JPPIPA 11(11) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Dynamics Approach to Analyzing the Water Pollution Carrying Capacity of the Batang Arau River in Padang City

Lisa Rahayu[1*], Indang Dewata[1], Nurhasan Syah[1], Iswandi Umar[1]

[1] Environmental Science Study Program, Postgraduate School, Universitas Negeri Padang, Padang, Indonesia.

Received: September 26, 2025
Revised: October 20, 2025
Accepted: November 25, 2025
Published: November 30, 2025

Corresponding Author:
Lisa Rahayu
tanyaayupdg@gmail.com

DOI: 10.29303/jppipa.v11i11.12959

Abstract: The Batang Arau River in Padang City exhibits contrasting environmental conditions between its upstream and downstream segments. The upstream–midstream areas still maintain good water quality with positive carrying capacity, while the downstream segment has exceeded its natural assimilation limit due to increasing pollutant loads originating from domestic and community activities. This study aims to analyze water quality, calculate carrying capacity, and model the relationship between community behavior and the river's assimilation capacity using a system dynamics approach. The modeling results indicate a continuous decline in carrying capacity driven by population growth and waste generation, illustrating that human behavior has a direct impact on the ecological balance of the river. Therefore, sustaining the ecological function of the Batang Arau River requires integrated pollution control policies, community-based waste management, and continuous environmental education to enhance public awareness and ensure the long-term sustainability of the river ecosystem.

Keywords: Batang Arau River; Carrying capacity; Community behavior; System dynamics; Water quality

Introduction

Rivers have long played a vital role as the source of life for human civilization. In addition to serving as raw water providers, rivers support agricultural, fisheries, tourism, and transportation activities. However, rapid population growth, urbanization, and industrialization have significantly increased the pollution load that aquatic ecosystems must bear. Globally, many rivers are experiencing serious stress due to organic matter, excessive nutrients, and hazardous chemicals, which degrade water quality and the ecological carrying capacity of river systems (Loucks & van Beek, 2017; UNEP, 2016).

Differences in pollution levels among river estuaries can be effectively identified using periphyton bioindicators, which reflect the actual ecological condition of the water body (Bahri et al., 2023). The water quality at river estuaries has declined due to increasing anthropogenic activities along the watershed (Melo et al., 2024). Community activities around rivers directly affect the quality of water used as a source of clean and raw water (Mangallo et al., 2023).

In Indonesia, river water pollution has reached an alarming level. Data from the Ministry of Environment and Forestry (KLHK, 2019) show that more than 75% of rivers are in moderately to heavily polluted condition. Major rivers such as the Brantas, Citarum, and Musi have experienced declining water quality due to domestic, agricultural, and industrial waste (Suryono et al., 2020; Pratama et al., 2021). Water quality parameters such as BOD, COD, and TSS in river flows exhibit spatial variations closely related to the intensity of domestic activities in surrounding communities (Supardiono et al., 2023). The main factors contributing to river pollution include community behavior, suboptimal waste management systems, and weak enforcement of environmental regulations (Yanti et al., 2024). Variations

How to Cite:
Rahayu, L., Dewata, I., Syah, N., & Umar, I. (2025). Dynamics Approach to Analyzing the Water Pollution Carrying Capacity of the Batang Arau River in Padang City. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 109–121. https://doi.org/10.29303/jppipa.v11i11.12959

in the physical and chemical characteristics of water often reflect the degree of contamination caused by human activities in densely populated areas (Latupeirissa et al., 2022).

Water quality assessment in Indonesia generally relies on the Pollution Index (IP) method, which, although useful, remains static and cannot capture the dynamic interactions among pollutants over time (MoEF, 2019). In reality, river ecosystems are dynamic systems that continuously change through feedback processes between human activities and the natural self-purification capacity of rivers. Therefore, analysis of natural water sources is essential to assess their feasibility as drinking water sources, particularly in coastal and urban areas (Safitri et al., 2024).

A similar condition is likely to occur in the Batang Arau River, one of the main rivers flowing through the center of Padang City. This river plays a vital role as a transportation route, tourism area, fishery resource, and livelihood support for surrounding communities. However, the increasing intensity of activities along the river basin—such as dense settlements, tourism, trade, and domestic waste disposal—has raised the pollution load. The accumulation of organic matter and suspended solids, indicated by increased Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS), reduces the river's ability to maintain its ecological function. The spatial distribution of BOD, COD, and TSS is strongly influenced by pollution sources from domestic and urban runoff activities (Marlina et al., 2020). Organic pollutant concentrations tend to rise in downstream areas due to the imbalance between pollutant input and the river's natural purification capacity (Lusiana et al., 2020). High BOD, COD, and TSS values are key indicators of the declining ecological carrying capacity of rivers resulting from suboptimal community waste management (Wifarulah et al., 2021). The Pollution Index method can be used to evaluate spatial variations in water quality and determine priority zones for pollution control (Suwatanti et al., 2022).

An imbalance between pollution load and natural purification processes leads to the degradation of river carrying capacity. Theoretically, this study is based on the concept of environmental carrying capacity, which describes a water body's ability to absorb pollutant loads without losing ecological stability (Hu et al., 2021; Zhang et al., 2022). BOD, COD, and TSS parameters are primary indicators of organic pollution and sediment load that directly affect water quality (Bader et al., 2022; Supardiono et al., 2023). High BOD and COD values reflect increased decomposition of organic matter, while high TSS concentrations indicate sedimentation and particle accumulation that disrupt aquatic environmental balance. Understanding the dynamic interaction among these parameters is crucial for assessing the river's sustainable pollution absorption capacity.

To capture such complex interactions, a system dynamics modeling approach offers significant advantages. This approach enables simulation of nonlinear feedback between pollution sources, water quality, and river carrying capacity over time (Forrester, 1994; Wang et al., 2018). Previous studies by Wang et al. (2018) on the Yangtze River and Huang et al. (2012) on the Pearl River Delta demonstrated the effectiveness of system dynamics models in evaluating water quality management scenarios. However, in Indonesia, studies integrating dynamic modeling with river pollution analysis remain limited. Existing research, such as by Purnama et al. (2019) and Pratama et al. (2021), primarily focuses on quantifying pollution loads without incorporating feedback relationships among pollution parameters and community-based perspectives.

The novelty of this study lies in integrating system dynamics modeling with the social dimension through community perception analysis to evaluate the Batang Arau River's carrying capacity against water pollution. This research combines field measurements of BOD, COD, and TSS parameters with system dynamics modeling to predict temporal changes in river pollution carrying capacity under various human activity scenarios.

