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To cite this article: Muhamad Komarudin *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1557** 012011

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Application of water quality modelling for effluent permit policy in the Cileungsi River, Bogor Regency, West Java Province

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Abstract. Effluent discharges from domestic and industrial sources have significantly deteriorated the water quality of the Cileungsi River. This study aims to calculate the allocation of water pollution load based on the capacity of water pollution load using a water quality model approach with the Qual2Kw software. The QUAL2K model was used to simulate the impact of pollutant loads on key water quality parameters, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). Simulation results revealed that the existing BOD load was 4,480.37 kg/day, exceeding the allowable limit of 1,012.43 kg/day, based on Class II water quality standards. For COD, the current load was 28,196.76 kg/day, surpassing the acceptable load of 9,169.16 kg/day. In contrast, the TSS load was 3,765.38 kg/day, which remains below the maximum threshold of 5,245.69 kg/day. The model was calibrated and validated using field data collected from selected segments of the river. Validation results indicate that the model reliably predicts BOD and COD concentrations but shows limited accuracy for TSS estimation. Despite this limitation, the model effectively demonstrates the river's pollutant carrying capacity under different discharge scenarios and helps identify acceptable effluent limits in compliance with national water quality regulations. This study underscores the critical role of integrating scientific modelling into environmental policymaking. It enables more precise, adaptive, and environmentally sound effluent management decisions. These findings serve as a valuable reference for the local government and environmental institutions in their efforts to improve river water quality through an evidence-based approach.



1. Introduction

Population growth has led to various global challenges. One of the major challenges is the continuous deterioration of water quality. Approximately one-third of global biodiversity has declined as a consequence of increasing water pollution. Deteriorating water quality has a direct impact on social, economic, and environmental quality [1]. In response to environmental concerns, the Indonesian government has implemented the industrial performance rating program (PROPER) since the early 2000s. This program has significantly contributed to enhancing industrial environmental performance, particularly in pollution management. However, despite these regulatory efforts, the overall trend of water quality in Indonesia continues to show signs of decline [2]. Rivers, as dynamic freshwater ecosystems, play a crucial role in supporting human livelihoods and ecological balance. However, they are increasingly subjected to pollution from anthropogenic activities occurring within their catchment areas. Wastewater discharged from domestic, industrial, and agricultural sources into rivers alters aquatic environmental conditions and often leads to the degradation of water quality [3]. Moreover, the excessive use of chemical fertilizers, the rise in livestock and poultry waste, and unregulated household waste disposal have contributed to serious environmental impacts, such as the contamination of water bodies, the loss of beneficial soil microorganisms, and land degradation [4].

Therefore, determining river water pollutant load allocations requires comprehensive research that considers the sustainable use of water resources, the sources and volumes of pollutants, and the extent to which these pollutants can be controlled across various activities in the watershed. The protection and management of river water quality are key components of governmental environmental policy, aimed at maintaining water quality in accordance with nationally established standards. From a technical standpoint, efforts to manage and protect river water quality are based on pollutant load allocation (PLA), a methodology used to calculate the maximum allowable levels of pollutants that can be discharged into water bodies without violating quality standards. PLA has become a recognized strategy for water quality control, allowing for the optimal distribution of pollutant loads across multiple discharge sources along a river [5]. In Indonesia, the issuance of effluent discharge permits is a critical instrument in managing surface water quality. In this context, the allocation of waste disposal permits plays a central role in managing cumulative pollutant loads. However, this process must navigate the complex trade-off between economic efficiency driven by industrial growth and social equity, which demands fair access to clean water resources [6].

The Cileungsi River in Bogor Regency, West Java Province, provides a relevant case study where both industrial and domestic waste discharges have led to significant water quality degradation. To address this issue and promote sustainable water resource management, this study applies water quality modeling as a scientific approach for formulating evidence-based effluent discharge policies. Human interventions in the catchment area, particularly those related to agriculture, domestic settlements, and industry, exert mounting pressure on river water quality by increasing the likelihood of pollutant runoff and waste disposal [7].

This study aims to analysed Pollutant Load (PLA), Total Maximum Daily Load (TMDL) and Allocation of Water Pollutant Load (AWPL) using a water quality model. Furthermore, based on this analysis, the basis for the licensing policy for the discharge of wastewater into the river can be obtained.

