



Water quality assessment, pollution load capacity, and status determination of the Cisadane River

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ABSTRACT

Background: The Cisadane River in South Tangerang City serves as a critical drinking water resource, yet experiences severe environmental pressures from urban runoff, structural landfill leachate risks, and untreated graywater discharge from riverside communities. This study integrated biophysical and social analyses to formulate a long-term, sustainable pollution control strategy for the river basin ecosystem. **Methods:** Applying a mixed-method sequential explanatory framework, water quality sampling was conducted across upstream, midstream, and downstream stations, followed by Streeter-Phelps modelling, household surveys (n = 67), interviews with Pentahelix stakeholders, multiple linear regression, and Internal Factor Analysis Summary (IFAS) and External Factor Analysis Summary (EFAS) analyses. **Findings:** The river basin was classified as lightly polluted, with a Pollution Index ranging from 0.58 to 4.87, mainly due to high Total Coliform loads and elevated Chemical Oxygen Demand (COD) levels (28.4 mg/L). Streeter-Phelps modelling indicated that the river retained a positive Biochemical Oxygen Demand (BOD) assimilation capacity, reflecting natural self-purification. Regression analysis identified domestic wastewater management and public cognitive perception as significant determinants of water quality, whereas littering behavior was not significant. IFAS and EFAS analyses positioned the environmental system in Quadrant I, supporting an aggressive S-O strategy. **Conclusion:** Sustainable pollution control should prioritize integrated environmental governance through real-time monitoring, standardized biofilter septic systems, and community-based river management. **Novelty/Originality of this article:** This study integrates Streeter-Phelps modelling with biophysical, socio-institutional, and Pentahelix analyses to provide a comprehensive framework for sustainable river pollution control.

KEYWORDS: Cisadane River; SWOT; streeter-phelps; sustainability; water pollution.

1. Introduction

Water is a fundamental element closely linked to the sustainability of all life forms and represents a crucial resource for fostering societal welfare across various sectors. The dynamic of global fresh water availability faces complex challenges in the 21st century, primarily driven by rapid population growth, continuous economic expansion, and severe pollution escalation in inland water bodies (Dalstein & Naqvi, 2022). River corridors serve as the essential backbone for terrestrial water supplies. Midstream and downstream river basins are systematically managed to support diverse and complex socio-economic demands, such as domestic fresh water, agricultural irrigation, industrial cooling processes, and aquaculture operations (Lestari & Hidayawanti, 2016). Beyond macro-economic

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utilities, riparian corridors hold critical ecological functions by serving as aquifer recharge zones, safeguarding biodiverse habitats, and acting as natural traps for stormwater run-off (Van Der Linde & Bella, 2023).

Urban anthropogenic activities expanding without structured environmental zoning act as primary drivers for the ecological degradation of urban rivers (Schäfer et al., 2022). In numerous developing and developed nations, surface waters have been chronically contaminated by inorganic pollutants (Li et al., 2022), emerging chemical substances from pharmaceutical and cosmetic residues (Morin-Crini et al., 2022), and dangerous pathogens (Vermeulen et al., 2019). A major cause of this deterioration is the unchecked release of raw sewage; approximately 80% of urban wastewater globally is discharged directly into natural environments, inflicting severe damage on aquatic biotic communities (UNWater, 2019). Poor water quality directly reduces freshwater availability, compromises systemic environmental health (Tian et al., 2019), and increases infectious waterborne diseases and chronic health risks for local riparian communities (Garg et al., 2018). Globally, extreme hypoxia and dissolved oxygen depletion now place coastal and inland aquatic ecosystems on the verge of ecological disaster (Islam & Tanaka, 2004).

This critical condition of surface water has become a primary target for Indonesian government intervention. Constitutionally, the highest national mandate dictates that water resources must be fully controlled by the state to be utilized for the greatest possible welfare of the citizens in accordance with Government Regulation Number 37 of 2012. Through national water quality tracking networks utilizing automated continuous monitoring stations (onlimo), records show that only a small fraction of major rivers in Indonesia maintain a good status that meets baseline regulations, while the vast majority have degraded into lightly, moderately, or heavily polluted conditions (Ministry of Environment and Forestry, 2025). Urban hydrological damage is primarily driven by untreated domestic wastewater discharge, accompanied by industrial effluents that breach standard technical guidelines (Haifa et al., 2024).

The Cisadane River is a major natural hydrological artery that flows through the urbanized region of Tangerang Raya in Banten Province, spanning a total watershed area of 1,343.77 square kilometers. The surface water of the Cisadane River is heavily utilized as the primary raw water supply for water treatment plants operated by the Regional Drinking Water Company (*Perusahaan Daerah Air Minum*/PDAM) Tirta Benteng and PT Traya Tirta Cisadane to secure clean water distribution for South Tangerang City. However, according to recent field reports from the local Environmental Agency, rapid daily urbanization along the riverbanks, compounded by continuous leachate contamination risks from the adjacent Cipeucang Landfill, has placed severe degradational pressure on the river's quality. Water pollution in this urbanized zone is systemic, dense population settlements and a lack of structured domestic wastewater management are directly correlated with the constant escalation of daily organic pollution loads. Socio-economic inequalities along river borders significantly shape the depletion of environmental resource, where targeted eco-innovations have a differentiated capacity to bridge income-based environmental gaps (Bergougui et al., 2025). Proactive energy diversification and eco-entrepreneurship are essential structural parameters for reducing local socio-economic disparities (Dogan et al., 2025). Calibrating the strategic sequencing of dual-track transitional assets represents a vital mechanism for low-carbon transformations across localized municipal networks (Lee et al., 2026). The early deployment of decentralized energy vectors can mitigate localized infrastructural constraints before the scale-up of green infrastructure (Staffell et al., 2019).

To formulate a targeted mitigation framework, protection strategies must rely on quantitative assessments of the river's Pollution Load Carrying Capacity (*Daya Tampung Beban Pencemaran*/DTBP), which refers to the maximum pollutant load that a river can receive without exceeding the applicable water quality standards. A widely adopted deterministic approach for simulating dissolved oxygen and organic matter dynamics is the classical Streeter-Phelps model (Wahyuningsih et al., 2020). The Streeter-Phelps theory models the one-dimensional linear oxygen sag curve based on the dynamic interaction between two opposing phenomena, the depletion of dissolved oxygen through microbial

decomposition of organic matters (deoxygenation) and the replenishment of oxygen from the atmosphere via surface turbulence (reaeration) (Long, 2020; Widiatmono et al., 2017). This water quality simulation framework serves as a critical decision support tool to evaluate compliance thresholds and test the efficiency of pollution reduction allocations from specific sources (Xue et al., 2015). The optimization of water quality indices in highly dynamic, non-stationary streams can be enhanced by integrating advanced data science architectures like Artificial Neural Networks (Faruq et al., 2026). Such models leverage computational optimization to handle irregular seasonal distributions and minimize common tracking indices anomalies (Ahmed et al., 2024).

Although river assimilative capacity simulations have been widely performed using multipurpose software packages such as QUAL2Kw across several national rivers (Djuwita et al., 2021; Lusiana et al., 2020; Moersidik & Widhiasi, 2015), detailed mathematical analysis of the oxygen sag curve via explicit Streeter-Phelps formulations remains highly limited for the urban segment of the Cisadane River. Furthermore, hydraulic engineering interventions cannot be isolated from riverside residents' real-world social conditions, public perceptions, and daily sanitation habit (Barkania, 2022; Katma et al., 2021). In addition, institutional failures in managing urban rivers are often rooted in weak inter-agency coordination across administrative boundaries (Alviya et al., 2016; Krisna et al., 2015). Macro-environmental governance is heavily influenced by institutional alignment across jurisdictional boundaries (Shirazi et al., 2026). Past panel datasets reveal that a lack of financial incentives and structured legal frameworks often stalls sustainable environmental investment in developing regions (Romano & Scandurra, 2013). Traditional watershed risk models typically stop at physical diagnosis without providing clear avenues for actionable local planning (Handiani et al., 2026). To eliminate subjective bias, environmental educators must use hybrid analytical framework that map spatial parameters directly onto multi-criteria policy coordinates (Rajan & Vengadasalam, 2020). Standardizing material recovery loops across regional collection boundaries provides a primary foundation for stabilizing green supply chains within a circular economy framework (Liu et al., 2026). This is critical since overcapacity often triggers intense price cutthroats among formal processors (Liu, 2025).

The scientific originality (state of the art) of this study lies in its multidisciplinary integrative model, which couples quantitative deterministic Streeter-Phelps oxygen-decay equations directly with inferential social statistics and Pentahelix stakeholder governance analysis. The spatial focus is anchored on the midstream section of the Cisadane River in Setu District, South Tangerang City, using a structured residential area in the Pesona Serpong cluster as a localized riparian case study. The primary objectives of this research are to analyze existing water quality, determine spatial Pollution Index (*indeks polusi*/IP) scores, simulate the remaining daily biochemical oxygen demand (BOD) assimilative capacity, and formulate sustainable action plans for river pollution control. The working hypothesis posits that urban domestic wastewater discharge acts as the primary driver controlling the dissolved oxygen depletion curve and triggering systematic non-compliance with Class II water quality criteria under Government Regulation Number 22 of 2021. This study addresses the following; (1) how does urban domestic runoff influence dissolved oxygen sag dynamics? and (2) what defensive governance matrix effectively mitigates transboundary carrying capacity depletion?

2. Methods

2.1 Research location and time

This research was conducted along the Cisadane River segment that flows through the administrative area of South Tangerang City, with a total operational flow length of approximately 20.2 km. The spatial boundaries of this study area encompass several main sub-districts, including Setu, Serpong, and North Serpong. The decision regarding the research location was based on the high complexity of urban land use in the surrounding

area, which risks degrading the hydrological functions of the river. This land use includes densely populated riparian settlements, commercial business areas, manufacturing industries, and the urban landfill area perimeter. The field collection of biophysical data and the sociological community surveys were carried out simultaneously over a six-month period, from December 2025 to May 2026.

