fluctuation can drown out a monotonic signal. Meanwhile, low variability could lead to the overall lowest average variability obtained by TDS (CV = 0.47), followed by NO_3 (CV = 0.75) and T-P (CV = 0.86). Note that NO3 was the most consistent in obtaining low variability, with all its CV values being lower than 1.00. It is worth noting that the overall result suggests that TSS has a higher variability than TDS, and BOD has a lower variability than COD.

The average variability of water quality parameters at each sampling point varies from CV = 0.97 to CV = 1.51 (Table 9). The highest variability occurred upstream of the Cimahi River, while the lowest occurred at the Cibeureum River's downstream. The CV values for each sampling point (Table 9) give river managers insight into which points would have a highly fluctuating parameter.

Meanwhile, spatially, the Cimahi River's upstream had the highest variability, while Cibeureum River's downstream had the lowest variability. This information on parameter variability over the period 2017–2022 might help river managers investigate pollution sources further.

4. Conclusion

Trend analyses using the test of Mann-Kendall and Seasonal Mann-Kendall (Hirsch-Slack) have been applied for water quality parameters and water quality indices data of three Cimahi City major rivers: Cibeureum River, Cimahi River, and Cisangkan River, for the period 2017–2022.

The Mann-Kendall test was used on the Indonesian water quality index (WQI-INA), pollution index (PI), and 12 water quality parameters. Meanwhile, the Seasonal Mann-Kendall test was applied to the PI and 12 water quality parameters. The trend rate of change was also estimated by calculating Sen's slopes.

Based on the WQI-INA, the overall water quality status of the three rivers from 2017 to 2022 was poor, especially at Cisangkan River. Based on the Mann-Kendall test on WQI-INA, the river's water quality trends were improved in the Cibeureum River, worsened in the Cimahi River, and remained consistent in the Cisangkan River. However, all results were not significant due to the lack of data. Meanwhile, only the Cibeureum River could obtain the rate of change (Sen's slope = 2.22).

For the remaining water quality parameters, the basic Mann-Kendall test showed clear monotonic trends for several parameters. The parameters that showed clear significant trends were NH_3 (decreasing), NO_2 (increasing), and TDS (decreasing). The pervasive decrease of NH_3 and increase of NO_2 might be linked to active nitrification processes in the rivers. The other three parameters were found to be significantly trending but only in a few sampling sites: BOD (increasing at two sites), NO3 (increasing at one site), and detergent (increasing at one site). It is also found that the Cimahi River and the Cisangkan River have the most significant trends.

However, the Seasonal Mann-Kendall test largely failed to reproduce the trends for those significantly trending parameters in the basic Mann-Kendall test. This opposite result also occurred on the Cibeureum River, which had very few significant trends in the basic trend test while having the most significant trends in the seasonal trend test. This result could be caused by the strong influence of inter-annual variability and irregular sampling intervals on trend detection.

This study found four seasonally significant trends, mainly for the pollution index (PI). The calculation of Sen's Slope showed that the dry season improved the water quality (decreasing PI) more than the wet season. Possible driving forces include the increasing urban runoff during the wet season and the increasing stable baseflows from groundwater during the dry season.

The coefficient of variation (CV) values show that NH_3, Total Coliform, and Fecal Coliform were the top three of the highest variability parameters. In contrast, the top three of the lowest variability parameters are TDS, NO_3, and T-P. The high variability of NH_3 marked as a driver in reducing statistical power to detect trends, making the significant trend of it in the basic trend test cannot be reproduced by the seasonal trend test. Meanwhile, looking from the site aspects, Cimahi River's upstream has the highest variability, while Cibeureum River's downstream has the lowest variability. It is also recommended to prioritize improving coliform parameters monitoring and control measures, as Fecal Coliform and Total Coliform variability were high, marking unstable microbiological pollutant loads.

This study's limitation is the irregular sampling months with only 45 points over six years. To better capture intra-seasonal dynamics, increasing sampling frequency to at least bi-monthly (once every two months) is recommended. Longer annual data should also be preferred to obtain a better trend, especially for the WQI-INA and other water quality indices, which aggregate data from many parameters.

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