2. Method

2.1. Time and Study Area

This research was conducted over a one-year period, from January 2023 to December 2023. The study was carried out in the Cileungsi Watershed (DAS), which spans from Bogor Regency to Bekasi Regency in West Java Province, Indonesia [9]. Geographically, the Cileungsi Watershed is situated between 6°18'15.28" S – 6°38'31.71" S latitude and 106°50'33.50" E – 106°59'11.56" E longitude. It covers a total area of approximately 26,614.68 hectares.

2.2. Analysis and Calculation

2.2.1. Water Quality

River water quality data were obtained through laboratory analysis of six water samples collected from each segment along the Cileungsi River in September 2023. The results of the laboratory analysis were then examined using descriptive methods and compared against the government-established water quality standards. This comparison aimed to evaluate the status of the river's water quality and to identify any deviations from the regulatory thresholds.

In addition, this study also calculates the water quality index (IKA/INA), to assess the water quality of rivers based on a number of chemical, physical, and biological parameters. This method aims to produce an index value that describes the status of water quality quantitatively and is classified, for example into the category of Good, Moderate, Poor, or Very Poor [8].

2.2.2. Water Pollutant Load

Water pollutant load refers to the total quantity of pollutants introduced into a water body from various sources, both anthropogenic and natural, over a specific period [9]. It is typically expressed as the mass of a specific pollutant discharged per unit of time (kg per day). The calculation of the potential load of wastewater pollutants uses the following two approaches:

2.2.2.1. Direct Calculation Method for Point Source

This method is used for quantifying pollutant loads originating from point sources such as industrial facilities, hotels, hospitals, and domestic sources equipped with Wastewater Treatment Plants (WWTPs). The calculation is based on empirical data, specifically measurements of pollutant concentrations and effluent discharge rates obtained through field sampling. The calculation formula is presented in equation 1.

$$PLPS = \frac{C \times V \times OpHrs}{1.000.000} \quad (1)$$

where as:

PLPS _i	: Pollutant Load of Parameter i, kg/year
C	: concentration of pollutant (BOD, COD, TSS) in wastewater discharge, mg/L
V	: Wastewater discharge flow rate, L/h
OpHrs	: Number of operating hours per year, hours/year
1.000.000	: Conversion factor, mg/kg

The value of Water Pollution Load from point source sources, obtained based on the measurement of Discharge and Concentration in tributaries and upstreams of Citeureup rivers as well as industrial data obtained from the Ministry of Environment and Forestry's report document.

2.2.2.2. Indirect Calculation Method for Non-Point Sources

The indirect calculation method employs emission factors to estimate pollutant loads from non-point sources, where direct measurement of pollutant concentration and discharge is challenging or impractical. Non-point sources typically include agricultural runoff, livestock waste, and diffuse domestic discharges. This approach relies on standardized emission factors combined with activity data to approximate the pollutant load. The basic equation for estimating pollutant water is presented in Equation 2.

$$PLNPS = AD \times EF \times AF \times D \quad (2)$$

where as:

- PLNPS : Estimated Non-Point Source Pollutant Load of Parameter i (kg/year).
- AD : is the basic data of the amount of an activity that results in load pollutant that occurs during a certain period.
- EF : is the concentration of pollutants (BOD, COD, TSS) emitted from a pollutant source per year, which has a unit of g/year/unit.
- AF : Attenuation Factor (AF), a factor that changes the concentration of pollutants during transport from source to water body, such as the distance factor (DF).
- D : Number of Pollutant Disposal Days (Days)

The estimated water pollutant load of BOD, COD and TSS parameters from non-point sources is calculated based on statistical data obtained from the BPS of Bogor district in 2023. The total water pollutant load is calculated as the sum of pollutant loads from both point and non-point sources, as shown in equation 3.

$$\Sigma PL = BPA + PBPA \quad (3)$$

2.2.3. Allocation of Water Pollutant Load (AWPL)

The Allocation of Water Pollutant Load (AWPL) is determined based on the Total Maximum Daily Load (TMDL) of the Cileungsi River. The concept of TMDL was first introduced by the United States Environmental Protection Agency (USEPA) under the Clean Water Act, serving as a regulatory framework aimed at improving the quality of water bodies across the country. Essentially, TMDL represents the maximum amount of a specific pollutant that a water body can assimilate while still meeting established water quality standards.