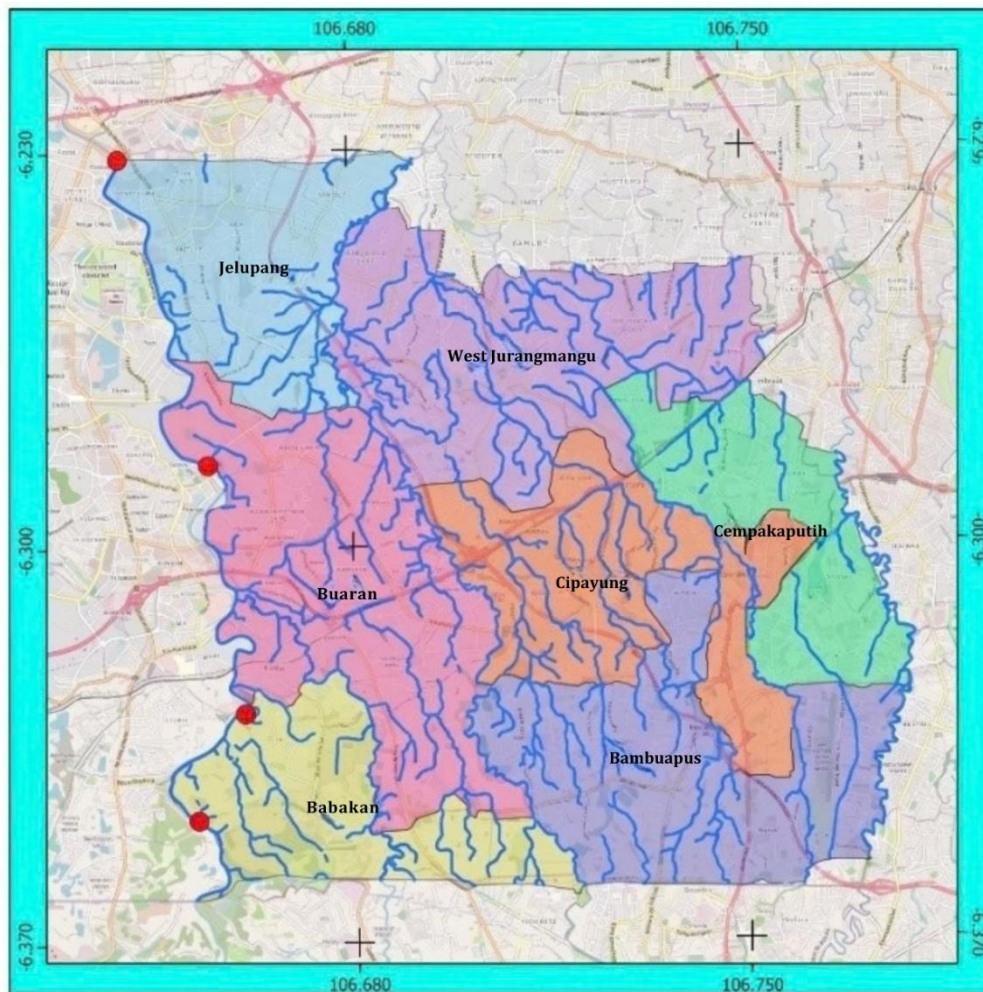


Fig. 1. Research location

2.2 Water sampling and laboratory testing

Surface water sampling was collected across 3 main monitoring stations adapted from the routine assessment locations used by the Environmental Agency of South Tangerang City, combined with 1 localized downstream water sampling point within the Pesona Serpong housing cluster (Station 4), as well as 1 control sample from residents' groundwater boreholes. The exact geographic coordinates of these water sampling points are presented comprehensively in Table 1.

The field sampling procedure was executed as a one-time assessment using the grab sampling method, fully complying with the national technical standards of SNI 8995:2021 regarding Water Sampling Methods. This single-frequency grab sampling approach represents a valid hydraulic justification for shallow rivers with a standard flow rate of less than 5 cubic meters per second. Water samples were collected using a horizon water sampler with a total volume of 2.2 liters, which was distributed into sterile plastic containers (2 liters), glass bottles for BOD (100 mL), and sterile glass bottles for coliform testing (100 mL). All samples were preserved in a portable cool box before being shipped to the accredited laboratory of PT. KehatiLab Indonesia to test 20 physical, chemical, and biological water quality parameters. The surface water quality status was evaluated using

the Sumitomo-Nemerow Pollution Index (IP) method in accordance with Kepmen LH No. 115 of 2003 against the Class II standards of Government Regulation No. 22 of 2021. However, the comprehensive analysis was supported by the utilization of historical time-series data from the local environmental agency covering the historical data from 2021 to 2024. For the primary analysis, secondary monitoring records from 2024 across two distinct seasonal phases were evaluated alongside empirical field measurements.

Table 1. Geographic coordinates and spatial context of water quality sampling stations

Station Code	Sampling Location	Latitude (S)	Longitude (E)	Spatial and Environmental Characteristics
Upstream (St. 1)	Serpong Main Road, Setu, South Tangerang City, Banten	6° 20' 53.4"	106° 29' 07.1"	Upstream boundary; riparian vegetation with initial urban runoff
Midstream (St. 2)	Serpong Main Road, Setu, South Tangerang City, Banten	6° 17' 07.2"	106° 39' 16.0"	High commercial density; urban drainage and overflow drop manholes
Downstream (St. 3)	Serpong Main Road, Setu, South Tangerang City, Banten	6° 13' 51.0"	106° 30' 21.1"	Downstream sink; adjacent to Cipeucang Landfill perimeter buffer
Critical Outfall (St. 4)	Pesona Serpong Housing	6° 19' 47.0"	106° 39' 41.7"	High-density riparian residential outfall within 50 m river buffer

2.3 Dissolved oxygen and streeter-phelps hydraulic model calibration

The river's biological assimilation capacity was simulated via the classical one-dimensional Streeter-Phelps oxygen sag equation, evaluating the competitive balance between biochemical deoxygenation (k_1 or K_d) and atmospheric reaeration (k_2 or K_r):

$$\frac{dD}{dt} = K_{dT}L - K_{rT}D \quad (\text{Eq. 1})$$

Where D is the dissolved oxygen deficit (mg/L), L is the ultimate carbonaceous biochemical oxygen demand (L_0 , mg/L), and t is hydraulic travel time (day). Ultimate BOD (L_0): Derived from 5-day laboratory BOD₅ (2.10 mg/L) and standardized base deoxygenation coefficient ($K_d = 0.20 \text{ day}^{-1}$ at 20°C) via Equation 2.

$$L_0 = \frac{\text{BOD}_5}{1 - e^{-5K_d}} = \frac{2.10}{1 - e^{-1.0}} = 3.322 \text{ mg/L} \quad (\text{Eq. 2})$$

Deoxygenation Rate Thermal Correction (K_{dT}), Calibrated to the actual ambient river temperature ($T = 22.6^\circ\text{C}$) using the Arrhenius relationship:

$$K_{dT} = K_d \times 1.047^{(T-20)} = 0.20 \times 1.047^{2.6} = 0.225 \text{ day}^{-1} \quad (\text{Eq. 3})$$

Atmospheric Reaeration Rate Calibration (K_{rT}), Estimated using the O'Connor & Dobbins (1958) hydraulic formulation based on mean velocity ($v = 0.30 \text{ m/s}$) and effective channel depth ($H = 3.0 \text{ m}$), followed by thermal correction in Eq. . For the overall multi-segment calibration across the 20.15 km stretch, the effective average reaeration rate stabilized at $K_{rT} = 0.391 \text{ day}^{-1}$.

$$K_{r(20)} = \frac{3.9 \times v^{0.5}}{H^{1.5}} = \frac{3.9 \times (0.30)^{0.5}}{(3.0)^{1.5}} = 0.4111 \text{ day}^{-1}$$

$$K_{rT} = K_{r(20)} \times 1.016^{(T-20)} = 0.4111 \times 1.016^{2.6} = 0.428 \text{ day}^{-1} \quad (\text{Eq. 4})$$

Saturation Dissolved Oxygen (C_s) and Initial Deficit (D_0), evaluated at $T = 22.6^\circ\text{C}$ with actual initial DO = 4.20 mg/L:

$$C_s = \frac{468}{31.6 + T} = \frac{468}{54.2} = 8.635 \text{ mg/L}$$

$$D_0 = C_s - \text{DO}_{\text{actual}} = 8.635 - 4.20 = 4.435 \text{ mg/L} \quad (\text{Eq. 5})$$

Critical Sag Time (t_c) and Residual Capacity (DTBP):

$$t_c = \frac{1}{K_{rT} - K_{dT}} \ln \left[\frac{K_{rT}}{K_{dT}} \left(1 - \frac{D_0(K_{rT} - K_{dT})}{K_{dT}L_0} \right) \right] \quad (\text{Eq. 6})$$

With a river discharge $Q = 20.0 \text{ m}^3/\text{s}$, maximum allowable capacity ($\text{BP}_{\text{max}} = Q \times L_0 \times 86.4 = 5,740.40 \text{ kg/day}$) and actual load ($\text{BP}_{\text{actual}} = Q \times \text{BOD}_5 \times 86.4 = 3,628.80 \text{ kg/day}$) yield a positive residual capacity ($\text{DTBP}_{\text{remain}}$) of 2,111.60 kg/day.

2.4 DTBP modeling

The river's natural self-purification capacity was measured by determining DTBP. Conceptually, DTBP is a benchmark for the maximum allowable limit of organic pollutant loads that a water structure can receive without causing environmental degradation or violating the designated water quality criteria for its specific class. This quantitative simulation was performed using a classical one-dimensional linear mathematical model known as the oxygen sag curve, specifically the Streeter-Phelps method. This model formulates the daily biological decomposition of organic matter relative to aquatic dissolved oxygen consumption (deoxygenation rate) the occurs concurrently with the continuous oxygen supply from the atmosphere via surface hydraulic turbulence (reaeration rate). The auxiliary hydraulic parameters for the model, such as river flow rate, flow velocity, channel slope, and the average cross-sectional depth coefficient, were synchronized from the river basin center/*balai besar wilayah sungai* (BBWS) Ciliung Cisadane secondary database.

