

Research Article

Pollution Load Assessment using QUAL2Kw and IDW (Case Study: Cisangkan Watershed, West Java Province)

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Abstract

Cisangkan River, a tributary in the Upper Citarum Watershed, West Java, stretches 8.91 km across 1,800 ha. Flowing through West Bandung Regency and three districts in Cimahi City, it discharges into the Saguling Reservoir. Over the past five years, the river's water quality has been classified as heavily polluted. This study aims to estimate potential pollution loads from domestic, industrial, and agricultural sectors and evaluate the impact of pollution load reduction on water quality improvement. Pollution loads were estimated using emission factors, urban equivalent ratios, and pollutant transfer coefficients. Water quality simulation was conducted using the QUAL2Kw model, while spatial distribution analysis employed the Inverse Distance Weighted (IDW) interpolation for BOD, COD, and TSS parameters. Results show that the domestic sector contributes the highest BOD load at 441.1 kg/day (54%), while the industrial sector dominates COD pollution with 738.67 kg/day (53%). The highest TSS load also originates from the domestic sector, contributing 421.9 kg/day (52%). The QUAL2Kw model achieved satisfactory accuracy, with RMSPE values of 1.4% for BOD, 2.73% for COD, and 5.06% for TSS. Scenario V, simulating a 90% reduction in pollution loads, demonstrates significant improvement in pollution load capacity, allowing the river to meet national water quality standards. Spatial analysis using IDW indicates the highest BOD pollution load from the domestic sector in Leuwigajah Sub-district, from the agricultural sector in Citeureup Sub-district, and from the industrial sector in Padasuka Sub-district.

Keywords: Cisangkan river, emission factor, pollution load, Qual2kw, IDW

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1. Introduction

Most water resources in developing countries are contaminated by domestic, industrial, and agricultural waste, which poses significant threats to human health (Shan et al., 2020). In Indonesia, domestic waste contributes approximately 85% of the total pollution load to water bodies, primarily originating from residential, industrial, and agricultural areas (Prilly et al., 2019). The Citarum River plays a vital role in supplying water for multiple sectors. However, intensive human activities along the riverbanks have resulted in pollution loads that exceed the river's ecological carrying capacity. According to the Indonesian Ministry of Environment and Forestry, the pollution load – particularly for biochemical oxygen demand (BOD) – in the Citarum River has surpassed the allowable threshold. The Cisangkan River, a tributary of the Citarum River that discharges into the Saguling Reservoir, faces similar environmental challenges. Flowing through densely populated areas, the river receives substantial pollution loads from domestic, industrial, and agricultural sources. Increasing population density and land use changes have further exacerbated the decline in water quality. Between 2019 and 2023, the water quality in the Cisangkan River – particularly for BOD – frequently failed to meet the national water quality standards set by Government Regulation No. 22 of 2021.

In 2017, the BOD pollution load in the Cisangkan River was estimated at 5.9 tons/day, and it was projected to increase to 11.5 tons/day by 2021 (Bukit & Yusuf, 2002; Hikmat & Juwana, 2019). With pollution loads

continuing to rise, there is an urgent need to assess the river’s pollution load capacity to determine its ability to assimilate pollutants without degrading water quality.

This study aims to evaluate the pollution load of the Cisangkan River using the QUAL2Kw model, which allows for simulation of the effects of varying pollutant loads on water quality. In addition, spatial analysis employing the Inverse Distance Weighted (IDW) method within a Geographic Information System (GIS) is used to map the spatial distribution of pollutants along the river. This integrated approach is expected to support more effective water quality management and pollution control strategies, thereby contributing to the sustainability of the aquatic ecosystem and the optimal utilization of water resources.

2. Methodology

2.1 Research location

This study was conducted in the Cisangkan watershed, a tributary of the Citarum River with a total length of 8.91 km, discharging into the Saguling Reservoir. The Cisangkan watershed covers an area of approximately 1,800 hectares. Its geographical location in a densely populated region makes the Cisangkan River particularly vulnerable to water quality degradation. The study area is illustrated in Figure 1.