The TMDL approach has been adopted by several countries, including Indonesia, as a core strategy for restoring and maintaining the quality of rivers, lakes, and estuaries [10]. The mathematical formulation of TMDL is presented in Equation (4) as follows:

$$TMDL = \Sigma WLA + \Sigma LA + MOS \quad (4)$$

where WLA denotes the waste load allocation from point sources, LA represents the load allocation for non-point sources and natural background levels, and MOS stands for the margin of safety, which accounts for uncertainties in the calculation.

The Pollution Load Allocation calculation model was tested based on the results of the calculation of R² and RMSE values. This is calculated using Equation (5):

$$R^2 = 1 - \frac{\Sigma(K_i - K_{mi})^2}{\Sigma(K_i - K_{mr})^2} \quad (5)$$

where K_i is the concentration of the results of laboratory analysis i , K_{mi} is the concentration of the results of the i th model, and K_{mr} is the average concentration of the model. From the value of the determination coefficient (R^2), the value of the correlation coefficient (r) can be obtained, which is the square root of the determination coefficient (R^2). In addition, the model suitability test was carried out by calculating an error indicator, namely the Root Mean Square Error (RMSE) with an equation of 6 [11].

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n \left(\frac{K - K_{mi}}{K_{mi}} \right)^2} \quad (6)$$

3. Results and Discussion

3.1. River Segmentation

The determination of river segments in this study was primarily based on hydrological boundaries (sub-watersheds). Additionally, the segmentation process considered the homogeneity of pollutant sources, both point and non-point sources, the locations of water quality monitoring stations, and existing administrative boundaries. The segmentation analysis uses the Geographic Information System (GIS), so that the Cileungsi River is divided into four segments. Within each segment, the river's width, depth, and flow discharge were systematically measured. Flow discharge was assessed using direct field measurements. Importantly, discharge measurements were conducted simultaneously with water sampling to ensure consistency in data collection. In this study, the Cileungsi River is divided into 4 segments, with a total length of 48.89 km. The data used in this section were derived from secondary sources and processed through spatial analysis using Geographic Information System (GIS) software. Spatial datasets were obtained from the Geospatial Information Agency of Indonesia. The segmentation of the river and the map of the Cileungsi Watershed are presented in Figure 1.

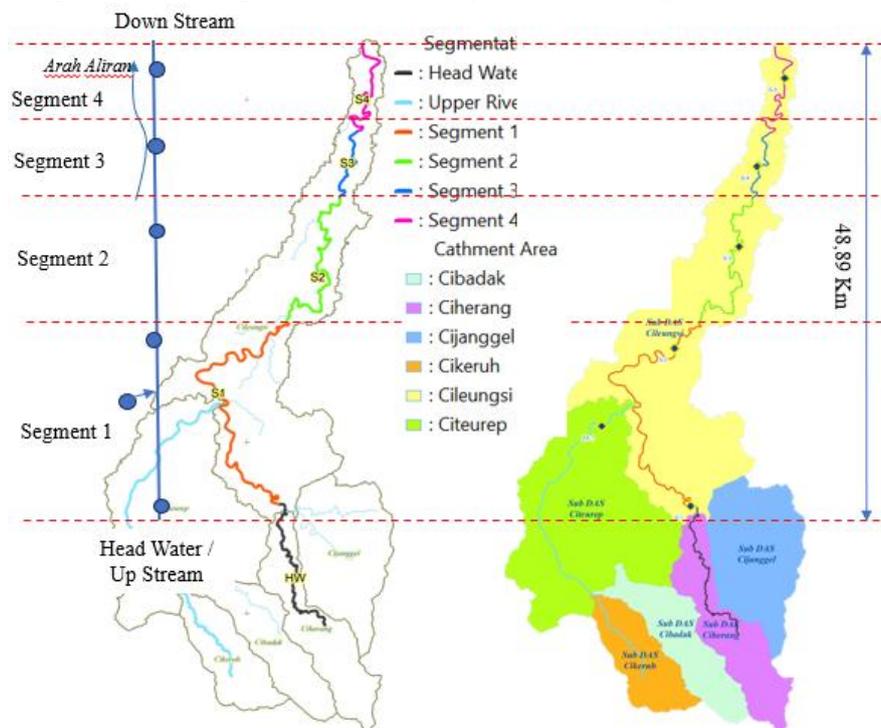


Figure 1 Segmentation and watershed sketch of Cileungsi, Bogor, West Java Province