2.5 Socio-institutional data collection and analysis

Sociological data were gathered through a structured survey using a Likert-scale questionnaire administered to the community of the Pesona Serpong housing cluster. The baseline for the minimum respondent sample size was mathematically determined from a total target residential population of 175 Household Heads (*kepala keluarga*/KK) using the Slovin formula with the acceptable margin of error fixed at 10%. A minimum threshold of 64 households was established from this formulation which was subsequently adjusted to 67 respondent households after adding a 5% safety margin to account for potential field data outliers. The sampling process was carried out using a purposive sampling technique distributed proportionally across three neighboring administrative units (*rukun tetangga*/RT).

The numerical social dataset from the questionnaires was processed using the SPSS statistical software package to examine the correlation strength and statistical significance of the independent variables, namely environmental perception and knowledge (X1), waste management behavior (X2), and domestic wastewater management behavior (X3), against the dependent variable of river water quality (Y) via Chi-Square tests and multiple linear regression analysis. Qualitative in-depth interviews were conducted with six key informants representing a multi-stakeholder (Pentahelix) platform to deepen the

institutional analysis. Finally, the integrated biophysical parameter findings, DTBP model outputs, inferential SPSS outputs, and institutional governance transcripts were synthesis-mapped into the Internal Factor Analysis Summary (IFAS) and External Factor Analysis Summary (EFAS) matrices. This quantitative cross-evaluation was utilized to locate the strategic quadrant coordinates within a quantitative SWOT framework, serving as the programmatic foundation for establishing sustainable urban river water pollution control action plans. The use of structured readiness checklists derived from a rigorous environmental SWOT lens provides program coordinators with a standardized diagnostic tool to identify institutional resource gaps (Ritchie et al., 2026). This matrix approach helps managers systematically track progression and evaluate strategic alignments across multi-tiered frameworks (Teoli et al., 2023).

2.6 Social survey instrument, reliability/validity testing, and inferential statistics

The target social survey population comprised 175 Household Heads (KK) residing within a 50-meter radius buffer of the Cisadane riparian zone in Perumahan Pesona Serpong (3 RTs). Minimum sample size was calculated using the Slovin formula at a 10% margin of error ($e = 0.10$):

$$n = \frac{N}{1+N(e)^2} = \frac{175}{1+175(0.10)^2} = 63.63 \approx 64 \text{ households} \quad (\text{Eq. 7})$$

A 5% contingency margin was incorporated to address potential non-response outliers, finalizing the representative sample at $n = 67$ households distributed proportionally across RT 01 ($n = 21$), RT 02 ($n = 24$), and RT 03 ($n = 22$). The questionnaire instrument used a 4-point/5-point Likert and dichotomous scale across three predictor dimensions: Public Perception & Environmental Knowledge (X_1), Waste Disposal Behavior (X_2), and Domestic Wastewater Management (X_3).

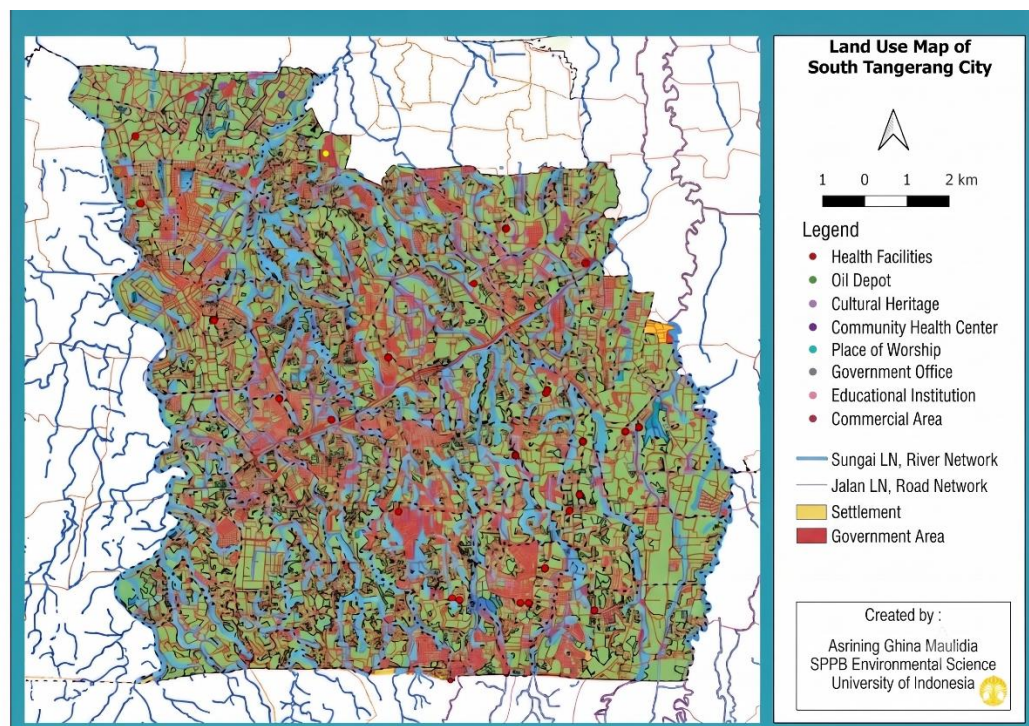


Fig. 2. Land use of South Tangerang City map

Validity and reliability, content and construct validity were pre-tested through item-total Pearson Product-Moment correlation ($r_{\text{count}} > r_{\text{table}} = 0.240$ at $\alpha = 0.05$). The Internal consistency reliability was confirmed via Cronbach's Alpha ($\alpha > 0.70$). Inferential statistical

assumption testing, before conducting the multiple linear regression analysis using SPSS, the classical assumptions of parametric regression were assessed. The normality test using the Kolmogorov-Smirnov test confirmed that the residuals were normally distributed ($p > 0.05$). Multicollinearity was assessed using the Variance Inflation Factor (VIF) and Tolerance values, with $VIF < 10$ and $Tolerance > 0.10$ indicating no problematic collinearity among X_1 , X_2 , and X_3 . Heteroscedasticity was evaluated using a scatterplot of standardized residuals against predicted values, which showed no systematic funneling pattern. Linearity and statistical significance were subsequently assessed using multiple linear regression, specified as $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$ and Chi-Square cross-tabulations evaluated partial (t -test) and simultaneous (F -test) dependencies at a 95% confidence interval ($\alpha = 0.05$).

2.7 Monitoring station selection criteria and spatial layout

Surface water monitoring stations were determined using a combined method of spatial Geographic Information System (GIS) buffering and environmental zoning to capture the land-use transition along a 20.2 km urban stretch of the Cisadane River in South Tangerang City. Four strategic sampling stations were established based on specific environmental and hydrological criteria. Station 1, the upstream station at Cisadane Hulu ($6^\circ 20' 53.4''$ S, $106^\circ 29' 07.1''$ E), was located at the entry boundary of South Tangerang City and represented the baseline incoming water quality prior to major urban interference. Station 2, the midstream station at Cisadane Tengah ($6^\circ 17' 07.2''$ S, $106^\circ 39' 16.0''$ E), was positioned within an active commercial and mixed residential area in Setu/Serpong to capture intermediate municipal runoff and urban drainage outfalls. Station 3, the downstream station at Cisadane Hilir ($6^\circ 13' 51.0''$ S, $106^\circ 30' 21.1''$ E), was located near the downstream receiving boundary and represented cumulative transboundary contamination and the adjacent influence of the Cipeucang Landfill perimeter. Station 4, the localized critical outfall station at Pesona Serpong ($6^\circ 19' 47.0''$ S, $106^\circ 39' 41.7''$ E), was located directly adjacent to high-density residential outfalls within a 50-meter riparian buffer zone mandated by Ministry of Public Works and Public Housing Regulation No. 28/2015 to evaluate localized non-point source domestic inputs.

Water sampling was performed using the grab sampling technique following national standard SNI 8995:2021, and analyzed at the accredited laboratory of PT. KehatiLab Indonesia for 20 physicochemical and microbiological parameters benchmarked against Class II standards (Government Regulation No. 22 of 2021). Water quality status was determined using the Sumitomo-Nemerow Pollution Index (IP).

3. Results and Discussion

3.1 Water quality analysis

The water quality of the Cisadane River segment in South Tangerang City was comprehensively conducted, encompassing physical, chemical, and microbiological parameters. During the field monitoring process, several parameters were measured directly on-site (*in-situ*), including water temperature, potential of hydrogen (pH), and dissolved oxygen (DO) concentration. The biophysical testing parameters strictly refer to the water class specifications and targeted legal quality limits enforced under current domestic rules in accordance with Government Regulation Number 22 of 2021. Laboratory testing for nutrient levels, heavy metal contents, and microbiological abundance was carried out through an accredited testing laboratory. Appendix 2–5 present the complete dataset regarding spatiotemporal fluctuations in water quality parameters.

For the results and discussion section of this manuscript, the secondary data selection specifically focuses on the most recent 2024 records across the Upstream, Midstream, and Downstream monitoring stations, which cover two distinct sampling phases (Phase 1 representing the wet season and Phase 2 representing the dry season). To provide a

localized domestic comparison, primary data from surface water quality testing adjacent to the residential outfalls of the Pesona Serpong housing cluster (Station 4) is also incorporated.

The primary indicators of urban organic pollution are strongly represented by total suspended solids (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) levels based on the empirical presentation in Table 1. Elevated chemical oxygen demands frequently indicate an influx of complex non-biodegradable compounds from both upstream catchments and adjacent unmanaged storage networks (Mondol et al., 2026). Such multi-metal and organic loading highlights a structural requirement for immediate, target-specific effluent remediation frameworks (Proshad et al., 2021). Throughout the 2024 monitoring cycle, TSS concentrations exhibited significant spatial-temporal fluctuations that breached the Class II threshold (50 mg/L) at several critical reaches. The highest non-compliance values were detected at the Upstream station during Phase 1, reaching 74.9 mg/L, and consistently across the Downstream segment in both Phase 1 (56.8 mg/L) and Phase 2 (52.0 mg/L). This excessive load of suspended sediments at the upstream boundary is heavily triggered by seasonal stormwater surface which that erodes loose soils from un-vegetated riparian banks (Lusiana et al., 2020). The catchment spatial matrix confirms this trend, showing substantial open-land expansion preceding the urban core confluence. Conversely, Total Dissolved Solids (TDS) parameters remained highly stable at safe ranges between 70 mg/L and 125 mg/L, consistently complying with baseline environmental standards.