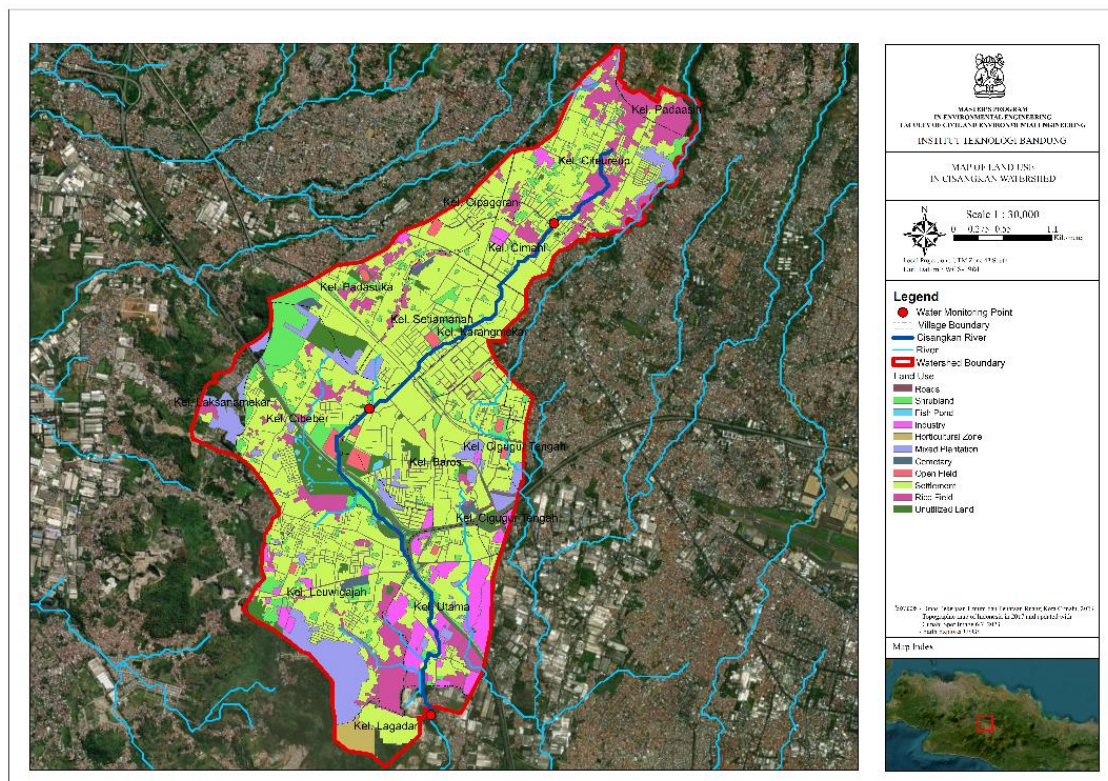


Figure 1. Research location map with land utilization

Table 1 presents land use in the study area on eleven different classifications, namely roads, shrubland, fish ponds, industrial zone, horticultural zone, mixed plantation, cemeteries, open fields, settlement area, rice fields, and unutilized lands. Overall, the land use of Cisangkan watershed was dominated by settlement area with 1,200.17 hectares of the total area (Dinas Lingkungan Hidup Kota Cimahi, 2023).

Table 1. Land use area in the research location

| No. | Land use | Area (Ha) |
|-----|--------------------|-----------|
| 1 | Roadways | 74.99 |
| 2 | Shrubs | 137.69 |
| 3 | Fishponds | 3.74 |
| 4 | Industrial zone | 80.47 |
| 5 | Horticultural zone | 0.46 |

| No. | Land use | Area (Ha) |
|-----|------------------|-----------|
| 6 | Mixed plantation | 104.18 |
| 7 | Cemeteries | 9.09 |
| 8 | Open fields | 19.97 |
| 9 | Settlement | 1,200.17 |
| 10 | Rice fields | 166.34 |
| 11 | Unutilized land | 89.16 |

2.2 Pollution load carrying capacity (PLCC)

The Pollution Load Carrying Capacity (PLCC) represents the ability of a water source to assimilate pollutants without causing the water to become contaminated. Three key water quality parameters are analyzed, namely BOD, COD, and TSS (Razif, 2022). The equations used are presented in Equations 1 to 3 below (Keputusan Menteri Negara Lingkungan Hidup Nomor 110 Tahun 2003 Tentang Pedoman Penetapan Daya Tampung Beban Pencemaran Air Pada Sumber Air, 2003).

$$PLCC = MPL - APL \quad (1)$$

$$MPL = c_m \cdot Q_{river} \quad (2)$$

$$APL = c_a \cdot Q_{river} \quad (3)$$

Where:

PLCC = Pollution Load Carrying Capacity (kg/day)

MPL = Maximum Pollution Load (kg/day)

APL = Actual Pollution Load (kg/day)

c_m = Standard concentration (kg/m³)

c_a = Actual pollutant concentration (kg/m³)

Q_{river} = River discharge (m³/day)

2.3 Pollution load potential (PLP)

Pollution Load Potential (PLP) refers to the number of pollutants that can be introduced into the environment, including rivers. In this study, potential pollution loads from various sectors – domestic, agricultural, and industrial – will be calculated.

Potential pollution load from the domestic sector

The potential pollution load of the domestic sector in a watershed is determined by several key variables, including population size, emission factors, the urban equivalent ratio, and the pollution load transfer coefficient. To estimate the population contributing to pollution in the Cisangkan watershed, the proportion of residential land use within each village or subdistrict is calculated relative to the total residential area in the watershed.

The load transfer coefficient reflects the estimated fraction of pollutants that reach the river. For settlements located within 0–100 meters of the river, the coefficient (α) is assigned a value of 1, indicating direct discharge into the river. For areas situated 100–500 meters away, α is set at 0.85, representing pollutant transport via open drainage systems. For locations more than 500 meters from the river, α is 0.3, corresponding to the use of septic tanks for wastewater management (Yusuf, 2009).

The urban equivalent ratio is determined by categorizing villages based on population size. Areas with populations exceeding 100,000 are classified as urban and assigned a ratio of 1. Villages with populations between 20,000 and 100,000 are considered rural, with a ratio of 0.8125, while those with fewer than 20,000 residents are classified as remote, with a ratio of 0.625 (Juwana et al., 2024).

Emission factors for the domestic sector provide estimates of pollutant generation from household activities. According to Pangestu, Riani, and Effendi (Pangestu et al., 2017), the emission factors are 0.040 kg/person/day for BOD, 0.055 kg/person/day for COD, and 0.038 kg/person/day for TSS. These parameters are used in Equation 4 to calculate the domestic pollution load potential (Yusuf, 2009).

$$PLP_{domestic\ sector} = P \cdot EF_{domestic\ wastewater} \cdot \alpha \cdot U_{ER} \tag{4}$$

Where:

P = Population (person)

$EF_{domestic\ wastewater}$ = Emission Factor of domestic wastewater (kg/person/day)

α = Load transfer coefficient

U_{ER} = Urban equivalent ratio

Potential pollution load from the agricultural sector

In the Cisangkan watershed, agricultural activities—comprising rice paddies and mixed plantation—contribute to the potential pollution load, which is calculated based on the extent of agricultural land, relevant emission factors, and the total planting duration.