This study is essential as it provides a scientific foundation for understanding the interaction between pollution load and ecological capacity in urban rivers, particularly in Padang City. Moreover, incorporating community perceptions offers a more holistic approach to sustainable river management. Based on these considerations, this study aims to address the following questions: (1) What is the current water quality condition of the Batang Arau River based on key pollutant parameters (BOD, COD, and TSS)? (2) To what extent can the river withstand pollution loads from community activities? (3) How do communities perceive river pollution and water quality? and (4) How can system dynamics modeling be applied to predict changes in the river's carrying capacity in the future? Therefore, the objective of this research is to analyze and model the carrying capacity of the Batang Arau River using a system dynamics approach by integrating physicochemical parameters and community perception data to support sustainable water resource management in Padang City.

Method

Spatially, the research location can be seen in Figure 1, which illustrates the administrative boundaries and the position of the study area.

Figure 1. Map of water sampling points in the Batang Arau River

Types of Research

This study employs a descriptive quantitative approach integrated with a System Dynamics Modeling framework as the main analytical method. The descriptive quantitative method was used to systematically describe and analyze the current conditions of water quality and the river's carrying capacity, providing a factual basis for understanding the extent of pollution in the Batang Arau River. This approach allows the researcher to measure, compare, and evaluate environmental parameters quantitatively based on field and laboratory data.

Meanwhile, the System Dynamics Modeling approach was applied to capture and simulate the dynamic interactions between environmental, social, and behavioral components that influence river water quality. This method enables a holistic analysis of feedback mechanisms (loops) between pollutant generation, community waste disposal behavior, and the natural self-purification process of the river over time. The use of system dynamics is particularly relevant in environmental studies, as it helps to represent complex cause-and-effect relationships that evolve dynamically rather than linearly.

In this study, the combination of descriptive quantitative analysis and dynamic system simulation allows for both a static assessment (current conditions) and a predictive analysis (future scenarios).

Research Sample

The research was carried out in the Batang Arau River, which flows through Padang City, West Sumatra, Indonesia, and serves as one of the major water bodies receiving domestic and non-domestic waste inputs. The river was selected purposively due to its significant socio-economic function as well as increasing environmental pressure caused by urban growth and community waste disposal activities.

The sampling framework was designed to represent the spatial and temporal variations of the river. A total of six sampling points were established along the river stretch, categorized into three segments: (a) Upstream (Points 1–2): representing the relatively less disturbed zone near the river's source; (b) Midstream (Points 3–4): representing the transition area influenced by mixed land use, including residential and small-scale commercial activities; (c) Downstream (Points 5–6): representing the highly impacted zone that receives cumulative waste loads before reaching the estuary.

Water samples were collected in two different seasons (dry and wet) during the year 2024, to account for seasonal variations in pollutant concentrations and river flow. The grab sampling method was applied in accordance with the SNI 6989.57:2008 standard procedure for surface water collection. Each sample was preserved, stored, and transported following standard laboratory protocols to minimize degradation before analysis.

The main parameters analyzed included Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD)—all of which serve as key indicators for determining the degree of organic and inorganic pollution in the river. Spatially, the research area and sampling locations are presented in Figure 1, illustrating administrative boundaries and the geographic distribution of sampling points along the Batang Arau River.

In addition to physical and chemical samples, this study also used behavioral and social data sourced from previous research by Nasution (2018) and Rini (2010). These data represent the population's level of environmental knowledge, attitudes, and waste disposal behaviors, particularly the proportion of residents who dispose of waste directly into the river (68.04%), the probability of waste disposal among low-knowledge groups (90.50%), and among moderate/high-knowledge groups (40.00%). These parameters were later incorporated as variables in the system dynamics model to simulate the human–environment interaction affecting pollution levels.

Data Collection and Instrument

Data collection involved primary and secondary data sources, covering both environmental quality measurements and social-behavioral variables.

Water Quality Data Collection

Primary data were obtained through direct field sampling at the six designated points along the Batang Arau River. Water samples were analyzed in the laboratory to measure TSS, BOD, and COD levels. These measurements provided the quantitative basis for calculating the river's pollution carrying capacity (DD), which reflects the river's ability to assimilate or neutralize pollutant loads without exceeding water quality standards. The carrying capacity (DD) was calculated using the following equation:

$$DD = (C_{max} - C_{existing}) \times Q \times 86.4 \quad (1)$$

Where: DD = river carrying capacity (kg/day); Cmax = maximum permissible pollutant concentration (mg/L) based on Government Regulation No. 22 of 2021; Cexisting = measured pollutant concentration (mg/L); Q = river discharge (m^3/s); 86.4 = conversion factor from mg/L·m^3/s to kg/day.

The resulting DD values were then used to determine whether each river segment had a positive carrying capacity (surplus)—indicating that it could still receive additional pollutants—or a negative carrying capacity (deficit)—indicating that the river segment was already overloaded with pollutants.

Behavioral and Social Data

Secondary data on community knowledge, attitudes, and waste management behaviors were utilized as complementary inputs to the system dynamics model. primarily previous studies conducted by Nasution (2018) and Rini (2010). These datasets captured the socio-behavioral dimension of pollution, including: (a) The proportion of households disposing waste directly into the river; (b) The relationship between knowledge levels and waste disposal probability; (c) The contribution of behavioral factors (knowledge, attitude, enforcement) to overall pollution dynamics.

The contributions of knowledge-related factors (41.21%) and other socio-behavioral factors (58.79%) were included as quantitative inputs to represent behavioral drivers affecting pollutant generation.

System Dynamics Modeling and Simulation

A System Dynamics Model was developed using Powersim Studio 10 software to simulate the interactions between pollutant loads, water quality, and community behavior. The model construction followed a structured series of steps: (a) Problem Identification: defining key variables influencing the relationship between pollutant loads, community waste behavior, and river carrying capacity. (b) Causal Loop Diagram (CLD) Development: mapping the feedback relationships between variables such as population growth, waste generation, knowledge level, and river quality. (c) Model Formulation: translating qualitative relationships into quantitative equations and flow diagrams. (d) Simulation and Validation: running the model for a 10-year projection period (2024–2033) under a baseline (no-intervention) condition to observe pollution trends. (e) Policy Scenario Evaluation: assessing the potential impacts of alternative management strategies, such as waste management improvements and environmental education campaigns, on future water quality and river capacity.

Simulation outputs included time-series graphs showing changes in pollutant loads (TSS, BOD, COD), trends in community waste generation, and variations in river carrying capacity over the projection period.

Overall, this integrated methodological framework provides a comprehensive understanding of both environmental and human behavioral dynamics, supporting the development of sustainable pollution control strategies for the Batang Arau River. The complete research procedure and methodological framework are illustrated in Figure 2.