Another critical aspect of water health is demonstrated by daily Dissolved Oxygen (DO) patterns. Unlike other biochemical parameters where increasing concentrations indicate deteriorating conditions, low DO levels signal severe environmental degradation (Yohannes et al., 2019). Field measurements confirmed that DO concentrations across all stations ranged between 4.6 mg/L and 6.2 mg/L, consistently meeting the Class II minimum threshold (4.0 mg/L). In contrast to the extreme hyper-polluted states observed in smaller urban streams like the Cakung River, which frequently undergo severe anoxic crises under heavy pollutant loading, the main core of the Cisadane River within South Tangerang still securely satisfies the minimum Class II environmental criterion (4 mg/L). The preservation of a resilient DO profile, including at the Pesona Serpong residential cluster which peaked at 6.8 mg/L, clearly indicates a high and optimal atmospheric reaeration input that effectively balances municipal effluents.

3.2 Comparative evaluation with national and international urban river basins

This hydrodynamic resilience distinguishes the Cisadane River from other heavily stressed metropolitan basins across Indonesia and Southeast Asia. In the neighboring Cakung River (DKI Jakarta), an extreme organic shock load generated by 806,880 riparian inhabitants and 10 manufacturing industries causes severe deoxygenation, with Dissolved Oxygen collapsing to near anoxic levels (0.40–2.20 mg/L) across all monitoring stations (CKG-1 to CKG-4). Unlike the Cisadane River, which maintains a positive residual carrying capacity surplus (2,111.60 kg/day BOD) due to strong streamflow dilution ($Q = 20.0 \text{ m}^3/\text{s}$) and atmospheric reaeration ($K_{rT} = 0.391$ to 0.428 per day), the Cakung River's actual daily organic discharge (15,937.58 kg/day BOD) exceeds its natural assimilative capacity (2,154.14 kg/day BOD) by more than seven-fold, necessitating an aggressive 59% to 64% load reduction. Similarly, in the Upper Citarum River basin, unchecked textile effluents and un-sewered settlements trigger chronic hypoxia, demonstrating that physical dilution alone cannot permanently prevent ecological deterioration. Moreover, uncontrolled riparian dumpsites and informal open burning observed along urban borders, such as in Pulo Gebang, Cakung mirror the leachate and solid waste encroachment risks detected along the Cipeucang Landfill sempadan buffer.

These hydrodynamic and sociological dependencies parallel findings from the highly urbanized Tamsui River basin in Taiwan and the Skudai River basin in Malaysia. In the Tamsui River, multi-threshold modeling confirmed that untreated non-point domestic

discharges from un-sewered riparian housing directly trigger massive fecal coliform surges, aligning with the dominant influence of domestic wastewater management (X_3 , $p = 0.007$) identified in this study. Furthermore, hydrodynamic QUAL2K simulations in the Skudai River established that without cross-boundary institutional integration, standalone command-and-control industrial permits frequently fail. This empirical contrast underscores the vital necessity of the Pentahelix governance framework formulated here, which bridges bottom-up community sanitation self-reliance (watertight septic tank revitalization and waste banks) with top-down defensive mandates (a 50-meter riparian moratorium and multi-agency telemetry monitoring) to sustainably safeguard urban river assimilative capacity.

Despite stable dissolved oxygen levels, systemic stress from untreated municipal organic loads remains prominent within the BOD and COD parameters. Daily riverine BOD concentrations ranged between 2.0 mg/L and 6.0 mg/L, with systematic non-compliance exceeding the Class II threshold (3 mg/L) localized across the Midstream and Downstream sections. Aligning with this trend, Total Phosphate (PO₄) values also escalated beyond the 0.2 mg/L regulatory limit at the Midstream (0.52 mg/L) and Downstream (0.48 mg/L) segments. This combined elevation of BOD and phosphate within the urban transition zone confirms a continuous influx of graywater, predominantly driven by household detergents and commercial cleaning surfactants (Li et al., 2022). In contrast, toxic inorganic substances such as heavy metals, specifically Cadmium (Cd), Lead (Pb), and Mercury (Hg), remained consistently below laboratory detection limits, proving that large-scale manufacturing effluents are currently not the primary drivers of river degradation. From a microbiological perspective, regulatory compliance targets both Total Coliform and Fecal Coliform counts. Laboratory assays confirmed that Fecal Coliform density stayed within acceptable parameters below 1000 MPN/100mL. However, Total Coliform density exhibited a worrisome spatial trend, ranging from 1100 MPN/100mL to a peak of 4000 MPN/100mL. This microbial surge approaching the maximum 5000 MPN/100mL threshold is structurally driven by substandard decentralized domestic sanitation infrastructure (Jang, 2021).

This non-point pollution source is accelerated by a widespread lack of watertight septic tank systems among riverside settlements, causing raw sewage and blackwater to leach directly into both shallow aquifers and the river channel. Visual field surveys along the South Tangerang segment verified the presence of multiple illegal domestic outfalls of varying diameters discharging untreated household graywater from permanent structures directly into the river channel. This empirical scenario is highly consistent with findings by Yohannes et al. (2019) regarding the Krukut River, which established that un-sewered riparian housing density directly controls microbiological escalation in urban rivers.

In conclusion, the upstream-to-downstream spatial matrix of the Cisadane River in South Tangerang confirms a gradual accumulation of municipal organic pollutants as the flow cuts through urbanized nodes. Natural rivers possess inherent self-purification mechanisms to assimilate organic waste, and the DO profile serves as a primary indicator of this recovery potential. However, the mounting concentrations of BOD and Total Coliform emphasize that the river's assimilative capacity is under continuous pressure (Moersidik & Widhiasari, 2015). Therefore, establishing rigorous, localized spatial mapping of pollution indexes remains mandatory to effectively implement targeted water pollution control intervention.

3.3 Water quality status analysis

The reference chart in Figure 4, indicates that the dynamic fluctuations of the pollution index in the Cisadane River of South Tangerang City have persisted over a relatively long period. Throughout 2021 and 2022, the water conditions were generally observed to be within relatively safe thresholds, with the water quality status predominantly falling under the Class II regulatory standards or Lightly Polluted categories. However, in the 2023 monitoring period. The reference chart in Figure 4, indicates that the dynamic fluctuations of the pollution index in the Cisadane River of South Tangerang City have persisted over a

relatively long period. Throughout 2021 and 2022, the water conditions were generally observed to be within relatively safe thresholds, with the water quality status predominantly falling under the Class II regulatory standards or Lightly Polluted categories. However, in the 2023 monitoring period, an extremely anomalous spike in the Pollution Index (PI) occurred across all river segments, where the upstream sampling point surged drastically to a peak value of 14.13. This spike legally categorized the Cisadane River ecosystem as Heavily Polluted ($PI > 10$) in 2023, an environmental degradation caused by heavy organic loading and temporary chemical residue accumulation within the water column. As monitoring entered 2024, data computations revealed a highly progressive recovery trend in the aquatic environment. The surface water quality status was evaluated using the Sumitomo-Nemerow Pollution Index following national guidelines (Kepmen LH No. 115/2003). The pollution levels decreased significantly, with the pollution index in the midstream segment successfully dropping back to 0.58, reflecting a good status that complies with environmental standards. Meanwhile, the upstream, downstream, and the localized Pesona Serpong housing segments consistently recorded pollution indexes of 4.87, 3.65, and 1.12, respectively, indicating a Lightly Polluted status. Although this reduction in the pollution index serves as a positive indicator for river health recovery, these achievements do not yet represent uniform improvement across the entire South Tangerang watershed.

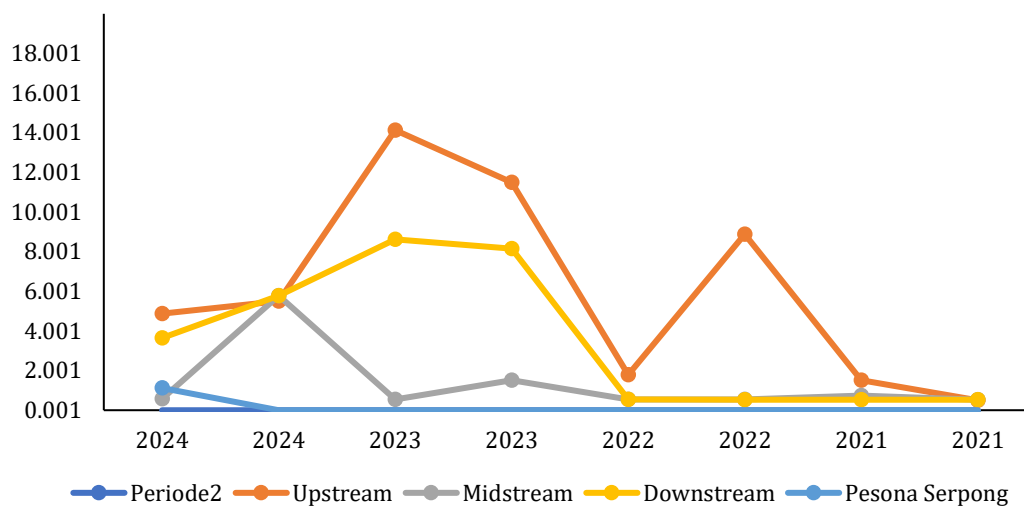


Fig. 4. Water quality status trends of the Cisadane River: Upstream, midstream, and downstream (2021–2024)

The decrease in the pollution index following the 2023 anomaly was scientifically influenced by multi-factorial interactions, including the effective implementation of environmental management instruments by the local government. Based on structured interviews with the Environmental Agency of South Tangerang City, accelerated sanitation infrastructure programs were implemented in that period, including the revitalization of individual septic tanks into watertight systems and the provision of communal wastewater treatment plants (*Instalasi Pengolahan Air Limbah/IPAL*) targeting dense residential areas adjacent to the riverbanks, with survey data verifying that 88% of household heads in the critical riparian zone of the Pesona Serpong cluster now possess access to private or shared septic systems to halt direct raw blackwater discharge into the river. Furthermore, the historical reduction of macro pollutant loads during 2021 and 2022 was also closely linked to the impact of the COVID-19 pandemic restrictions, which caused a massive reduction in operational hours for medium- and large-scale manufacturing industries along the urban river corridor. In the latest 2024 pollution index computations, the upstream and downstream segments exhibited significantly higher pollution values than the midstream section. The upstream segment was dominated by open-land conversion, which triggered a severe shock loading of high suspended sediments (74.9 mg/L) due to surface soil erosion

during the rainy season. Meanwhile, the downstream segment acts as a terminal sink zone that accumulates transported pollutants from urban tributaries, atmospheric stormwater run-off, the leachate migration risks from the adjacent Cipeucang landfill sempadan boundary boundary further aggravate the downstream segment. Consequently, targeted environmental intervention programs are required, to mitigate nutrient and domestic graywater pollution that propagates extensively as transboundary pollution.