The agricultural land area data were obtained from the land use map of the Cisangkan watershed. While the emission factors for rice fields were recorded at 0.4 kg/ha for TSS, 225 kg/ha for BOD, and 337.5 kg/ha for COD. In contrast, other types of plantation areas exhibited lower emission factors compared to rice and mixed-crop fields, namely 0.6 kg/ha for TSS, 32.5 kg/ha for BOD, and 48.75 kg/ha for COD (Yusuf, 2009). The average cropping period for rice fields in Indonesia is approximately 107 days (Ardiansyah et al., 2022a), while other types of plantations are assumed to have a cultivation period of 365 days. The potential pollution load for the agricultural sector is calculated using equation 5 (Yusuf, 2009).

$$PLP_{agricultural\ sector} = \frac{EF_{agricultural\ wastewater} \cdot A \cdot 10\%}{D} \tag{5}$$

Where:

$EF_{agricultural\ wastewater}$ = Emission Factor of agricultural wastewater (kg/ha/day)

A = Area of agricultural zone (ha)

10% = Percentage of waste entering the river

D = Harvest period (day)

Potential pollution load from the industrial sector

The calculation of pollution load from the industrial sector in this study is based on environmental standards and the discharge of industrial wastewater from each industry type. The concentration of wastewater used in the calculation is assumed to meet environmental quality standards, in accordance with the provisions in Ministerial Regulation No. 5 of 2014 on Wastewater Quality Standards and its amendments in Ministerial Regulation No. P.16/MENLHK/SETJEN/KUM.1/4/2019. The industrial wastewater quality standards can be shown in Table 2. The industrial sector's potential contribution to the overall pollution load was estimated by applying Equation 6 (Pangestu et al., 2017).

$$PLP_{industrial\ sector} = Q \cdot C_m \tag{6}$$

Where:

Q = Industrial discharge (m³/s)

C_m = Maximum concentration allowed (mg/L)

Table 2. Industrial wastewater quality standards

| No | Type of industry | Number of Industries (Units) | Standard used | Discharge (m ³ /s) | Maximum concentration allowed (mg/L) | | |
|----|------------------|------------------------------|--|-------------------------------|--------------------------------------|-----|-----|
| | | | | | BOD | COD | TSS |
| 1 | Textiles | 16 | Appendix II P.16/MENLHK/SETJEN/ KUM/1/4/2019 | 100 | 60 | 150 | 50 |
| 2 | Food | 4 | Appendix XLV PermenLH 5/2014 | 489 (Sakti, 2021) | 100 | 200 | 100 |

| No | Type of industry | Number of Industries (Units) | Standard used | Discharge (m ³ /s) | Maximum concentration allowed (mg/L) | | |
|----|-------------------------------------|------------------------------|--------------------------------|----------------------------------|--------------------------------------|-----|-----|
| | | | | | BOD | COD | TSS |
| 3 | Metals | 1 | Appendix XLVII PermenLH 5/2014 | 0.532 (Jauharoh et al., 2020) | 150 | 300 | 400 |
| 4 | Automotives/ Motorcycle spare parts | 2 | Appendix XLVII PermenLH 5/2014 | 2.41 (Nimassari & Purnomo, 2021) | 150 | 300 | 400 |
| 5 | Ceramics and tiles | 1 | Appendix XLVII PermenLH 5/2014 | 248.5 (Sari et al., 2017) | 150 | 300 | 400 |
| 6 | Plywood | 1 | Appendix VII PermenLH 5/2014 | 88 (Sahubawa, 2008) | 75 | 125 | 50 |
| 7 | Printing | 2 | Appendix XXXV PermenLH 5/2014 | 10 (Rosidi & Razif, 2017) | 100 | 300 | 400 |

2.4 QUAL2Kw model

Water quality modelling is conducted using the QUAL2Kw software, which has the capability to simulate or predict changes in water quality based on variations in pollutant flow. Calculations in QUAL2Kw are performed through programming written in Visual Basic for Applications (VBA). This software generates various graphs that plot the model output along with comparative distance (in kilometers) data along the river’s course (Pelletier et al., 2006).

In the modelling using QUAL2Kw, three key water quality parameters are modelled, namely BOD, COD, and TSS (Razif, 2022). The QUAL2Kw model is also calibrated to adjust the model parameters so that the simulation results align with observational data. The suitability between the model and observed water quality data evaluated through model validation. Model validation in this study was carried out using the Root Mean Square Percent Error (RMSPE) method. If the RMSPE value is below 20%, then the model can be considered acceptable and reliable for use in subsequent scenario-based simulations (Aliffia & Karnaningroem, 2019). The RMPSE was calculated by using equations 7.

$$RMSPE = \sqrt{\frac{\sum_{i=1}^n (D_p - D_o)^2}{D_p}} \cdot 100\% \tag{7}$$

Where:

RMSPE = Root mean square percent error (%)

D_p = Data prediction (mg/L)

D_o = Data observation (mg/L)

2.5 Pollution load reduction simulation

River water quality simulations are performed using the validated model. Simulations are conducted under five different scenarios. A trial and error process is applied in the modelling to evaluate various pollution load reduction scenarios until the water quality meets the standards stipulated by applicable regulations (Komarudin et al., 2015). The five scenarios carried out in this study are summarized in Table 3.

Table 3. Pollution load reduction scenarios

| No. | Water quality at the headwater | Pollution load | |
|-----|--------------------------------|--------------------|--------------------|
| | | Point source | Nonpoint source |
| I | Existing condition | Existing condition | Existing condition |
| II | Existing condition | 50% of reduction | Existing condition |
| III | Existing condition | Existing condition | 50% of reduction |
| IV | Existing condition | 50% of reduction | 50% of reduction |
| V | Existing condition | Trial and error | Trial and error |

2.6 Pollution load analysis using Inverse Distance Weighted (IDW)

Inverse Distance Weighted (IDW) is a commonly used spatial interpolation method in GIS to predict values at unmeasured locations based on values from the nearest measured points (Novita et al., 2023). In this study, IDW is applied to estimate the pollution load that can be absorbed by the receiving water body based on the distribution of identified pollution sources.