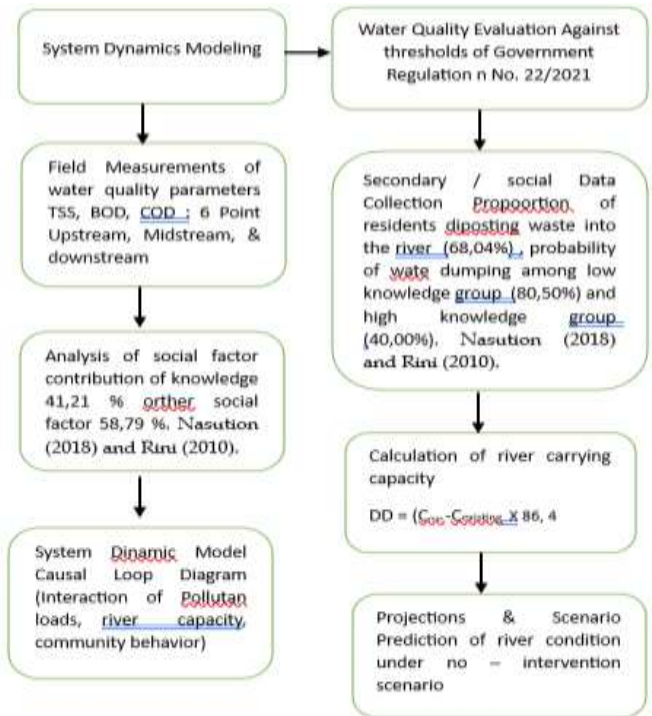

Figure 2. Research methods

Result and Discussion

Water Quality Analysis Compared to the Quality Standards of Government Regulation No. 22 of 2021

The water quality analysis of the Batang Arau River shows that at sampling points 1 to 4, the conditions still comply with the quality standards according to Government Regulation No. 22 of 2021 for TSS, BOD, and COD parameters. However, at points 5 and 6, a significant increase in concentration was observed. The TSS value at point 6 reached 50.2 mg/L, slightly exceeding the quality standard of 50 mg/L. The BOD values at points 5 (3.68 mg/L) and 6 (4.96 mg/L) also exceeded the threshold of 3 mg/L, while the COD values at points 5 (25.34 mg/L) and 6 (30.53 mg/L) surpassed the standard of 25 mg/L. These findings indicate an accumulation of pollution load in the downstream segment, primarily originating from domestic, commercial, and tourism activities along the riverbanks.

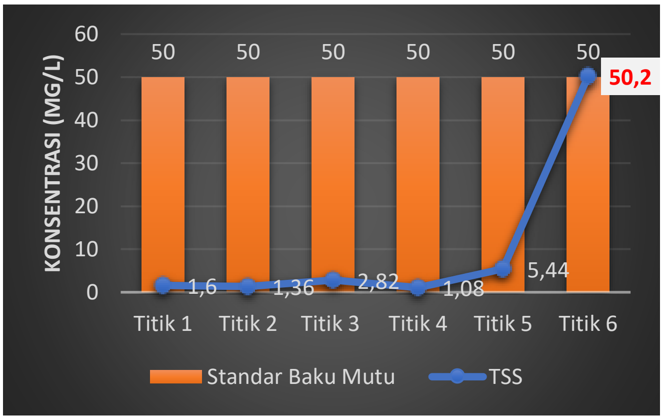

Figure 3. TSS concentration change in Batang Arau River

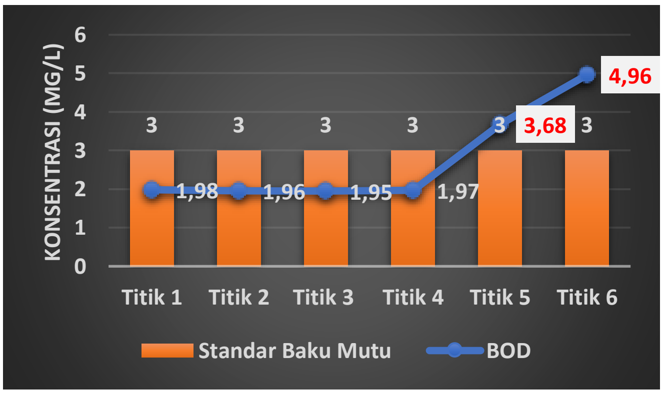

Figure 4. Changes in BOD concentration of Sungai Batang Arau

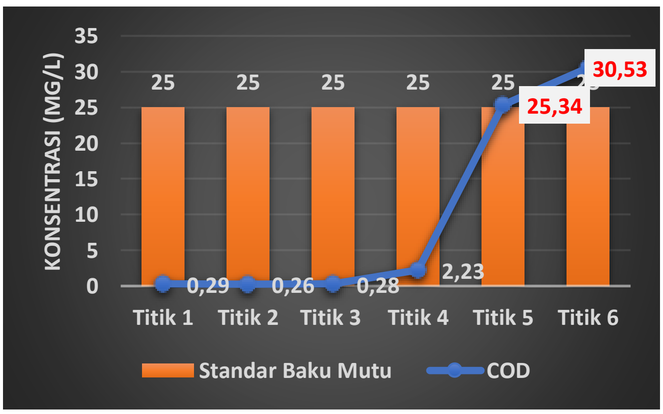

Figure 5. Changes in COD concentration of Batang Arau River

The sharp increase in TSS at point 6 indicates high sedimentation caused by erosion of open land along the riverbanks and the discharge of solid waste from local communities. Suspended particles not only affect water turbidity but also act as carriers of organic materials and heavy metals that deteriorate water quality. The interaction between TSS, BOD, and COD illustrates that an increase in suspended solids can accelerate biological and chemical reactions that reduce dissolved oxygen levels and overall river carrying capacity. Therefore, changes in TSS should not be viewed as a static condition but rather as part of a dynamic process influenced by anthropogenic and hydrological pressures. This condition strengthens the urgency of using a dynamic systems approach to model parameter interactions and project future water quality trends.

These results are consistent with studies on the Karang Mumus River in Samarinda, where all river segments exhibited BOD and COD values exceeding quality standards due to domestic waste discharge (Pramaningsih et al., 2020). A similar pattern was found in the Ciasem River, Subang, where the river's assimilative capacity declined in downstream areas because of high domestic and agricultural waste loads (Sosiawan et al., 2024). Thus, the degradation of water quality in the downstream segment of the Batang Arau River reflects a common phenomenon observed in urban rivers across Indonesia, which are under environmental pressure from population growth and economic activities.