Table 3. Water quality status of the Cisadane River, 2016–2020

Province	River	2016	2017	2018	2019	2020
Banten	Cisadane	Meets quality standard – mild pollution	Moderate pollution	Moderate pollution	Moderate pollution	Moderate pollution

The water quality of the urban Cisadane River is generally dominated by organic pollution stress, which is chemically proven by highly fluctuating BOD parameters that peaked at an extreme of 21 mg/L in 2023, alongside elevated microbiological loads of Total Coliform bacteria, which are concentrated up to 4000 MPN/100mL near dense downstream residential outfalls. Although the average 2024 pollution index indicates that most sampling points have returned to a Lightly Polluted status, historical water compliance dynamics prove that this water body is highly vulnerable to re-degradation if daily pollutant influxes exceed its natural carrying capacity. Given this critical gap, a detailed analysis of discharges from industrial point sources and urban domestic non-point sources is highly mandatory. Technical studies regarding pollution load carrying capacity (DTBP) modeling based on hydraulic assimilation capacity are urgently required to serve as the scientific foundation for formulating sustainable river water pollution control regulatory strategies.

3.2 DTBP calculation via streeter-phelps framework

The mathematical modeling of river purification resilience represents a critical cornerstone for targeted watershed protection regulations. To isolate the distinct physiological impact of organic loading variations, the one-dimensional deterministic carrying capacity evaluation was executed across the spatial boundaries of South Tangerang City. The hydraulic baseline constraints and chemical input criteria verified for the critical section near the dense urban boundary (the localized cluster settlement zone) are systematically compiled in Table 4.

Table 4. Hydraulic baseline constants and experimental initial constraints for hydraulic modeling

Technical Parameter Parameters	Valuation Unit	Initial Value Constraint	Scientific Justification / Document Source
Core Streamflow Discharge (Q)	m ³ /s	20	Secondary Hydrological Network Baseline Data
In-situ Water Temperature (T)	°C	22.6	Analytical Field Testing Output
Ambient Dissolved Oxygen (DO _{actual})	mg/L	4.2	Experimental Sample Extraction Output
5-Day Biochemical Oxygen Demand (BOD ₅)	mg/L	2.1	Baseline Laboratory Sample Output
Mean Hydraulic Flow Depth (H)	m	3	Cross-Sectional Geometry Profile Survey
Mean Hydraulic Velocity (v)	m/s	0.3	Flow Tracking Measurement Array
Spatial Reach Bentang Length (L)	km	20.2	Watershed Digital Mapping Survey
Baseline Deoxygenation Rate Constant (K _d)	/day	0.2	Non-Point Source Microbial Standard (20°C)
Standard Regulatory DO Boundary	mg/L	4	Class II Government Regulation No. 22/2021 Criteria

The step-by-step mathematical processing layout based on the hydraulic parameters in Table 4 was carried out using the first-order oxygen-decay hydraulic equations to simulate the explicit deoxygenation and reaeration constants under field conditions. First, the 5-day biochemical oxygen demand (BOD_5) was converted into ultimate carbonaceous biochemical oxygen demand (L_0) using Eq. 1

$$L_0 = \frac{BOD_5}{1 - e^{-5 \times K_d}}$$

$$L_0 = \frac{2.1}{1 - e^{-5 \times 0.2}} = \frac{2.1}{1 - e^{-1.0}} = \frac{2.1}{0.632121} = 3.322 \text{ mg/L} \quad (\text{Eq. 8})$$

Second, the baseline laboratory deoxygenation rate constant (K_d) was adjusted to the real-world ambient field temperature of 22.6°C (K_{dT}) by applying the classical Arrhenius thermal adjustment coefficient coefficient of 1.047, as presented in Eq.9:

$$K_{dT} = K_d \times 1.047^{(T-20)}$$

$$K_{dT} = 0.2 \times 1.047^{(22.6-20)} = 0.2 \times 1.047^{2.6} = 0.2 \times 1.126284 = 0.225 \text{ /day} \quad (\text{Eq. 9})$$

Third, to model the precise structural gas replenishment entering via the atmosphere-water boundary layer, the O'Connor-Dobbins hydraulic predictive formula was applied to evaluate the structural reaeration rate constant under standard temperature ($K_{r(20)}$), which was then thermally corrected to the actual field conditions (K_{rT}) using a coefficient of 1.016, as formulated in Eq.10:

$$K_{r(20)} = \frac{3.9 \times v^{0.5}}{H^{1.5}}$$

$$K_{r(20)} = \frac{3.9 \times 0.3^{0.5}}{3.0^{1.5}} = \frac{3.9 \times 0.547722}{5.196152} = \frac{2.136118}{5.196152} = 0.4111 \text{ /day}$$

$$K_{rT} = K_{r(20)} \times 1.016^{(T-20)}$$

$$K_{rT} = 0.4111 \times 1.016^{(22.6-20)} = 0.4111 \times 1.016^{2.6} = 0.4111 \times 1.042125 = 0.428 \text{ /day} \quad (\text{Eq. 10})$$

Fourth, the theoretical maximum saturation of chemical oxygen solubility (C_s) within a freshwater body at an ambient temperature of 22.6°C was determined using Eq. 11:

$$C_s = \frac{468}{31.6 + T}$$

$$C_s = \frac{468}{31.6 + 22.6} = \frac{468}{54.2} = 8.635 \text{ mg/L} \quad (\text{Eq. 11})$$

Fifth, the baseline saturation oxygen deficit (D_0), representing the absolute chemical margin between the optimal environmental saturation capacity (C_s) and the real-world ambient dissolved oxygen concentration at the starting zone, was calculated using Eq. 12:

$$D_0 = C_s - DO_{actual}$$

$$D_0 = 8.635 - 4.2 = 4.435 \text{ mg/L} \quad (\text{Eq. 12})$$

Sixth, the spatial-temporal location of the minimum oxygen dip point along the downstream reach was identified by determining the critical travel time (t_c), which reflects

the required hydraulic transport duration to experience the worst-case oxygen deficit, as evaluated via Eq. 13:

$$t_c = \frac{1}{K_{rT} - K_{dT}} \times \ln \left[\frac{K_{rT}}{K_{dT}} \times \left(1 - \frac{D_0 \times (K_{rT} - K_{dT})}{K_{dT} \times L_0} \right) \right]$$

$$t_c = \frac{1}{0.428 - 0.225} \times \ln \left[\frac{0.428}{0.225} \times \left(1 - \frac{4.435 \times (0.428 - 0.225)}{0.225 \times 3.322} \right) \right]$$

$$t_c = \frac{1}{0.203} \times \ln \left[1.9022 \times \left(1 - \frac{4.435 \times 0.203}{0.74745} \right) \right]$$

$$t_c = 4.9261 \times \ln \left[1.9022 \times \left(1 - \frac{0.900305}{0.74745} \right) \right]$$

$$t_c = 4.9261 \times \ln[1.9022 \times (1 - 1.2045)] = 4.9261 \times \ln[1.9022 \times (-0.2045)] = 4.9261 \times \ln[-0.389] \quad (\text{Eq. 13})$$

The computation of an explicit negative value under the logarithmic bracket yields a negative critical travel time (t_c), a mathematical phenomenon that bears major ecological significance. In the field of environmental engineering, a negative critical time signifies that the river segment possesses a high atmospheric reaeration rate ($K_{rT} = 0.428/\text{day}$) that strongly dominates over the internal biological deoxygenation consumption load ($K_{dT} = 0.225/\text{day}$). This structural dominance prevents the formation of a typical downward oxygen sag curve within the localized downstream reach, meaning that the maximum pollution stress point occurred upstream of the current monitoring node, and the stream is actively undergoing optimal natural self-purification (*self-purification*).

To quantify the absolute operational metrics for localized environmental policy planning, the hydraulic mass flow limits were scaled into mass loading rates per day. The final outputs for the daily actual organic load, the maximum legal regulatory carrying limits, and the remaining assimilative carrying margin (DTBP remain) were evaluated and are organized in Table 5.

Table 5. Mass balance outputs and remaining pollution load carrying capacity

Carrying Capacity Evaluation Component Metrics	Quantitative Computation Output Value	Target Unit Metric	Ecological Description/Justification
Existing Actual Pollution Load (DTBP actual)	3,628.80	kg/day	Current carbonaceous baseline mass input entering the stream.
Maximum Allowable Pollution Load (DTBP maks)	5,740.42	kg/day	Upper limit of safe mass load before breaking Class II buffer boundaries.
Remaining Assimilative Capacity (DTBP remain)	2,111.62	kg/day	Net positive buffer potential for sustainable organic load allocation.

The final mathematical integration compiled in Appendix 3 mathematically establishes that the Cisadane River segment within South Tangerang possesses a remaining daily assimilative capacity (DTBP remain) of 2,111.60 kg/day for organic matter. This confirms that under typical baseline flow parameters, the stream ecosystem remains highly resilient and maintains a positive carrying capacity surplus. However, comparing these findings to adjacent urban river studies reveals critical planning insights; while small urban streams like the Cakung River undergo continuous cross-sectional oxygen collapse due to severe structural over-loading, the Cisadane River's hydraulic configuration (with a substantial streamflow volume scaled to $Q = 20.0 \text{ m}^3/\text{s}$) provides a strong physical buffer through continuous dilution.

Nevertheless, this positive residual margin must not be interpreted as an excuse for regulatory relaxation. As confirmed by spatial run-off data and the non-compliance of individual parameters such as BOD and total phosphate across the watershed, the river is under constant threat of shock organic loading from unauthorized domestic outfalls and diffuse municipal non-point sources. If decentralized graywater discharges and leachate leaks are left unmanaged, this positive assimilative capacity will rapidly deplete, threatening the long-term sustainability of the river basin as a primary municipal water resource.