3. Result and Discussion

3.1 Water quality of the Cisangkan River

The assessment of water quality was conducted by evaluating the monitored parameters against the threshold values set forth in Government Regulation No. 22 of 2021 on Water Quality Standards. The result of the sampling for various water quality parameters and their comparisons with respective threshold values are presented in Figure 2.

The concentration of BOD and COD parameters did not meet the quality standards since the upstream river monitoring point. Geographically, the upstream monitoring point of the Cisangkan River is located in Citeureup Village, part of it is in Cipageran Village, and part of it is in Cimahi Village. Land use in these areas is predominantly residential land and agricultural, both of which are identified as major sources of pollution in the Cisangkan River. The BOD concentration at the upstream section of the Cisangkan River during the March an October monitoring period showed a significant spike, reaching 181 mg/L. This condition is likely linked to the presence of untreated domestic wastewater discharges through pipelines (see Figure 2). A study by Ikbal, Sudarno, and Priyambada (Ikbal et al., 2023) in the Beringin River, Semarang City, found BOD levels reaching 129.17 mg/L in areas located near direct discharges from domestic and laundry activities that were not pre-treated.

In addition to land use for residential areas, agricultural activities in Citeureup Sub-district serve as an important factor influencing the upstream river water quality. In March, the BOD concentration in the upstream area was recorded to be very high. This coincides with the second harvest season (Planting Season II) in most regions of Indonesia, including West Java, which generally occurs around 105 days after planting (Ardiansyah et al., 2022b), typically taking place between February and March. During this period, rainfall remains relatively high, resulting in increased surface runoff from paddy fields. Agricultural practices commonly involve the use of fertilizers, pesticides, and herbicides to enhance crop productivity. However, uncontrolled or improper application of these agrochemicals can lead to the entry of chemical residues into water bodies, either through surface runoff or infiltration into groundwater that subsequently flows into the river. This process contributes to elevated concentrations of organic and inorganic compounds (Wurtsbaugh et al., 2019). Rainwater carrying fertilizer residues, pesticides, organic matter from harvest waste, and irrigation water enters the river, causing a spike in BOD concentration. In June, BOD levels in the upstream area significantly decreased. This period marks the end of the rainy season, according to the Citarum River Basin Authority (BBWS Citarum), and corresponds to the post-harvest phase when agricultural land is relatively inactive or undergoing initial soil preparation. Reduced agricultural activity and lower rainfall limit the input of organic matter and nutrients into the river. By October, BOD concentrations rise again, coinciding with the resumption of agricultural activities prior to the next planting season, along with the onset of early wet season rainfall. These conditions trigger surface runoff that transports residual organic matter, fertilizers, and pesticides into the upstream river.

The middle monitoring point of the Cisangkan River is also dominated by residential land use around Setiamanah Village, Karangmekar Village, Padasuka Village, Cibabat Village, and Baros Village. The use of agricultural land becomes less prevalent, while residential development increases near the Middle Cisangkan River monitoring point. Downstream of the Cisangkan River through the Utama Village and Leuwigajah Village, where land use includes residential areas, agriculture, and designated industrial zones. Pollution levels at the downstream monitoring points rise significantly, leading to increased concentrations of pollutants. This aligns with the findings of Khouni, Louhichi and Ghrabi (Khouni et al., 2021), who reported that rivers flowing through industrial areas tend to show the highest BOD concentrations. Similarly, a study on the downstream of Citarum watershed found that the highest BOD levels occurred in areas designated for commercial land use (Ayu et al., 2022). COD concentrations near industrial zones are also likely to increase, as supported by (Khouni et al., 2021), who found that the upstream section of the Wadi Tahouna had the highest COD concentrations due to the presence of nonbiodegradable inorganic substances from industrial activities.

From a temporal perspective, BOD and COD concentrations in the Cisangkan River fluctuated across the three monitoring periods in 2023. In March, high BOD and COD levels could be associated with high rainfall in the early months of the year. High rainfall has the potential to increase surface runoff which carries more pollutants into the river body. This is in accordance with the research of (Wang et al., 2024) that intense rainfall can increase the volume of surface runoff, thus potentially transporting more pollutants from urban areas to the river body.