Analysis of the Bearing Capacity of the Batang Arau River

The results of the analysis of the carrying capacity of the Batang Arau River show that at points 1 to 4, the water quality condition is still relatively good with the values of TSS, BOD, and COD being below the quality standards and the carrying capacity of the river with positive values. This indicates that the upstream to middle segment of the river is still able to accommodate the incoming pollution load. However, different conditions occurred in the downstream segment, especially at points 5 and 6. At point 5, the BOD value of 3.68 mg/L and COD of 25.34 mg/L have exceeded the quality standard, so that the carrying capacity of the river has negative values of -2,552 kg/day and -1,276 kg/day, respectively. The condition worsened at point 6, where TSS reached 50.2 mg/L, BOD 4.96 mg/L, and COD 30.53 mg/L, so that the carrying capacity of the river for these three parameters was negative. This shows that the downstream segment of the Batang Arau River is no longer able to accommodate additional pollutant loads, both suspended solids and organic and chemical waste. This of course confirms that the carrying capacity of the Batang Arau River continues to decline due to the high burden of domestic waste and the behavior of people who still throw garbage directly into water bodies. A similar situation was found in the Ciasem River near the Bantargebang Integrated Waste Management Site (IWMS), where analyses revealed that

BOD, COD, and TSS levels have exceeded water quality standards, and the river has lost its capacity to accommodate further pollution loads (Sosiawan et al., 2024).

Table 1. Bearing Capacity Analysis of the Batang Arau River

Point	TSS (kg/day)	BOD (kg/day)	COD (kg/day)
Point 1	1899711	3827	92722
Point 2	1909131	3902	92834
Point 3	1851826	3940	92759
Point 4	1920121	3865	85442
Point 5	1748990	-2552	-1276
Point 6	-7850	-7355	-20751

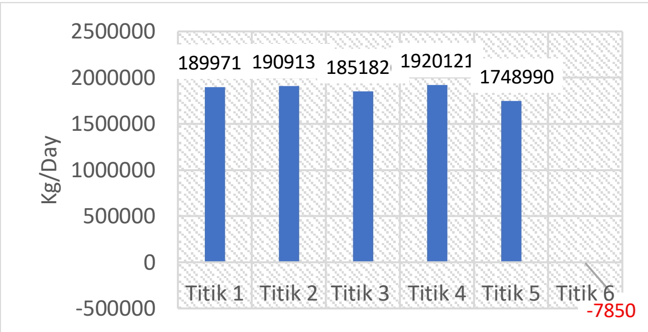

Figure 6. Bearing capacity analysis of TSS Batang Arau River

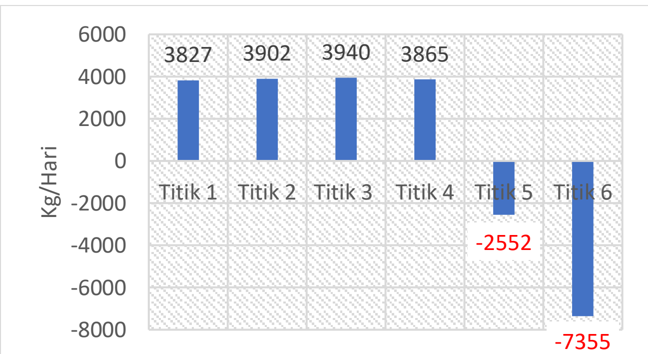

Figure 7. Analysis of BOD carrying capacity in Sungai Batang Arau

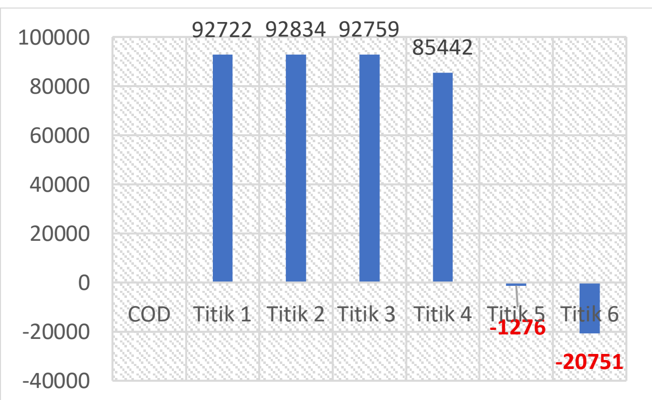

Figure 8. COD carrying capacity analysis in the Batang Arau River

Field observations were conducted to visually validate the measured water quality parameters along the Batang Arau River. The documentation presented in Figure 7 and Figure 8 illustrates the real environmental conditions observed at the study site.

Figure 9. Sampling process at the Batang Arau River

Figure 10. Field measurements of water quality parameters

Community Knowledge and Behavior

Based on Table 1, the proportion of people who still throw garbage into the river is quite high, which is 68.04%. This behavior is more dominant in the low-knowledge group with a probability of 90.50%, while in the moderately or good knowledgeable group it is only 40.00%. The results of the calculation show that around 55.52% of people are included in the category of low knowledge. Of these, the contribution of waste disposal behavior influenced by knowledge factors reached 41.21%, while the remaining 58.79% was influenced by other factors such as attitudes, habits, availability of facilities, social norms, and rule enforcement. Similar findings have been reported in Selangor, Malaysia, where households with lower environmental knowledge and less favourable attitudes demonstrated significantly poorer waste disposal practices, despite moderate awareness levels (Samsuri et al, 2025).

Table 2. Proportion and Probability of Community Behavior in Throwing Garbage into the River

Variable	Value (%)	Source
Proportion of people throwing garbage (observed)	68.04	Nasution (2018)
P(remove | low knowledge)	90.50	Rini (2010)
P(remove | knowledge enough/good)	40.00	Rini (2010)

Table 3. Results of Analysis Such as Attitudes, Information Distribution, Social Norms, and Rule Enforcement

Calculation Results	Value	Source
Proportion of people with low knowledge	55.52%	Secondary data analysis (Nasution, 2018; Rini, 2010)
Low knowledge contribution	41.21%	Secondary data analysis (Nasution, 2018; Rini, 2010)
Contribution of other factors (Attitude, Action, etc.)	58.79%	Secondary data analysis (Nasution, 2018; Rini, 2010)

Dynamic Modeling

Dynamic modelling is a computational approach used to represent and analyse systems that evolve over time, incorporating feedback loops, delays, and nonlinear interactions to capture complex dynamics. This method is widely applied in environmental and resource management to evaluate scenarios and support decision-making. For instance, recent studies have applied dynamic modelling to simulate biological nutrient removal in wastewater treatment plants to improve operational efficiency and water quality management (Aliyu et al., 2024), and to integrate wastewater treatment and reuse processes into large-scale hydrological simulations for better resource planning (Fridman et al., 2025).

The Causal Loop Diagram illustrates the systemic interconnections between environmental, social, and pollutant-related variables influencing river carrying capacity. An increase in population and per capita waste generation leads to greater waste accumulation, which directly deteriorates water quality through higher pollutant loads such as BOD, COD, and TSS, ultimately reducing the river's carrying capacity. On the other hand, hydrological factors such as rainfall, which increase river discharge, can enhance the assimilative capacity and improve carrying capacity if water quality is maintained. From the social perspective, increased public knowledge is strongly associated with environmentally friendly behavior such as proper waste management and domestic wastewater handling that helps to reduce pollution loads and preserve water quality. Recent studies support these feedback loops: research on the Jangkok River in West Nusa Tenggara, Indonesia, revealed that pollutant loads of BOD, COD, and TSS have exceeded the river's carrying capacity, with community perceptions, waste disposal behavior, and the availability of waste facilities identified as key factors (Haryono et al., 2024). Similarly, an optimization model study in the Yangtze River Economic Belt demonstrated that stronger environmental regulations significantly improved water resource carrying capacity, though with threshold effects and diminishing marginal returns under shifting industrial structures (Yi & Li, 2024).