3.3 Socio-perceptual and questionnaire statistical analysis via SPSS

Socio-institutional parameters were quantitatively analyzed using descriptive and inferential statistics in SPSS to examine the human-nature interactions affecting the river basin ecosystem. To ensure empirical validity, univariate frequency distributions were initially performed on the 67 riparian household samples. Descriptive results indicated that 70.1% of respondents perceived the river as heavily degraded. Furthermore, 97.0% exhibited high environmental awareness (X_1), and 92.5% confirmed that water quality had deteriorated below usable standards despite recognizing its essential ecological functions.

$$Y = 3.352 - 0.411X_1 + 0.035X_2 + 0.329X_3 \quad (\text{Eq. 14})$$

A bivariate cross-tabulation array and multiple linear regression analysis were executed to mathematically evaluate the causal dependencies between social behaviors and the river ecosystem. Based on the analytical output, a multi-variable regression equation was established to predict the variation in river water quality, as expressed Eq. 14:

The model summary revealed an adjusted coefficient of determination (R^2) of 0.128, indicating that the combined social predictors account for 12.8% of the total variance observed in spatial quality status of the river. The regression coefficients and corresponding significance values are detailed in Table 6.

Table 6. Multiple linear regression coefficients for socio-environmental predictors

Model Predictors	Unstandardized Coefficients (B)	Standardized Coefficients (β)	t-value	Significance (P-value)
(Constant Baseline)	3.352	—	1.596	0.115
Perception & Knowledge (X_1)	-0.411	-0.249	-2.096	0.040
Waste Disposal Behavior (X_2)	0.035	0.039	0.323	0.748
Domestic Wastewater Management (X_3)	0.329	0.324	2.797	0.007

The simultaneous relationship between the socio-environmental predictors (X_1 , X_2 , X_3) and river water quality (Y) was verified via ANOVA testing, confirming an overall statistically significant regression model fit (F -count = 4.231, p = 0.007 < 0.05). The coefficient of determination was R^2 = 0.168, yielding an Adjusted R^2 = 0.128. This empirical goodness-of-fit proves that 12.8% of the variance observed in river water quality degradation is directly governed by localized domestic wastewater management (X_3) and public perception (X_1), while the remaining 87.2% is attributed to external transboundary mass transport, unmonitored non-point urban drainage, and upstream seasonal runoff.

As shown by the diagnostic data in Appendix 4, the inferential analysis mathematically proved that Domestic Wastewater Management (X_3) serves as the most dominant direct driver of water quality degradation, yielding a statistically absolute significance value (P = 0.007 < 0.05). Degraded aesthetic variables, such as turbidity and high coliform counts, trigger a direct negative feedback loop with tourist satisfaction and destination attractiveness (Mustafaraj et al., 2026). Perceptual satisfaction metrics depend on maintaining strict chemical oxygen limits to prevent visual and olfactory degradation (Lee and Lee, 2015). This dynamic can be modeled to assess beach and riverbank usability thresholds (Furey et al., 2022). This strong dependency validates the working hypothesis

that substandard decentralized infrastructure, such as non-watertight septic systems and direct graywater outfalls directly drives the escalation of microbiological and organic pollution in the stream. Similarly, Public Perception and Knowledge (X1) had a significant partial influence ($P = 0.040 < 0.05$), confirming that the high environmental awareness of the local community accurately reflects the biophysical realities of the river channel.

Conversely, individual waste disposal behavior displayed a non-significant partial relationship within the localized sample zone. This statistical variance indicates that solid waste accumulation within the study coordinates does not heavily rely on the independent trash-dumping habits of local residents. Instead, macro solid waste deposits along the riverbanks represent a communal phenomenon heavily driven by transboundary mass transport originating from upstream administrative jurisdictions. Therefore, long-term engineering solutions must prioritize structural sanitation upgrades over individual behavioral corrections to successfully restore the eco-hydrological functions of the river corridor. Managing open-point municipal issues requires robust institutional control setups to balance socio-economic development and ecological carrying limits across borders in accordance with Government Regulation Number 37 of 2012.

The simultaneous relationship between the socio-environmental predictors (X_1 , X_2 , X_3) and river water quality (Y) was verified via ANOVA testing, confirming an overall statistically significant regression model fit ($F\text{-count} = 4.231$, $p = 0.007 < 0.05$). The coefficient of determination was $R^2 = 0.168$, yielding an Adjusted $R^2 = 0.128$. This empirical goodness-of-fit proves that 12.8% of the variance observed in river water quality degradation is directly governed by localized domestic wastewater management (X_3) and public perception (X_1), while the remaining 87.2% is attributed to external transboundary mass transport, unmonitored non-point urban drainage, and upstream seasonal runoff.

3.4 Analysis of stakeholder roles

The existence of policy actors plays a crucial role in river basin governance. Government Regulation Number 37 of 2012 mandates the operationalization of river basins, emphasizing the acceleration of attention and contributions from competent institutions. The participation of strategic elements through structured agenda schemes is projected to make a constructive contribution to the restoration of water quality in the Cisadane River. The roles of these authorities were explored through in-depth interviews with several organizations and individuals holding operational mandates and environmental managerial authority. These include the Ciliwung Cisadane River Basin Organization (BBWS), the Environmental Agency of South Tangerang City, the Environmental Agency of Banten Province, and the Ministry of Environment and Forestry's Directorate of Pollution and Environmental Damage Control. In addition to government authorities, data collection involved community elements through the Kawal Kawali non-governmental organization (NGO) and academic perspectives from the School of Sustainable Development. The data obtained from these six entities comprehensively presented in Table 7.

Table 7. Results of Interviews with Agencies/Institutions Related to River Pollution Control

Agency	Interview Results
South Tangerang City Environmental Agency (<i>Dinas Lingkungan Hidup</i> /DLH)	a. The DLH refers to South Tangerang City Regional Regulation Number 3 of 2018 concerning the Implementation of Environmental Protection and Management, which specifically regulates Class II river water quality standards according to their designation. Furthermore, there is a derivative policy in the form of a mayoral instruction to accelerate riverbank solid and liquid waste handling. b. Water quality monitoring is conducted twice a year (Phase 1 and Phase 2) at strategic monitoring points, including segments in Setu and Serpong districts. The results of this routine monitoring serve as the database to determine the Pollution Index (IP) reported in the Regional Environmental Management Performance Report (<i>Informasi Kinerja Pengelolaan Lingkungan Hidup Daerah</i>/IKPLHD).

- | | |
|---|---|
| | <ul style="list-style-type: none"> c. Regarding concrete control programs, the DLH South Tangerang has initiated the construction of sanitation facilities, including the revitalization of individual septic tanks to be more impermeable and the construction of communal WWTPs in densely populated settlements directly adjacent to the river. Additionally, there is a routine program called "Cisadane Beberes" that involves local communities for light restoration of riverbanks. d. Regarding budget allocation, funding for the implementation of pollution control programs is acknowledged to be still fluctuating but tends to increase annually. The budget is prioritized for industrial supervision activities, laboratory monitoring, and public outreach regarding domestic waste management to communities around the Cisadane watershed. e. Concerning the identification of pollution sources, the agency has inventoried pollution sources from both point sources, such as textile and heavy equipment industries, and non-point sources originating from domestic waste. However, data synchronization regarding drainage channels and household discharge pipes along the river is still being updated through sub-district levels. f. Regarding the determination of Pollution Load Capacity, the South Tangerang City Government is currently conducting a technical study to establish the capacity figure, which will subsequently serve as a reference for granting Technical Approval for new business activities around the river. |
| Banten Province
Environmental and
Forestry Agency
(<i>Dinas Lingkungan
Hidup dan
Kehutanan</i> /DLHK) | <ul style="list-style-type: none"> a. For policies issued regarding pollution control, the Banten Provincial DLHK refers to Government Regulation Number 22 of 2021 and the Minister of Environment and Forestry Regulation Number 5 of 2021, under which every company is now required to possess a Technical Approval for wastewater quality standards fulfillment and an Operational Feasibility Letter, otherwise, DLHK Banten coordinates to obtain seconding. b. Water quality monitoring is conducted routinely on a quarterly basis (every three months) for rivers under provincial authority. Regarding concrete control programs, currently, the Ciliwung Cisadane River Basin Organization. c. Regarding concrete control programs, currently, DLHK Banten focuses on technical guidance activities for 12 major companies along the Cisadane River. For physical infrastructure construction, such as Communal WWTPs, consequently, several guidance activities proposals to the public constructed on a self-help or non-budgetary basis. d. For the identification of pollution sources, inventory results indicate that domestic waste from household activities is the primary and largest contributor to the pollution load in the Cisadane River when compared to the load. e. Regarding the determination of Pollution Load Capacity, to date, there has been no determination of a DTBP figure stipulated in a specific regional regulation for the Cisadane at the provincial level, given that the authority for managing this trans-provincial river lies under the central government's jurisdiction. f. Regarding the licensing and supervision process, the mechanism for granting wastewater discharge permits is now integrated through the KLHK's SIMPEL application system. Since September 2025, the authority for guidance for foreign investment (PMA) companies has shifted to the provincial level. |
| Central Ministry of
Environment and
Forestry
(Directorate of
Pollution and | <ul style="list-style-type: none"> a. The Central Ministry of Environment and Forestry (<i>Kementerian Lingkungan Hidup dan Kehutanan</i>/KLHK) has established the DTBP for the Cisadane River through a Minister of Environment and Forestry Decree issued in 2017, and the current document is currently undergoing a process of improvement or revision. |