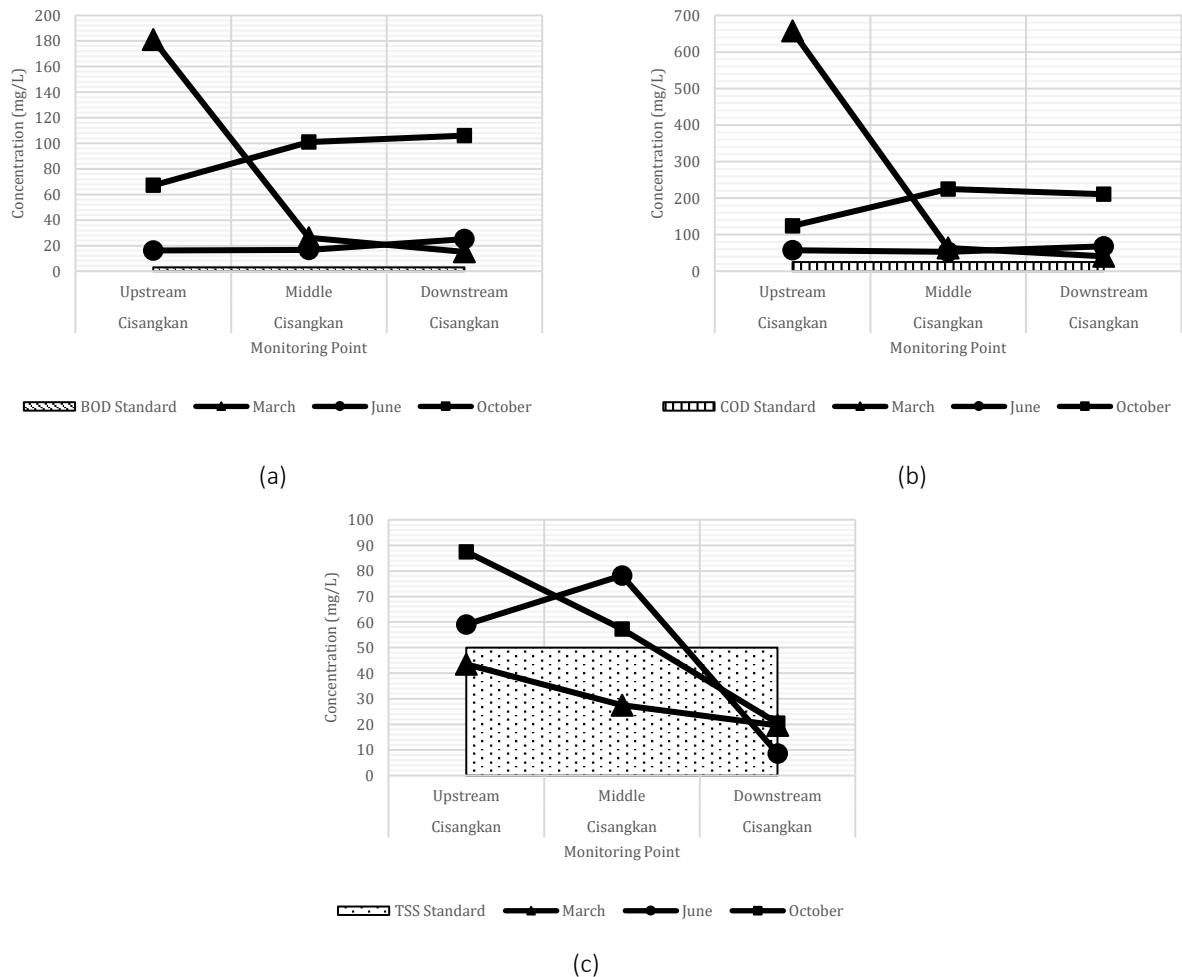


Figure 2. Graph of water quality in Cisangkan River: (a) BOD parameter; (b) COD parameter; (c) TSS parameter.

3.2 Potential pollution load

Comparison of potential pollution load from all sectors

The potential pollution load in the Cisangkan watershed was estimated from three main sectors: domestic, agricultural, and industrial, based on three key water quality parameters: BOD, COD, and TSS. Figure 3 presents a comparison of the potential pollution loads from all sectors.

Based on the calculation, the domestic sector was identified as the largest contributor to BOD load, accounting for 441.1 kg/day or approximately 54% of the total BOD load, which reached 812.12 kg/day. This is higher than the contributions from the industrial sector (344.93 kg/day) and the agricultural sector (26.09 kg/day). This load illustrates the significant contribution of household waste, especially from bathing, washing, and defecating/urination activities. These findings are consistent with a study by (Juwana et al., 2024), which reported that the domestic sector was the main source of pollution in the Cikembar River, particularly in Bojongkembar Village. Similarly, Pramaningsih, Suprayogi, and Purnama (Pramaningsih et al., 2020) reported that domestic activities are the main contributors to the BOD load in the Karang Mumus River, with a total reaching 5,686.75 kg/day. Kalavaty (2011) in (Pramaningsih et al., 2020) also emphasized that urbanization and dense settlements along riverbanks significantly contribute to water pollution from domestic wastewater.

In contrast to BOD, most of the COD pollution load originated from the industrial sector, contributing 738.67 kg/day, or approximately 53% of the total COD load of 1,388.4 kg/day. This indicates that industrial wastewater within the Cisangkan watershed still contains a significant amount of nonbiodegradable organic compounds, such as residual solvents, chemical substances, and complex carbon compounds. Similar findings were reported in a study of Wadi El Bay, where high COD levels were attributed to the presence of inorganic substances and large amounts of non-biodegradable components originating from industrial activities (Khouni et al., 2021). Another study by (Ayu et al., 2022) reported that in various industrial zones, COD levels tend to increase due to direct discharge of untreated or inadequately treated wastewater into receiving water bodies.