The comparison with major international rivers such as the Yangtze, Mekong, and Hau Rivers is particularly relevant because these rivers share similar characteristics with the Batang Arau River, especially in terms of rapid urbanization, increasing domestic wastewater discharge, and intensified human activities along the watershed.

Like the Batang Arau River, these river systems flow through densely populated and economically active regions where urban growth and tourism have accelerated pollution accumulation in downstream segments. This similarity allows the findings from the Batang Arau River to be contextualized within broader Southeast and East Asian environmental challenges, highlighting that the decline in river carrying capacity is not an isolated local issue but part of a wider regional pattern of urban river degradation under socio-economic pressures.

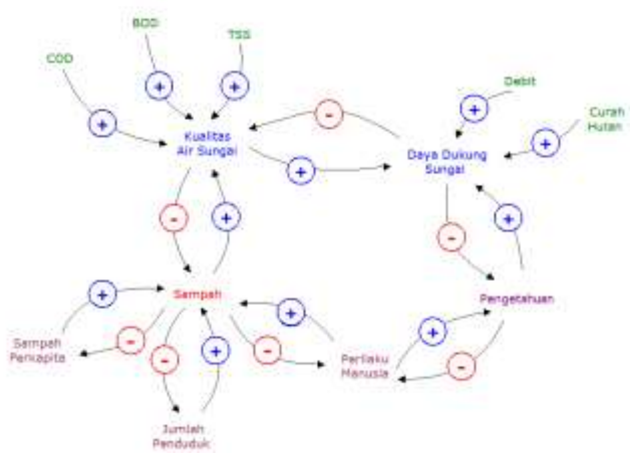

Figure 11. Causal loop diagram

Related to Waste

The 2024–2033 waste generation trend chart shows a consistent increase from 125,308 tons in 2024 to 127,837 tons in 2033. The average increase of around 250 tons per year illustrates the growth of waste generation in line with the increase in community activities, so that without control, the pollution burden is projected to continue to increase. In South Korea, a machine-learning forecasting study across metropolitan regions found that waste generation has shown an upward trend year after year, with population and GRDP (Gross Regional Domestic Product) strongly correlated with the increase (Lee et al, 2023). This finding is comparable to the projected waste trend in the Batang Arau River Basin, where similar socio-economic dynamics are driving pollutant accumulation, reinforcing that population growth and economic expansion are universal determinants of waste-induced water quality degradation.

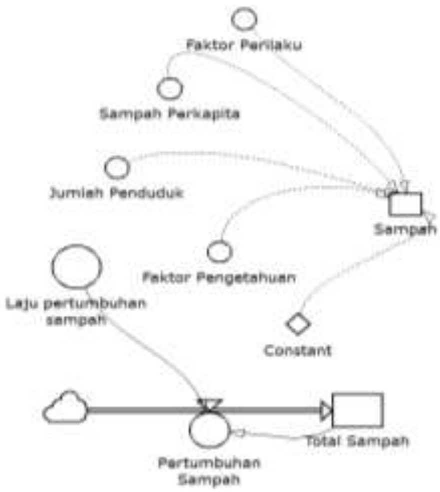

Figure 12. Waste simulation diagram

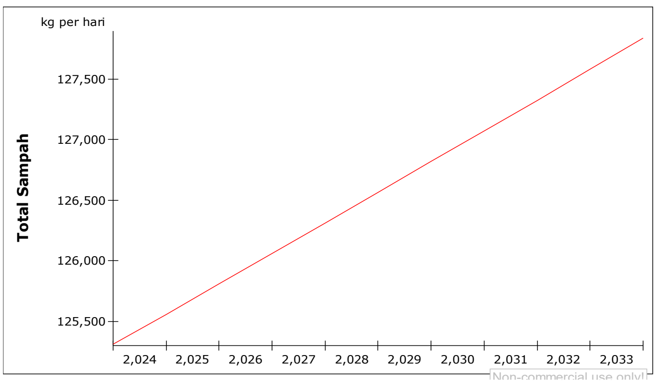

Figure 13. Sub-model of trend of increasing community waste generation

Results of BOD carrying capacity modeling in the Batang Arau River

The trend chart of the bearing capacity of the BOD shows a downward trend from year to year. At POINT 5 and point 6, the carrying capacity value is negative which means that the river is no longer able to accommodate the organic load, but as the pollutant load increases, the value continues to decrease. This indicates that the capacity of river assimilation to organic waste is decreasing, especially in the downstream segment, so that water quality is threatened to decline and the risk of pollution increases if there are no control efforts. Similar patterns have been documented in the downstream Citarum Watershed in Indonesia, where studies report the pollution load capacity (PLC) of BOD in downstream segments turning negative under current pollutant loads, implying a need for pollutant reduction or improved wastewater/treatment controls (Permatasari et al, 2022). Other international studies reinforce this trend: a review of assimilative capacity and water quality modelling shows many rivers lose self-purification when organic waste loads surpass natural degradation and dilution (Darji et al, 2023). In the Changjiang (Yangtze) River Basin, spatial analyses found that monthly BOD5 and CODMn loads have increased significantly downstream, reducing water quality capacity to cope under high pollution loads (Zhang et al., 2023). Also, in the Muda River (Malaysia), observed BOD values in many samples exceeded class norms and the study identified decreased river assimilative capacity associated with low flow and increased anthropogenic discharge in urban/rural catchments (Lee et al, 2024). This suggests that tropical and subtropical river systems such as those in Indonesia, China, Vietnam, and Malaysia share hydrological and anthropogenic similarities that make cross-river comparisons meaningful for understanding common degradation mechanisms.