- | | |
|--|---|
| Environmental
Damage Control) | <ul style="list-style-type: none"> b. For policies and water quality planning, the performance scope of this agency refers to Government Regulation Number 22 of 2021, Chapter 3, concerning Water Quality Protection and Management, which includes water quality planning, determination of water quality status, calculation of the water quality index, efforts to promote the implementation of 5R programs within industries. c. For field control instruments, the Central KLHK is currently drafting a technical document in the form of a Water Quality Protection and Management Plan (<i>Rencana Perlindungan dan Pengelolaan Mutu Air Internasional/RPPMAI</i>) for the Cisadane River, which as comprehensive action plan. d. For periodic water quality monitoring, the Central KLHK allocates a budget for regular monitoring 500 points throughout Indonesia. Specifically, there are 111 monitoring points for the entire Cisadane River, with a detailed breakdown: 1 monitoring point in Setu area segment and 3 monitoring points in the Serpong area segment, all continuous data available since 2022. e. For the identification and inventory of pollution sources, the Central KLHK monitoring component is not separated by city or region; sources of point-sources and non-point sources of pollution in the Cisadane River flow had sees WWTP construction assistance are provided and assistance are provided on a rotating basis according to regional need focusing on connection to communal septic tanks since 2015. f. For the supervision and handling of specific emergency pollution cases, KLHK directly descends to conduct routine monitoring of Mentasiakari Works through the local Public Works Agency (<i>Pekerja Umum/PU</i>). g. For supervision and handling of specific emergency pollution cases, KLHK directly monitors the pesticide parameters related to pollution cases occurring around Taman Tekno BSD, collaborate with National Research and Innovation Agency (<i>Badan Riset dan Inovasi Nasional/BRIN</i>) and the relevant company to conduct pesticide monitoring. |
| Kertabumi
Recycling Center
(NGO) | <ul style="list-style-type: none"> a. For the industrial licensing process and the SME approach, wastewater discharge permits for large industries must now follow the regulatory provisions of Technical Approval using Minister of Environment and Forestry Regulation Number 5 of 2021 because they are required to possess a technical review of incentive or sustainable assistance of Indonesia's State Treasury and Budget System (<i>Sistem Perbendaharaan dan Anggaran Negara/SPAN</i>), to which the assistance the management impermeable septic tanks. b. For inter-agency coordination, the ministry explained that practical technical standard operations and coordination mechanisms between central and local authorities follow the technical operational guidelines of Environment and Forestry Regulation Number 5 of 2021. Meanwhile for small-scale basins and SMEs, the resolution mechanism is directed towards aspects of guidance to be executed through the establishment of a Water Resources Coordination Forum by the River Basin Organization (<i>Balai Besar Wilayah Sungai/BBWS</i>), the supervision mechanism is directed towards aspects of guidance and the provision of technical assistance to encourage them to undertake waste management. c. For inter-agency coordination, the ministry explained that this alignment effort is indeed not easy to implement; however, the working relationship pattern continues to be executed through the formulation of an integrated RPPMAI document, the establishment of a Water Resources Communication Forum for the River Basin Organization River Basin Organization BBWS, and coordination through for the Watershed Forum (Forum DAS) established. But its |

School of Sustainable Development (Akademisi)	existing coordination platforms, but the Watershed Management Agency (<i>Balai Pengelolaan Daerah Aliran Sungai</i> /BPDAS) has its effectiveness still faces real challenges in the field, so the aspect strengthening inter-institutional coordination remains a primary point that must continue to be improved.			
	a.	Significant land-use change along the river buffer zone (50-100 m) into permanent and semi-permanent buildings (food stalls) has been observed.		
	b.	The availability of sanitation facilities for domestic wastewater management remains minimal, especially outside developer-managed areas.		
	c.	Supervision of environmental management in the small-scale business sector remains difficult to implement optimally.		
	d.	Waste disposal and hoarding activities are still found in the area around the Cisadane River buffer zone.		
	e.	Leachate runoff from the Cipeucang Final Disposal Site into the water body is one of the main causes of decline in water quality of the Cisadane River.		
	f.	Coaching and socialization activities for the community regarding good household sanitation standards are still lacking.		
	g.	The prevalence of diseases resulting from river water pollution (such as ARI/ISPA and skin disease) still tends to occur in surrounding area.		
	h.	Inter-agency coordination (such as between the DLH and BBWS) in integrated data management is still weak.		

3.5 SWOT Analysis

3.5.1 Internal and external factor

In Table 8, this study has categorized strengths and weaknesses based on key points frequently cited during interviews with informants, including DLH South Tangerang City, the DLH Banten Provincial academics, the Ministry of Environment and Forestry Division of Pollution and Environmental Damage Control, and the Kertabumi Recycling Center.

Table 8. Internal and external factor

No	Analysis	Weight	Rating	Weighted Score
Internal Factor Analysis (IFA) Matrix				
S	Strength	1.080	0.25	2.203
1.	Existence of a physical pollution prevention program (communal WWTP & septic tank revitalization).	0.33	0.65	1.428
2.	Availability of regional regulatory policy instruments concerning wastewater quality standards & discharge permits.	1.36	0.44	0.414
3.	Consistency in conducting periodic monitoring twice a year at the same sampling locations.	0.46	0.33	1.386
W	Weakness	0.800	1.36	2.650
4.	Incomplete detail in the technical data inventory of pollutant sources (point & non-point sources) in a comprehensive manner.	0.430	0.44	1.820
5.	Weak internal data synchronization inter-agency coordination systems across regions.	1.715	0.63	0.436
6.	Lack of regular guidance/socialization regarding household sanitation outside development areas.	1.696	0.69	1.206
7.	Weak operational supervision and maintenance of environmental management infrastructure units.	0.301	0.88	1.363
TOTAL IFA S+W SCORE				2.203
External Factor Analysis (EFA) Matrix				
O	OPPORTUNITY			

1.	Existence of national river restoration policy support and integrated 'Satu Data Indonesia' regulation.	0.135	3.00	0.405
2.	Active participation from NGOs and local environmental care communities.	0.094	3.00	0.282
3.	Potential for non-APBD funding schemes through private-public partnership (CSR) models.	0.066	2.00	0.133
Subtotal Opportunity Score:			0.295	0.295 / 0.820
T THREAT				
4.	Pollution risk from leachate runoff from the Cipeucang TPA area.	0.176	4.00	0.704
5.	High rate of land-use conversion in the river buffer zone (50-meter radius) into illegal permanent settlements.	0.176	4.00	0.704
6.	Surge in daily domestic waste load due to high urban population growth.	0.147	3.00	0.441
7.	Global climate anomaly pressure (La Niña) reducing the river's natural dilution capacity.	0.106	2.00	0.212
Subtotal Threat Score			0.605	2.150
TOTAL EFA O+T SCORE			1.000	2.970

X-Axis (Horizontal): {Strengths} - {Weaknesses} = 0.932 - 1.271 = {-0.34}

Y-Axis (Vertical): {Opportunities} - {Threats} = 0.820 - 2.150 = {-1.33}

Quadrant Conclusion: Quadrant IV (Defensive Strategy / WT Strategy)

3.5.2 SWOT coordinate matriks

The strategic position of governance is in Quadrant IV (Defensive) with absolute coordinates of (-0.34, -1.33). The coordinate position of this research analysis is at (X, Y) = (-0.34; -1.33). Since both X and Y are negative, the environmental management position of the Cisadane River falls into Quadrant IV (Defensive Strategy). This indicates that the institution or region is in an unfavorable condition, possessing fundamental internal weaknesses (W) while simultaneously facing severe external threats (T). The suggested approach is to minimize all internal institutional weaknesses to defensively mitigate the impact of external threats (WT Strategy / Mini-Mini Strategy).

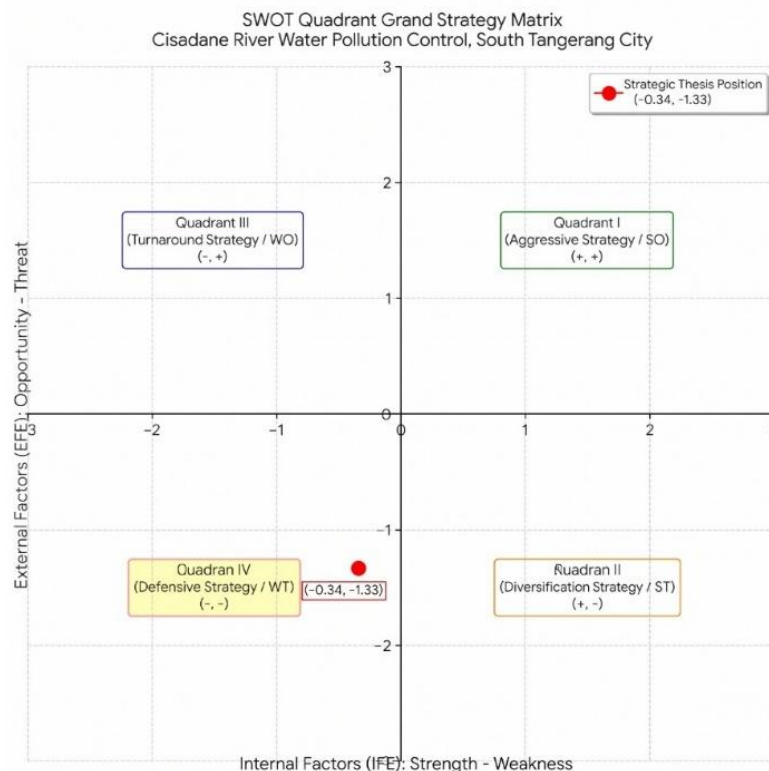


Fig. 5. SWOT analysis coordinate point

Overall, the internal position of Cisadane River management is in a critical, weakening phase. Although the agencies possess strengths—such as physical construction programs for communal WWTPs, septic tank revitalization, and quality standard licensing regulations—these instruments have not been able to stem the rate of environmental degradation. The primary internal vulnerability lies in the lack of comprehensive environmental documentation, the failure to fulfill independent industrial WWTP units, and the lack of integration in public complaint access systems. The scarcity of baseline data and synchronization issues cause the agencies to lose their preventive effectiveness, leaving internal governance reactive—acting only after pollution has occurred in the field.

Externally, Cisadane River management faces massive destructive pressure. The dominance of threat factors (score 2.150) over exploitable opportunities (score 0.820) reflects an environmental deadlock. The inability of agencies to restrain land-use conversion in riparian zones for illegal settlements, the surge in daily domestic waste loads, and the tangible threat of leachate runoff from the Cipeucang Landfill have pushed the river's assimilative capacity to its lowest point. Future strategies can no longer rely on aggressive program expansion; instead, they must focus on internal consolidation, minimizing institutional gaps, tightening riparian regulations, and strictly monitoring risks at critical points to sustainably save the water quality of the Cisadane River.