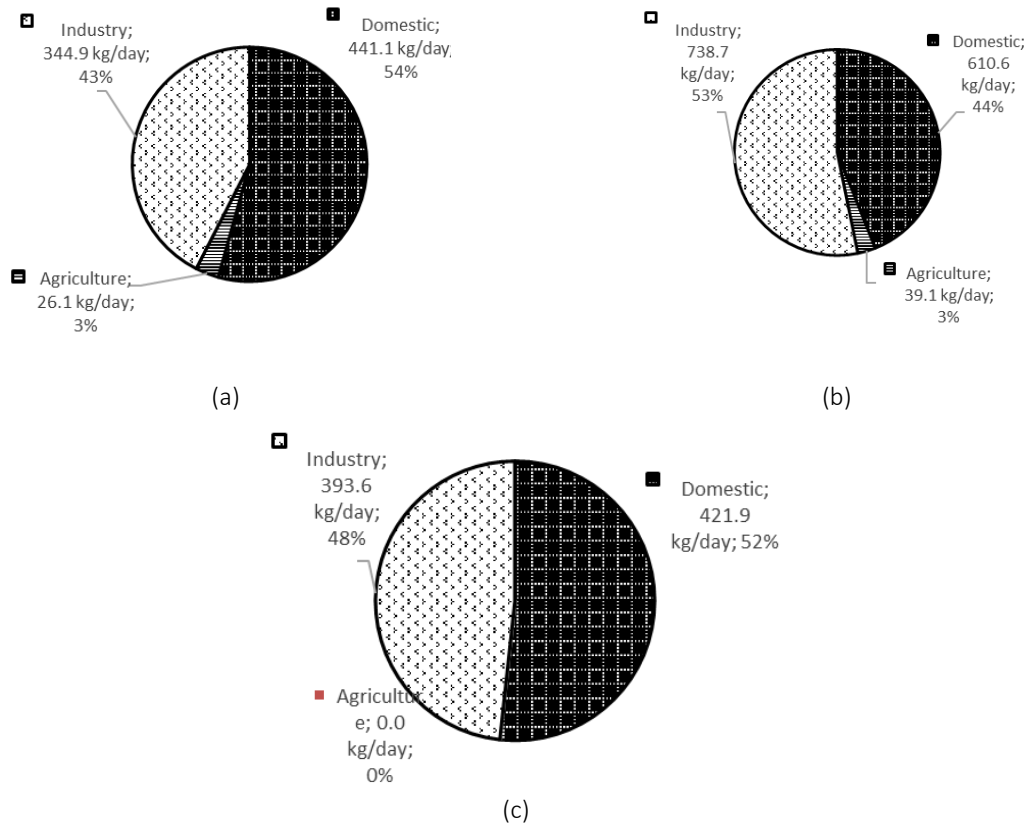


Figure 3. Comparison of potential pollution loads from all sectors in the Cisangkan watershed: (a) BOD parameter; (b) COD parameter; (c) TSS parameter.

As for TSS, the domestic sector contributed the highest load at 421.9 kg/day, accounting for nearly 52% of the total TSS load of 815.55 kg/day. Meanwhile, the agricultural sector contributed only about 0.04 kg/day, which

is relatively negligible. The substantial contribution of domestic and industrial sectors to TSS indicates that both sectors generate wastewater containing a significant amount of suspended solids.

Spatial distribution of potential pollution loads by sectors

The analysis of potential pollution load distribution in the Cisangkan watershed reveals distinct spatial patterns across villages, primarily driven by industrial, domestic, and agricultural activities. Leuwigajah, Baros, and Padasuka villages are identified as dominant contributors to pollution loads, as illustrated in Figure 4 by the yellow to orange zones. These areas are home to various industries, including ceramic and tile manufacturing in Baros, and food processing industries in both Leuwigajah and Padasuka, which significantly contribute to pollutant discharges into the river system.

Regarding domestic pollution, Leuwigajah and Citeureup villages show the highest estimated BOD loads. These are represented by the orange to red gradients in Figure 4, indicating substantial contributions from untreated domestic wastewater, such as household greywater, laundry effluents, and food waste. The high population density and lack of adequate wastewater treatment facilities in these areas further exacerbate the pollutant load entering the Cisangkan River.

For the agricultural sector, the results show that Cipageran village contributes the highest BOD load, suggesting that farming activities – including fertilizer use and organic waste runoff – have a notable impact on water quality. In contrast, although Leuwigajah also has agricultural land use, its overall contribution to agricultural pollution is lower due to limited farmland area and the prevalence of mixed land uses (residential and industrial), which reduces the intensity of agricultural runoff. The spatial distribution of potential pollution loads from all sectors can be seen in Figure 4.