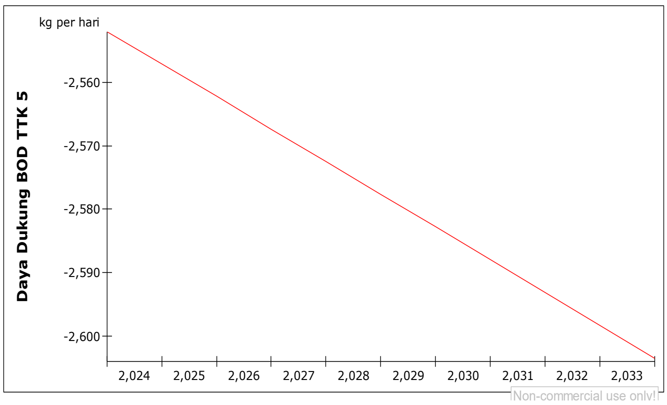

Figure 14. sub-model of the trend of decreasing the bearing capacity of BOD at points 5

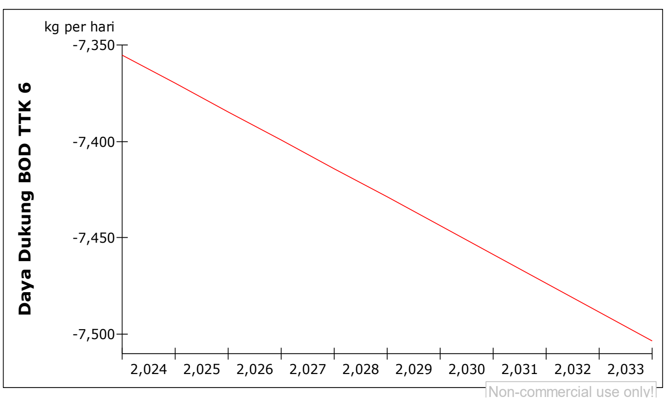

Figure 15. Sub-model of the trend of decreasing the bearing capacity of BOD at points 6

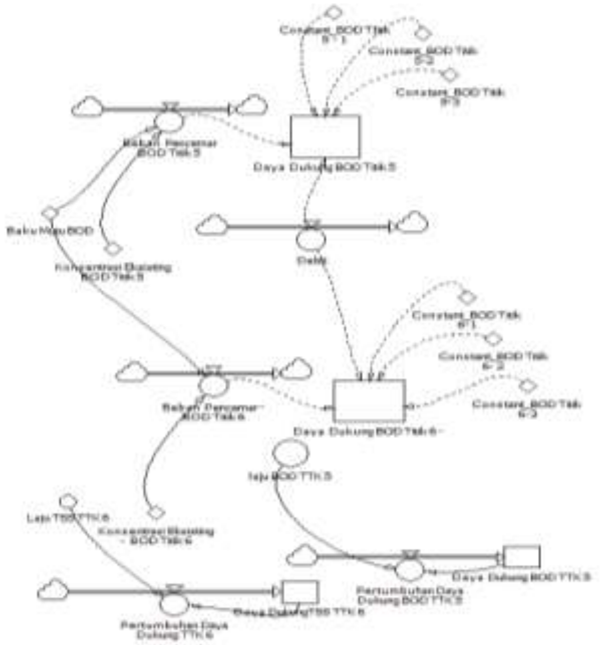

Figure 16. Simulation diagram of the bearing capacity of the BOD in the Batang Arau River

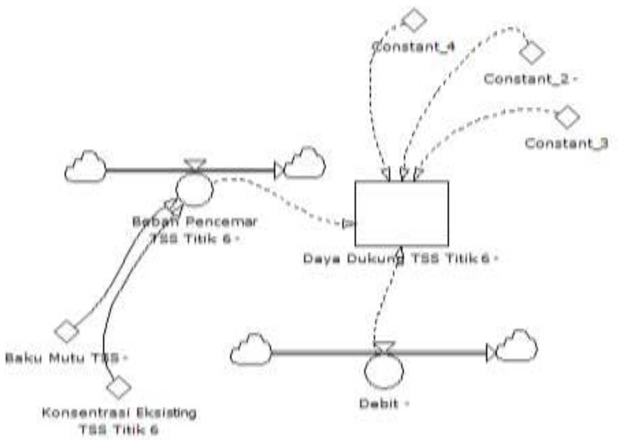

Figure 17. TSS bearing capacity simulation diagram point 6

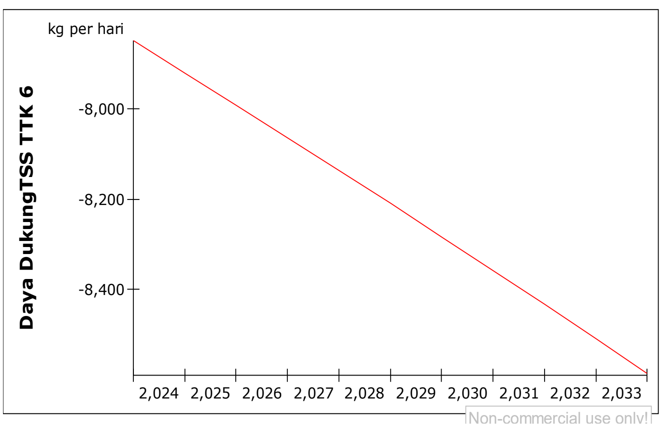

Figure 18. TSS bearing capacity decline sub model

The graph of the TSS bearing capacity trend at sample point 6 for the 2024–2033 period shows an alarming condition because since the beginning of the calculation of the carrying capacity value has been negative and continues to decline from year to year. This means that the Batang Arau River, especially in the downstream segment, will no longer be able to accommodate the additional load of suspended solids since 2024. The continuous decline in carrying capacity reflects the high pollution burden due to sedimentation, domestic waste, and community activities along the riverbanks. If this trend continues until 2033, the level of water turbidity will increase, the quality of the waters will decline, and the ecological function of rivers has the potential to suffer serious damage. Similar findings have been observed in major rivers such as the Yangtze and Mekong, where studies have shown that downstream TSS concentrations have decreased due to factors like dams, but upstream and midstream segments continue to face high suspended sediment loads contributing to ecological stress (Guan, 2022). Another study in Vietnam's Hau River showed extremely high variation of suspended solid concentrations (minimum ~10 mg/L, maximum >300 mg/L) particularly in floodplain or areas influenced by community activity, indicating the river's limited capacity to dissipate or settle suspended solids effectively (Nguyen et al., 2022). These parallels emphasize that the Batang Arau River's challenges are part of a wider phenomenon in tropical Asia, where rapid urban expansion and domestic discharges continually threaten sediment balance and water quality.

Results of COD carrying capacity modeling in the Batang Arau River

The projected results of the COD carrying capacity modeling in the 2024–2033 period show an increasingly sharp downward trend, especially in the downstream segment of the river. Since the beginning of the calculation, namely at points 5 and 6, the carrying capacity value has been negative, which means that the river is no longer able to accommodate the additional load of organic chemical pollutants. In the future, this condition is expected to continue to worsen as domestic activity increases, population growth, and the entry of household waste and detergents into water bodies. If there is no intervention effort, the carrying capacity of COD will decrease from year to year so that the water quality of the Batang Arau River has the potential to be in the category of severely polluted permanently. This can have an impact on the decline of the ecological function of the river, the disruption of aquatic biota, and the increased health risks of the people who use river water. Therefore, this projection emphasizes the importance of planned pollution control measures, both through waste treatment and changes in community behavior, so that the carrying capacity of COD does not decrease further in the future. Similar declines have been observed in other Indonesian rivers: in the Musi River, where high COD levels due to community wastewater (e.g. kitchen, bathroom, laundry) have been reported and threaten river health (Purba et al, 2023) and also in the Batang Ombilin River, where community pollution led to COD concentrations that compromise water safety and aquatic life (Monica et al, 2023).