3.2. Water Quality

The results of the water quality analysis revealed that the majority of parameters exceeded the quality standards established in Government Regulation No. 22 of 2021 for Class 2 rivers. For instance, pH values at several monitoring points—specifically Points 2, 3, 5, and 6—were found to be above the maximum permissible limit of 7.00, suggesting a tendency toward alkaline conditions. This condition may result from industrial effluents or excessive photosynthetic activity, both of which are known to elevate pH levels. In terms of dissolved oxygen (DO), the values at Points 5 and 6 were particularly low, recorded at only 2.4 mg/L, which falls significantly below the minimum acceptable threshold of 4 mg/L. Such low DO levels indicate the presence of a high organic pollutant load or intensive microbial decomposition, both of which consume oxygen and degrade water quality. This situation is often associated with the direct discharge of untreated waste into the water body [14]. While Total Suspended Solids (TSS) were generally within safe limits, an exception was noted at Point 4, where the concentration reached 43 mg/L—close to the regulatory limit of 50 mg/L. This elevation may point to surface erosion or stormwater runoff carrying suspended materials into the river.

More concerning, however, are the levels of Biochemical Oxygen Demand (BOD), which serve as indicators of organic pollution. At segment 1, 4, and 5, BOD values reached as high as 17 mg/L, far exceeding the Class 2 standard of 3 mg/L. These elevated levels are indicative of significant organic contamination, likely originating from domestic sewage or industrial discharges. Similarly, Chemical Oxygen Demand (COD) values were alarmingly high across all monitoring sites, with segment 4 recording 86.33 mg/L, reflecting the presence of persistent organic chemicals that are resistant to natural decomposition. In addition, both Total Phenol and Total Nitrogen concentrations were found to surpass regulatory thresholds, particularly at Points 4 through 6. These results suggest the presence of toxic substances and nutrient pollutants, which may contribute to eutrophication and pose risks to both human health and aquatic ecosystems. The data on water quality and flow discharge analysis in each segment are presented in Table 1.

Table 1 Water Quality and Flow Discharge Data in each Segment

Data Description	Unit	Quality Stand. Class 2	Head Water (P1)	Citeureup river (P2)	Segment 1 (P3)	Segment 2 (P4)	Segment 3 (P5)	Segment 4 (P6)
Temp ^{*)}	°C	Dev 4	27.3	27	27	27	27	27
PH	-	6-7	7.00	7.30	7.30	6.8	7.7	7.80
DO	mg/L	4	4.50	4.20	3.80	3.80	2.40	2.40
TSS	mg/L	50	<8	10.00	13.00	43.00	19.00	15.00
BOD5	mg/L	3	17.00	12.80	14.40	17.00	17.00	13.60
COD+	mg/L	25	4.95	62.16	69.41	86.33	3.57	5.27
TF	mg/L	0.2	0.52	0.07	0.27	0.80	0.66	0.71
TN	mg/L	15	8.89	20.09	24.36	48.17	2.04	5.06
Flow ^{**)}	m ³ /s	-	0.51	1.40	1.16	0.61	0.81	1.39

^{*)} Field Water Temperature Measurement

^{**)} Instantaneous Discharge Measurement

Given these findings, this study focuses on three key parameters BOD, COD, and TSS for calculating the allocation of water pollutant loads in the Cileungsi River. COD and TSS, in particular, are considered critical indicators in assessing river water quality and are central to the development of the West Java Water Quality Index (WJWQI). These parameters were selected

based on three main criteria: cost-effectiveness in monitoring, consistency with regulatory standards, and the frequency with which they exceed the permissible limits [12].