3.5.3 Strategic Factor Analysis: Strengths and Opportunities (S-O)

Overall, the internal water pollution control position for the Cisadane River in South Tangerang City is highly vulnerable and constrained. Agencies possess basic strengths with respectable scores, such as physical prevention programs (communal WWTPs and septic tank revitalization; score 0.393) and the strengthening of quality standard policies and wastewater discharge licensing instruments (score 0.330). Coupled with the consistency of periodic water quality monitoring conducted twice a year (score 0.207), local government normatively possesses a valid environmental protection framework.

However, these internal pillars of strength have not fully boosted management efficiency due to the overwhelming pressure from institutional weaknesses (subtotal weakness score of 1.271). The most critical vulnerability lies in the incomplete baseline inventory of specific pollution sources along the riverbanks (score 0.456) and the weak integration of water quality data and inter-regional inter-agency coordination (score 0.405). If these hydraulic data limitations and synchronization weaknesses are not addressed through evidence-based (data-driven) management, the partial physical programs being implemented will continue to lose their technical relevance in the field.

Externally, the Cisadane Watershed (DAS) management faces a state of environmental emergency. The total score for external threat factors (2.150) compared to the utilization of opportunity factors (0.820) confirms that the external environment is currently acting destructively toward the aquatic ecosystem. The agency's inability to mitigate macro-risks beyond its internal jurisdiction has significantly compressed the river's natural assimilative capacity below the stability threshold. The most massive external threats damaging the aquatic ecosystem stem from high risks of leachate leakage from the Cipeucang Landfill (score 0.704) and the rampant conversion of land within the 50-meter riparian radius into illegal settlements (score 0.704). This anthropogenic pressure is exacerbated by surges in domestic waste loads from dense urban populations (score 0.441) and flow fluctuations due to global climate change (score 0.212). Meanwhile, external opportunities—such as support for national river restoration policies (score 0.405) and active involvement from environmental NGOs (score 0.282)—remain latent and are not yet integrated tactically. Consequently, future control strategies cannot rely on reactive measures but must apply defensive interventions (WT Strategies / Mini-Mini Strategy) to strictly close institutional gaps to save the Cisadane River.

Table 12. Pentahelix strategy for Cisadane river pollution control

Weakness (Internal Factors)	Strategy for DLH Tangsel & Banten	Strategy for KLHK (PPA Directorate)	Strategy for Academics	Strategy for Kertabumi Environmental Organization
Lack of comprehensive detailed technical data inventory of pollutant sources (point & non-point).	DLH Tangsel: Conduct spatial surveys and digital geo-tagging of all domestic illegal outfall pipes in the Kademangan segment. DLH Banten: Large industries are required to validate liquid waste outfall coordinates online within 30 days.	KLHK: Develop national technical guidelines on inventory point source and non-point source pollution (agriculture/domestic waste) for data standardization.	Academics: Participatory spatial mapping was conducted to validate the visual distribution of non-point source pollution discharge points in residential buffer zones.	Kertabumi: Activate RT/RW level citizen networks to conduct independent data collection of illegal dumping in river buffer zones.
The Internal data synchronization and cross-regional inter-institutional coordination systems are still weak.	DLH Tangsel & Banten: Implement a mandatory digital forced data synchronization policy, replacing manual inter-agency reporting across regencies/cities and provinces.	KLHK: Provide an electronic-based reporting platform that dynamically integrates national water quality data from upstream to downstream.	Academics: Build a dynamic river hydraulic modeling database and release periodic governance compliance reports openly to the public.	Kertabumi: Act as an inter-agency critical partner periodically supplying visual evidence and GPS coordinates of buffer zone violations.
Lack of regular guidance/socialization regarding household sanitation outside developer areas.	DLH Tangsel: Allocate specific grant funds to accelerate standardized individual/communal Sanimas programs (SNI 2398:2017 compliant) in non-developer settlements.	KLHK: Compile a national guideline module on technical criteria for water-tight septic tanks for densely populated, water-critical areas.	Academics: Conduct environmental epidemiology studies on the correlation between water-tight septic tanks and the prevalence of diarrhea/skin diseases in buffer zones.	Kertabumi: Establish independent waste monitoring posts and educate on organic and inorganic waste sorting at the source in upstream residential drainage, and develop composting programs.
Weak operational supervision and maintenance of environmental management infrastructure units.	DLH Tangsel & Banten: Automatically lock secondary operational permits for industries that fail to report quarterly liquid waste self-monitoring results via SIMPEL.	KLHK: Install automatic telemetry sensors for real-time waste detection at large industrial outfall points bordering raw water sources.	Academics: Conduct independent technology audits on the efficiency of BOD/COD reduction in domestic communal WWTP units periodically.	Kertabumi: Establish community-based independent waste monitoring posts around overflow drainage infrastructure leading to river bodies.

3.5.4 Mitigation of weaknesses and threats (W-T)

The strength of communal WWTP physical programs often clashes with spatial regulations in the field. Streeter-Phelps modeling in the critical segment (Pesona Serpong Housing) confirms 20.15 km flow has a positive remaining assimilative capacity, supported by an actual reaeration coefficient ($K_{rT} = 0.391/\text{day}$) that dominates the deoxygenation coefficient ($K_{dT} = 0.225/\text{day}$). However, this remaining capacity is threatened by riparian land conversion (50-meter radius) which triggers shock loading of organic pollutants, where BOD levels spiked to 21 mg/L and Total Coliform accumulation reached 10,000 MPN/100mL in the downstream segment.

The root cause of non-point source pollution was dissected through SPSS multiple linear regression analysis: Water Quality (Y) = $3.352 - 0.411 X_1 + 0.035 X_2 + 0.329 X_3$. The Domestic Wastewater Management variable (X_3) emerged as the dominant determinant ($p\text{-value} = 0.007$), confirming that leaky septic tanks and grey water discharge are the primary contributors to microbiological degradation. This finding confirms that downstream macropollutants are more transboundary in nature from upstream, rather than purely local domestic contributions. In this equation, the negative sign (-) indicates that the higher the level of public perception and knowledge, the lower the perceived water quality. It must be emphasized that the "knowledge" variable here is not formal education level (primary/secondary school), but the degree of negative public perception regarding the Cisadane River's condition. Thus, it can be concluded that the public is aware that water quality of the Cispadane River is low. Although partial multiple linear regression tests showed that individual waste-disposal behavior did not statistically correlate linearly the decline in surface water quality, actual field conditions indicate that solid waste accumulation has a significant communal external influence on the organic parameter on river.

The macro-influence of solid waste is emphasized by spatial analysis showing that the Cipeucang Final Disposal Site is located exactly in the riparian zone with a radius of < 200 meters from the Cisadane River body. This close proximity triggers a high risk of solid waste entering directly due to embankment landslides or the release of contaminants through leachate, which carries a very high organic load. This degradation phenomenon is worsened by the continuous accumulation of "sent" macro-waste carried by currents from the upstream region (Bogor Regency). This transboundary solid waste input visually lowers the river's aesthetics and chemically triggers drastic spikes in Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) parameters, especially during the hydrological rainy season.

4. Conclusions

This study establishes a comprehensive ecological baseline for the urban catchment of the Cisadane River in South Tangerang City by successfully integrating multi-criteria biophysical parameters with deterministic hydraulic modeling and inferential social statistics. Spatiotemporal water quality analysis indicates that the river basin is currently in a lightly polluted state, with Pollution Index scores stretching from 0.58 to 4.87, structurally driven by non-compliant chemical oxygen demand concentrations and extreme microbiological surges of Total Coliform up to 4000 MPN/100mL near dense municipal sectors. Despite these evident anthropogenic pressures, the one-dimensional deterministic Streeter-Phelps oxygen sag simulation reveals that the critical urban transition segment still holds a robust, positive residual carrying capacity of 2,111.60 kg/day for organic waste. This substantial hydraulic carrying capacity surplus is structurally supported by a dominant atmospheric reaeration rate ($K_{rT} = 0.428/\text{day}$) over the first-order microbial deoxygenation decay rate ($K_{dT} = 0.225/\text{day}$), culminating in a negative critical transport travel time ($t_c = -21.95$ days) that mathematically proves the optimal operational efficiency of the river's natural self-purification processes.

The primary scientific contribution of this research breaks away from conventional, isolated water monitoring models by coupling physical oxygen-decay equations with multivariate inferential regressions under a standardized Pentahelix governance framework. Inferential SPSS diagnostic arrays mathematically confirm that decentralized domestic wastewater management (X3) and public cognitive perception (X1) function as the primary direct causal drivers controlling surface water quality variation ($P = 0.007 < 0.05$). Conversely, individual littering habits (X2) are statistically non-significant ($P = 0.333 > 0.05$) due to transboundary sediment accumulation from upstream reaches. Limitation of this study is that it only captures the observed conditions at a single point in time rather than changes over time as it employed a cross-sectional design.

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Author Contribution

Conceptualization, A.G.M. and D.M.H.; Methodology, A.G.M. and D.N.M.; Validation, D.M.H. and D.N.M.; Formal Analysis, A.G.M.; Investigation, A.G.M.; Resources, A.G.M.; Data Curation, A.G.M.; Writing—Original Draft Preparation, A.G.M.; Writing—Review & Editing, D.M.H. and D.N.M.; Visualization, A.G.M.; Supervision, D.M.H. and D.N.M.; Project Administration, A.G.M.; and Funding Acquisition, D.M.H. All authors have read and agreed to the published version of the manuscript.

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Ethical Review Board Statement

The study was conducted in accordance with the institutional guidelines of the Universitas Indonesia and approved by the School of Environmental Science (SIL) Administration System. The research protocol was officially verified and documented on January 13, 2026, and received formal ethical approval (Kaji Etik) on January 23, 2026 (Protocol code: 2306195354).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the findings of this study are publicly available in an online database. The datasets can be accessed at <https://tinyurl.com/AES-3920>. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions regarding the specific

location of residential household respondents and the sensitive nature of unpublished industrial monitoring reports utilized in this research.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Declaration of Generative AI Use

During the preparation of this work, the authors used Gemini AI to assist in generating and formatting the professional blue-and-white visual data tables from the existing water quality datasets. After using this tool, the author(s) reviewed and edited the content as needed and took full responsibility for the content of the publication.

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