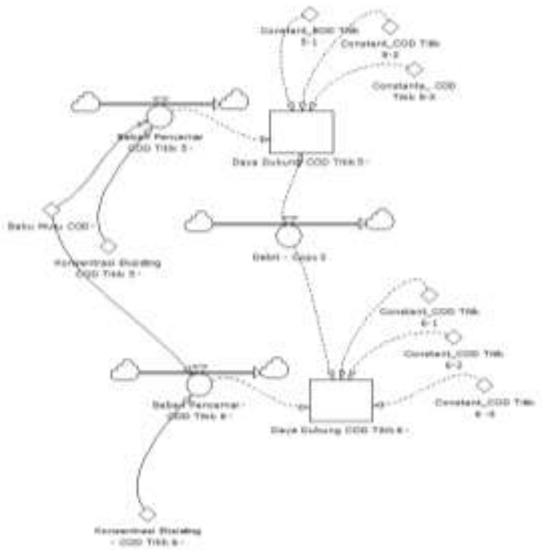

Figure 19. COD carrying capacity simulation diagram points 5 and 6

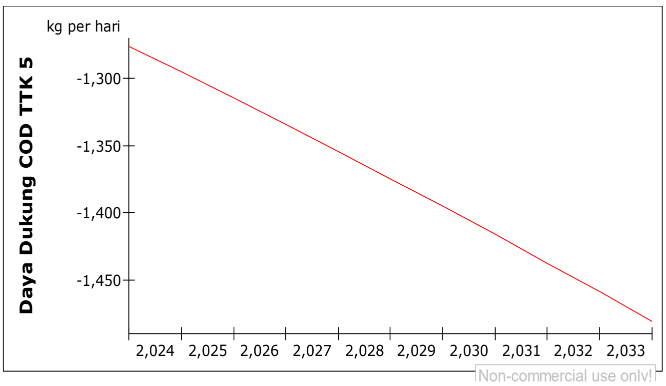

Figure 20. sub-model of the trend of decreasing the bearing capacity of BOD at points 5

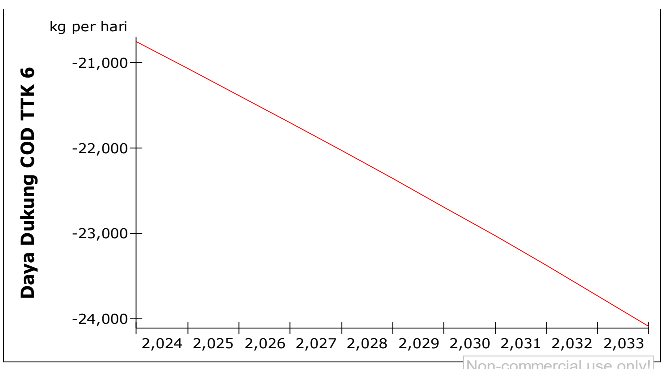

Figure 21. sub-model of the trend of decreasing the bearing capacity of BOD at points 5

year	Carrying capacity BOD 5	Carrying capacity BOD 6	Carrying capacity TSS 6	Carrying capacityg COD 5	Carrying capacityg COD 6	total rubbish
2024	-2,552.00	-7,355.00	-7,850.00	-1,276.00	-20,751.00	125,306.60
2025	-2,557.10	-7,369.71	-7,920.65	-1,295.14	-21,062.27	125,559.21
2026	-2,562.22	-7,384.43	-7,991.94	-1,314.57	-21,378.20	125,810.33
2027	-2,567.34	-7,399.22	-8,063.86	-1,334.29	-21,698.87	126,061.95
2028	-2,572.48	-7,414.02	-8,136.44	-1,354.30	-22,024.36	126,314.08
2029	-2,577.62	-7,428.84	-8,209.67	-1,374.61	-22,354.72	126,566.70
2030	-2,582.78	-7,443.70	-8,283.55	-1,395.23	-22,690.04	126,819.84
2031	-2,587.94	-7,458.59	-8,358.10	-1,416.16	-23,030.39	127,073.48
2032	-2,593.12	-7,473.51	-8,433.35	-1,437.41	-23,375.85	127,327.62
2033	-2,598.31	-7,488.45	-8,509.25	-1,458.97	-23,726.49	127,582.28
2034	-2,603.50	-7,503.43	-8,585.81	-1,480.85	-24,082.38	127,837.44

Figure 22. Sub-model of the trend of deflation of carrying capacity in the Batang arau river

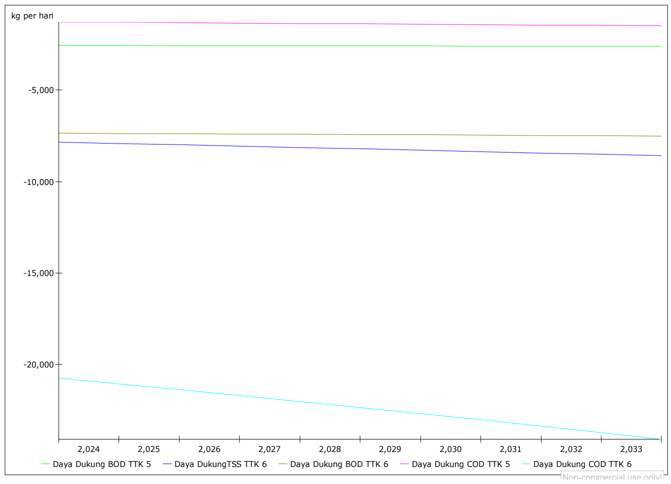

Figure 23. sub-model of the trend of decline in carrying capacity in the Batang Arau River

Conclusion

The Batang Arau River shows contrasting environmental conditions between its upstream and downstream segments. The upstream–midstream areas still maintain good water quality and positive carrying capacity, while the downstream segment has exceeded its natural assimilation limit due to increasing domestic and community-derived pollutants. System dynamics modeling confirms a continuous decline in the river's carrying capacity driven by population growth and waste generation, illustrating how human behavior directly affects the ecological balance of the river system. These findings emphasize that sustaining the Batang Arau River's ecological function requires integrated pollution control policies, community-based waste management, and continuous environmental education to strengthen public awareness and maintain the long-term sustainability of the river ecosystem.

Acknowledgments

The author would like to thank the Environmental Agency of Padang City (DLH Kota Padang) for providing access to water quality data and logistical support during sampling. Appreciation is also extended to Universitas Negeri Padang for academic guidance and to the local community around the Batang Arau River for their cooperation during field activities.