Based on the eight water parameters above, water quality conditions are obtained by calculating the value of the Water Quality Index (IKA/INA). The results of the calculation of IKA/INA obtained an index value between 34.11 and 47.47. Point 5 in segment 3 had the lowest index value (34.11), which was categorized as very poor. The other points have a poor status, with the highest index value being at point 2 (47.47). The IKA/INA value shows that the water quality at all points is polluted. This index is calculated based on physical and chemical parameters such as pH, DO, BOD, COD, TSS, TN, and TF, all of which show a fairly high tendency to pollution. Decreased water quality at point 5 and point 4 can be attributed to low DO (2.4-3.8 mg/L) and high TSS, as well as total nitrogen (TN) content which can lead to eutrophication and degrade the quality of aquatic ecosystems [13].

3.3. Water Pollutant Load of Parameter BOD, COD and TSS Parameters

In the BOD parameters, the estimated total water pollution load reached 21,043.72 kg/day, with the largest contribution coming from non-point source (NPS) of 18,920.08 kg/day (90%), while point source (PS) only accounted for 2,123.64 kg/day (10%). The source of NPS comes from household domestic activities (80.5%), waste (4.7%), agriculture (1.7%), and livestock (2.8%). Segmentation shows that segment 1 accounts for the highest load, which is 13,971.83 kg/day (66%), indicating that densely populated upstream areas have a dominant contribution to the BOD load. This observation aligns with the study by Nugraha et al. (2022), which found that domestic waste and industrial discharges are primary contributors to elevated BOD levels in populated regions such as Citeureup and Cileungsi [17]. Although increased river discharge during the rainy season can help reduce pollutant concentration through natural dilution, the situation becomes critical during the dry season, when reduced flow exacerbates pollutant accumulation. In support of this, Mitta (2021) emphasized that rivers experiencing BOD loads over 5,000 kg/day require the construction of communal wastewater treatment plants (WWTPs) to meet the requirements of Class 2 water quality standards [14].

For COD parameters, the estimated total pollution load is 28,196.76 kg/day, with an NPS contribution of 29,277.41 kg/day and PS of 7,939.48 kg/day. The largest dominance also comes from domestic waste (88%), followed by waste (5%), agriculture (1.6%), and livestock (5%). Segments 1 and 2 are the segments with the highest load, indicating that areas with high residential and industrial activity are the main sources of COD load. Notably, the segment with the highest load indicates significant pollutant pressure, which is generally associated with dense residential areas and industrial estates. This distribution pattern of COD loads underscores the critical need for effective management of domestic and industrial waste, particularly in the middle to downstream segments of the Cileungsi watershed. Moreover, these findings are consistent with the results of a study by Mitta (2021), which highlights that watersheds experiencing high anthropogenic pressure, such as the Cileungsi, often face elevated COD levels that are not adequately mitigated by existing waste treatment systems. Consequently, water quality tends to decline significantly, especially during the dry season [14].

In the TSS parameters, the estimated total pollution load is 3,765.38 kg/day, with the largest contribution coming from NPS (mainly domestic and waste). Segment 1 recorded the highest TSS load (2,312.82 kg/day), due to a combination of runoff from dense settlements and lack of solid waste management. In general, the three parameters show that the pollution burden of the Cileungsi River is dominated by non-point source pollutants, especially from domestic waste, indicating the urgency of improving household wastewater management and waste management

in the Cileungsi watershed. These findings are consistent with those of Adelina Chandra (2015), whose research demonstrated a strong correlation between increased TSS levels in the Cileungsi River and land clearing, domestic waste discharge, and inadequate erosion control in upstream and catchment areas. Additionally, Mitta (2021) emphasized that when TSS loads exceed the natural assimilative capacity of a river, they can lead to reduced flow capacity, accelerated sediment deposition, and degradation of aquatic habitats [14]. Therefore, effective control of TSS requires a comprehensive, watershed-based approach. Such an approach should integrate vegetation conservation, improved domestic waste management, and strict regulation of development activities along riverbanks and within the catchment area to ensure the long-term sustainability of the Cileungsi River's water quality and hydraulic function.