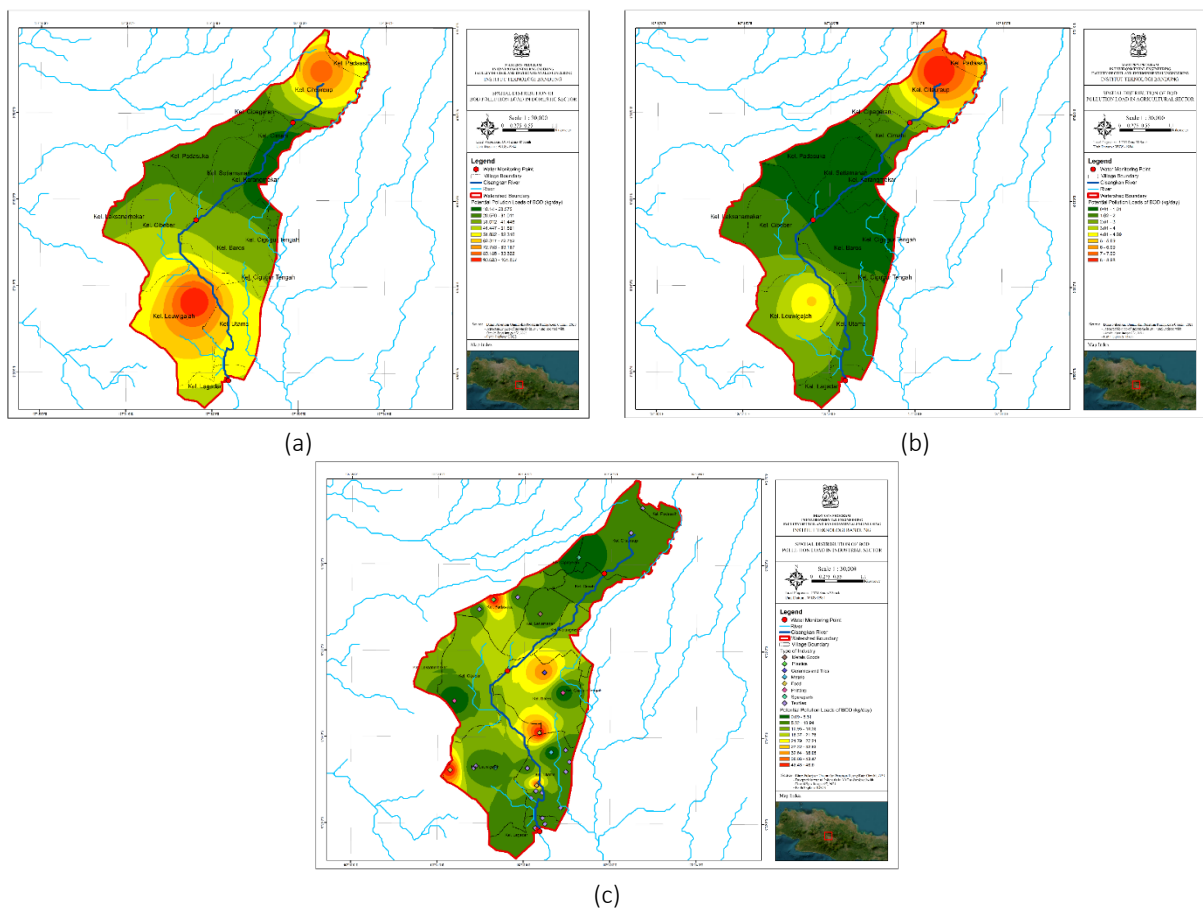


Figure 4. Spatial distribution of potential BOD pollution loads: (a) domestic sector; (b) agricultural sector; (c) industrial sector.

3.3 QUAL2Kw model and simulation of pollution load reduction

Water quality modelling using the QUAL2Kw software requires a set of data that represents the physical, chemical, and hydrological conditions of the river. Model validation was conducted using the RMSPE method to quantify the average percentage error between simulated values and field data. Based on the calculation

results using both modeled and field data for the year 2023, the RMSPE ranged from a minimum of 1.4% to a maximum of 5.06%, indicating a very low relative error between simulation and observation results. These values fall well below the commonly accepted threshold of 20% for hydrological and water quality models, thus confirming that the model performance is adequate for further scenario-based simulations (Aliffia & Karnaningroem, 2019).

Figure 5 illustrates the results of water quality modeling under five different scenarios, as outlined in Table 3. Water quality modeling of the Cisangkan River using QUAL2Kw incorporated scenario-based simulations to evaluate the attainment of Class II river water quality standards, as outlined in Government Regulation No. 22 of 2021. Among the tested scenarios, 5th scenario, which simulates a 90% reduction in pollutant loads, was implemented to determine the extent to which such a reduction could improve water quality to meet the regulatory threshold.

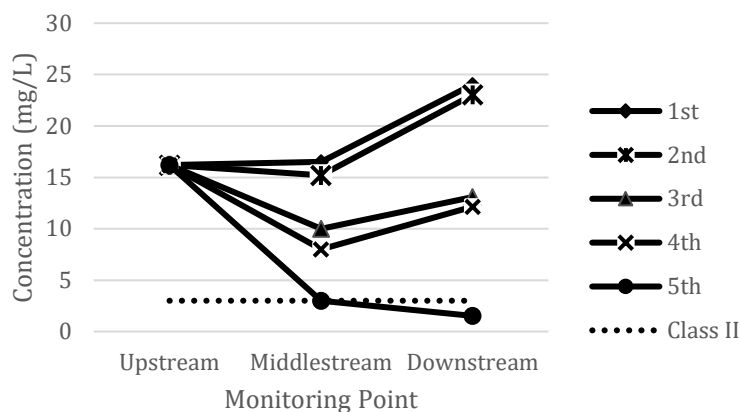


Figure 5. Comparison of BOD concentration value from five different scenarios.

River water quality, particularly as a source of raw water, has been designated as a key indicator in assessing the declining carrying capacity of surface water in the region. The Cimahi City Government projects this indicator using a linear trend under a business-as-usual (BAU) approach up to the year 2030. Although the projection suggests a gradual improvement in water quality, it still falls short of meeting the Class II standard required by Government Regulation No. 22 of 2021 (Peraturan Daerah Kota Cimahi Nomor 4 Tahun 2024 Tentang Rencana Tata Ruang Wilayah Kota Cimahi Tahun 2024-2044, 2024). This target aligns with SDG Indicator 6.3.2.(b), which calls for “the improvement of river water quality as a source of raw water toward meeting the average Class II water quality standard.” Therefore, interventions beyond the BAU scenario are urgently needed to accelerate progress toward these targets. In this context, 5th scenario of the QUAL2Kw model presents a strategic alternative, as it demonstrates a condition in which the water quality meets the Class II standard. The implementation of this scenario not only supports the achievement of the SDG indicator but also represents a concrete step toward enhancing environmental carrying capacity, particularly in terms of surface water quality in Cimahi City.

3.4 Allocation of pollution load using IDW

Spatial analysis in this study was conducted using the Inverse Distance Weighted (IDW) method to visualize the distribution of pollutant loads based on the modelling results in the optimal scenario, namely a 90% reduction in pollutant loads. The spatial distribution of BOD pollutant loads from domestic, agricultural, and industrial sectors in the Cisangkan watershed is shown in Figure 6. Areas with higher pollutant loads are represented in green to blue, while yellow to red zones indicate areas with lower pollution input.

In the domestic sector, the spatial distribution of BOD pollutant load allocation indicates that Leuwigajah Village has a relatively high pollution load. This condition is influenced by the village's extensive area within the watershed and its high population density, both of which contribute significantly to domestic wastewater generation. As visualized in the map, regions shaded in blue to green indicate a higher concentration of pollutant loads, whereas yellow to light yellow areas correspond to zones with relatively lower pollution input.