3.4. Pollutant Load (PLA), Total Maximum Daily Load (TMDL), and Allocation of Water Pollutant Load (AWPL) of parameter BOD

This paper is part of the dissertation research. In this paper, the calculation of PLA, TMDL, and AWPL is only discussed for modelling the BOD parameters. The Pollutant Load (PLA) for the BOD (Biochemical Oxygen Demand) parameter is calculated based on the existing pollutant load in the Cileungsi River, as simulated using the water quality model under Scenario 1 (current conditions). Meanwhile, the Total Maximum Daily Load (TMDL) represents the maximum allowable pollutant load under conditions where the water quality meets the Class 2 Quality Standards, corresponding to Scenario 2.

Both PLA and TMDL were estimated using the Qual2Kw water quality modelling tool, applying two different scenarios to evaluate the river's pollutant carrying capacity. The Allocation of Water Pollutant Load (AWPL) is derived by subtracting the TMDL from the PLA. In this context, a positive AWPL value ($PLA > TMDL$) indicates that the current pollutant load exceeds the allowable threshold, and thus, pollutant discharges must be reduced. Conversely, a negative AWPL value ($PLA < TMDL$) suggests that there is still room within the river's capacity to accommodate additional pollutant discharge, within regulated limits.

The simulation results for BOD parameters under the actual pollutant load conditions (PLA) are illustrated in Figure 1a, providing a visual representation of the river's pollution profile and its capacity limitations. Based on Figure 1a, the model output demonstrates that the spatial pattern of BOD (Biochemical Oxygen Demand) concentrations in the Cileungsi River closely aligns with the observed field data. The modelled section of the river spans 48.89 km, which is divided into four segments. The simulation results indicate that almost all river segments exceed the Class II river water quality standard, which sets a maximum allowable BOD concentration of 3 mg/L.

From the water quality model under Scenario 1 (actual conditions), the total existing BOD pollutant load (PLA) is estimated at 3,731.28 kg/day. Of this total, 1,374.55 kg/day (or 36.84%) originates from point sources, which include discharges from tributaries and institutional sources such as industrial facilities operating along the river. Meanwhile, non-point sources, such as surface runoff from residential, agricultural, or open land areas, contribute a larger portion of the load 2,356.73 kg/day, accounting for 63.16%. The performance of the water quality model for BOD is supported by a high coefficient of determination (R^2) of 0.99, indicating a very strong correlation between the modeled BOD concentrations and measured field data. The model error is relatively low, with a Root Mean Square Error (RMSE) of 0.052, corresponding to an error rate of less than 10%. These results confirm that the water quality model is sufficiently accurate and reliable for predicting BOD parameter concentrations in the Cileungsi River, and can be used as a decision-support tool in water quality management planning.

Following the analysis of Scenario 1, a simulation under Scenario 2 was conducted to estimate the Total Maximum Daily Load (TMDL) for BOD, which corresponds to the pollutant load that the river can receive while still meeting Class 2 water quality standards. The results of this simulation are presented in Figure 2, providing a reference for pollution control targets and allowable discharge limits under sustainable conditions. Based on Figure 2, the simulation results indicate that the modelled BOD (Biochemical Oxygen Demand) concentrations in the river water body closely approach the Class 2 river water quality standard. However, it is important to note that the observed field data in all river segments still exceed the Class 2 standard of 3 mg BOD/L, indicating persistent water quality issues despite the modelled improvements.

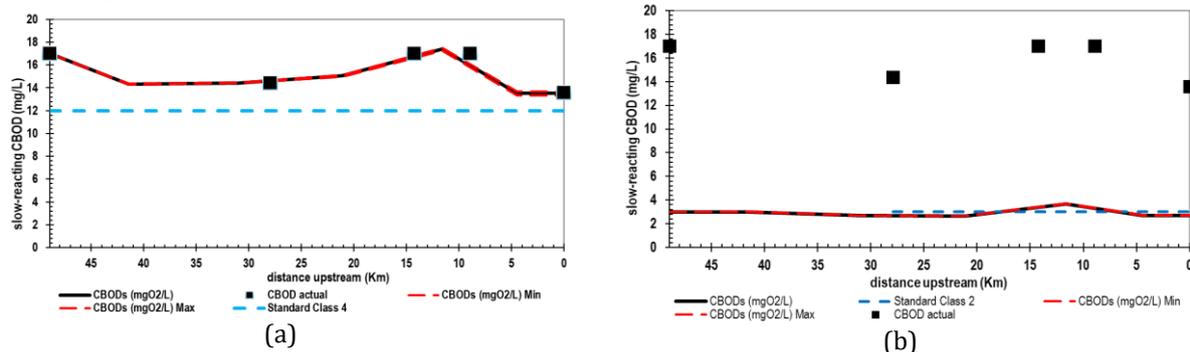


Figure 2 Water Quality Modelling: (a) scenario 1 : Existing Condition, (b) scenario 2 : meet to class II water quality standard.

From the simulation under Scenario 1, the Total Maximum Daily Load (TMDL) for BOD was quantitatively determined to be 1,012.43 kg/day. Of this total 750.59 kg/day (or 74.14%) is allocated to point sources, while 261.84 kg/day (or 25.86%) is attributed to non-point sources.

Overall, the results of the Cileungsi River water quality modeling suggest that the current BOD pollutant load (PLA) 4,480.37 kg/day has significantly exceeded the allowable TMDL of 1,012.43 kg/day. Consequently, the Allocation of Water Pollutant Load (AWPL-BOD) must focus on a substantial load reduction of 3,467.94 kg/day, equivalent to 77% of the total existing load. This reduction is necessary across all four river segments.

The target for reducing the BOD pollutant load was determined using the AWPL (Allocation of Water Pollutant Load) approach, calculated proportionally based on the Pollutant Load (PL-BOD) from each source. The total reduction of BOD pollution load needed to meet Class II water quality standards in the Cileungsi River is primarily dominated by the domestic sector, with a required reduction of 16,984.07 kg/day (81%), followed by 990.74 kg/day (5%) from unmanaged solid waste, 588.83 kg/day (3%) from livestock waste 356.44 kg/day (2%) from agricultural runoff, and 349.97 kg/day (1%) from industrial discharges. The largest reduction demand is concentrated in Segment 1, where domestic sources contribute the highest pollution load (1,902.88 kg/day), reflecting the influence of dense residential areas. These findings emphasize the urgency of integrated and targeted pollution control strategies focusing on domestic wastewater and informal waste disposal practices to achieve substantial improvement in river water quality. These results are similar to the research in the Citarum River in the west of Java. In the Citarum River, domestic wastewater contributes about 84% of the BOD pollution burden that enters the river water. This condition is caused by the low coverage of domestic wastewater management services and the large number of households that dispose of sewage directly into waterways without treatment [15]. This problem is overcome by interventions in the upstream part which include the construction of communal Wastewater Treatment Plants

(WWTPs), expansion of sanitation coverage, and increased control of household waste disposal. Although the industrial sector is not the dominant contributor overall, it remains a significant source of pollution in the downstream segments, warranting strict monitoring and enforcement of industrial wastewater discharge permits.

3.5. Application to Policy

The results of water quality modelling show the worst water quality conditions in all four segments. The Cileungsi River has exceeded its capacity to accommodate the additional pollutant load. As a result, activities that produce wastewater (having BOD parameters), must be prohibited from discharging wastewater into rivers to prevent further deterioration in water quality.

The simulation of two different pollutant scenarios provides a clear understanding of the river's current carrying capacity. These results are essential for determining permissible pollutant discharge limits that comply with national Class 2 water quality standards. The findings underscore the critical role of scientific modelling in informing and strengthening environmental policy frameworks. Incorporating such modelling into the policy-making process enables more accurate, adaptive, and environmentally responsible approaches to effluent permitting and pollution control. This evidence-based methodology offers a practical and strategic reference for local governments and environmental management agencies aiming to improve river water quality through data-driven decision-making.

4. Conclusion

The water quality modeling results indicate that the water pollution load capacity of the Cileungsi River for BOD parameters has been significantly exceeded. The current BOD load is 4,480.37 kg/day, while the allowable limit based on Class 2 water quality standards is 1,012.43 kg/day. Immediate action is required to reduce BOD by 84.08%, respectively, to meet regulatory water quality standards. Segment 1 recorded the highest pollutant load and required the most significant reductions, targeting a BOD load of 1,989.74 kg/day. It is forbidden to effluent wastewater discharge into the river except with compensation (referring to the Government Regulation Number 22 of 2021).

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