For the agricultural sector, the IDW analysis reveals that Citeureup Village, located in the upstream region, has the highest agricultural BOD load, suggesting that farming activities in this area contribute substantially to the overall pollutant load entering the river.

In the industrial sector, Leuwigajah Village is identified as having the lowest BOD carrying capacity, as also depicted in Figure 6, highlighting the need for targeted industrial wastewater management interventions in this area.

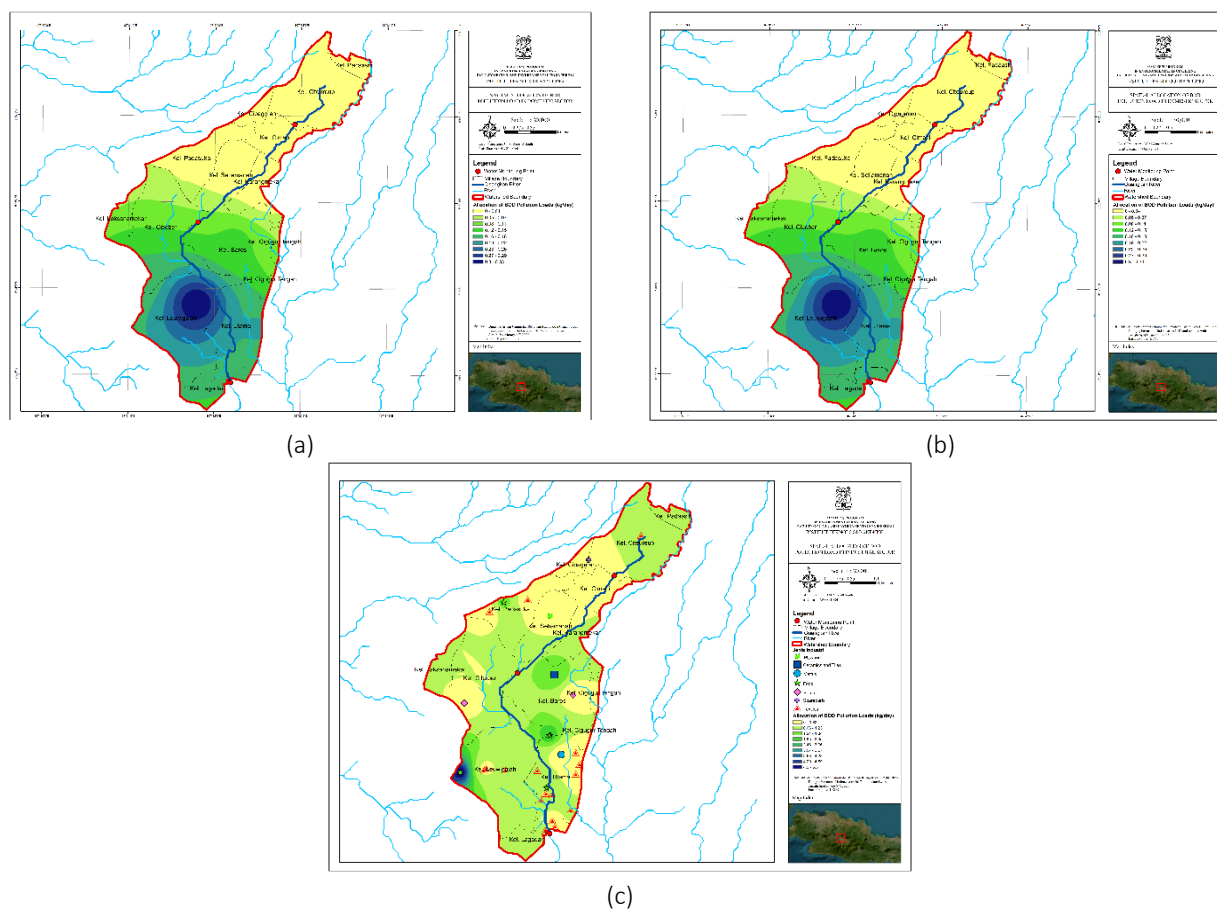


Figure 6. Spatial distribution of BOD pollution loads allocation: (a) domestic sector; (b) agricultural sector; (c) industrial sector

4. Conclusion

Based on the results of this study, it can be concluded that the water quality of the Cisangkan river is significantly influenced by spatial, temporal, and anthropogenic factors within the watershed.

Temporally, BOD and COD concentrations showed notable fluctuations throughout 2023, with the highest levels recorded in March. This peak is closely related to high rainfall intensity, which increased surface runoff and carried larger amounts of pollutants into the river.

Spatially, BOD and COD concentrations in the upstream areas – dominated by residential and agricultural land uses – frequently exceeded the national water quality standards. In the midstream segment, the dominance of residential land use continued to contribute to pollution, while in the downstream segment – characterized by industrial zones – BOD and COD concentrations increased significantly.

The domestic sector was identified as the largest contributor to BOD and TSS pollution in the Cisangkan river, accounting for approximately 54% of total BOD load and 52% of total TSS load. In contrast, the industrial sector contributed the majority of COD load, amounting to 53% of the total. These findings indicate that both domestic and industrial activities have substantial impacts on river water quality, necessitating enhanced pollution control and management efforts.

Spatial analysis of pollutant load allocation revealed that the domestic sector contributes most significantly in densely populated areas, particularly in Leuwigajah Village. The agricultural sector showed higher pollutant loads in upstream regions, especially in Citeureup Village. Meanwhile, the industrial sector exhibited

variations across parameters: Leuwigajah Village had the highest BOD and COD loads, while Baros Village showed the highest TSS loads, likely due to differences in the types of industries operating in each area.

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