Author Contributions

L.R: preparation of original draft, methodology, data collection, analysis, system dynamics modeling, results and discussion, review, and editing.

Funding

This research received no external funding and was supported by the author with institutional assistance from Universitas Negeri Padang.

Conflicts of Interest

The author declares no conflict of interest.

References

Aliyu, A., Mohamed, T. S., ElSayed, N. B., Abdelbaki, C., Bessedik, M., & Kumar, N. (2025). Modeling Biological Nutrients Removal for Wastewater Treatment Plant (WWTP) Management: A Case Study of Ain El Houtz WWTP (Algeria). *Water, Air, & Soil Pollution*, *236*(1), 72. https://doi.org/10.1007/s11270-024-07735-9

Bader, A. C., Hussein, H. J., & Jabar, M. T. (2022). BOD: COD Ratio as Indicator for Wastewater and Industrial Water Pollution. *International Journal of Special Education*, *37*(3), 2022. Retrieved from https://www.researchgate.net/publication/362053527

Bahri, S., Hartanto, P., Kusumadewi, A. A. A. D., Halimatusa'adiah, & Kahfi, B. A. (2023). Comparison of Pollution Level at Jangkok River Estuary and Ancar River Estuary Using Periphyton Bioindicators. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 986–990. https://doi.org/10.29303/jppipa.v9i2.3784

Bregaglio, S., Cappelli, G., & Donatelli, M. (2012). Evaluating the suitability of a generic fungal infection model for pest risk assessment studies. *Ecological Modelling*, *247*, 58–63. https://doi.org/10.1016/j.ecolmodel.2012.08.004

Darji, J., Lodha, P., & Tyagi, S. (2022). Assimilative capacity and water quality modeling of rivers: a review. *AQUA — Water Infrastructure, Ecosystems and Society*, *71*(10), 1127–1147. https://doi.org/10.2166/aqua.2022.063

Fridman, D., Smilovic, M., Burek, P., Tramberend, S., & Kahil, T. (2025). Wastewater matters: incorporating wastewater treatment and reuse into a process-based hydrological model (CWatM v1.08). *Geoscientific Model Development*, *18*(12), 3735–3754. https://doi.org/10.5194/gmd-18-3735-2025

Guan, Q., Feng, L., Tang, J., Park, E., Ali, T. A., & Zheng, Y. (2022). Trends in River Total Suspended Sediments Driven by Dams and Soil Erosion: A Comparison Between the Yangtze and Mekong Rivers. *Water Resources Research*, *58*(10). https://doi.org/10.1029/2022WR031979

Handayani, T., Sari, D. P., & Fitri, L. (2021). Study of pollution index and assimilative capacity of the Cisadane River. *Jurnal Ilmu Lingkungan Lestari*, *18*(2), 89–98. https://doi.org/10.14710/jill.18.2.89-98

Haryono, I., Agustina, H., & Soesilo, T. E. B. (2024). Biophysics indicators as the sustainable strategy for river pollution control (case study in Jangkok River, Mataram City, West Nusa Tenggara). *Journal of Sustainability, Society, and Eco-Welfare*, *2*(1), 1–23. https://doi.org/10.61511/jssew.v2i1.2024.943

Hu, G., Zeng, W., Yao, R., Xie, Y., & Liang, S. (2021). An integrated assessment system for the carrying capacity of the water environment based on system dynamics. *Journal of Environmental Management*, *295*, 113045. https://doi.org/10.1016/j.jenvman.2021.113045

Khairudin, K., Ul-Saufie, A. Z., Senin, S. F., Zainudin, Z., Rashid, A. M., Abu Bakar, N. F., Anas Abd Wahid, M. Z., Azha, S. F., Abd-Wahab, F., Wang, L., Sahar, F. N., & Osman, M. S. (2024). Enhancing riverine load prediction of anthropogenic pollutants: Harnessing the potential of feed-forward backpropagation (FFBP) artificial neural network (ANN) models. *Results in Engineering*, *22*, 102072. https://doi.org/10.1016/j.rineng.2024.102072

KLHK. (2019). *Status Lingkungan Hidup Indonesia 2019*. Jakarta: KLHK. Retrieved from https://www.menlhk.go.id/site/download

Latupeirissa, A. N., & Latupeirissa, J. (2022). Analysis of Physical and Chemical Quality of PDAM Water in Teluk Ambon Baguala Sub-District. *Jurnal Penelitian Pendidikan IPA*, *8*(3), 1314–1319. https://doi.org/10.29303/jppipa.v8i3.1535

Lebreton, L. C. M., Van Der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications*, *8*(1), 15611. https://doi.org/10.1038/ncomms15611

Lee, J. S., & Shin, D. C. (2025). Prediction of Waste Generation Using Machine Learning: A Regional Study in Korea. *Urban Science*, *9*(8), 297. https://doi.org/10.3390/urbansci9080297

Lee, M.-J., Kim, T.-H., Min, B., & Hwang, S.-J. (2012). Sodium (Na+) concentration effects on metabolic pathway and estimation of ATP use in dark fermentation hydrogen production through stoichiometric analysis. *Journal of Environmental Management*, *108*, 22–26. https://doi.org/10.1016/j.jenvman.2012.04.027

Loucks, D. P., & van Beek, E. (2017). *Water Resource Systems Planning and Management*. Springer International Publishing. https://doi.org/10.1007/978-3-319-44234-1

Mangallo, B., & Oktaviani, D. (2023). Study on the Quality of Mako-mako River Water as Clean and Raw Water Source in Yembekiri Village. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 8204–8209. https://doi.org/10.29303/jppipa.v9i10.4536

Melo, R. H., Alfin, E., & Niode, A. S. (2024). Water Quality River Estuary of Batang Hari, Musi Banyuasin District, the Province of South Sumatera. *Jurnal Penelitian Pendidikan IPA*, *10*(5), 2860–2870. https://doi.org/10.29303/jppipa.v10i5.6223

Monica, F., Umar, I., Dewata, I., & Barlian, E. (2023). Water Quality Analysis in the Batang Ombilin River, Sawahlunto City. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 178–183. https://doi.org/10.29303/jppipa.v9iSpecialIssue.6371

Nguyen, T. H. D., Phan, K. D., Nguyen, H. T. T., Tran, S. N., Tran, T. G., Tran, B. L., & Doan, T. N. (2020). Total Suspended Solid Distribution In Hau River Using Sentinel 2a Satellite Imagery. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *VI-3/W1-20*, 91–97. https://doi.org/10.5194/isprs-annals-VI-3-W1-2020-91-2020

Permatasari, P. A., Amalo, L. F., Pangestu, R., & Putra, M. D. (2022). Pollution Load Capacity in the Downstream Citarum Watershed: 4 years after Citarum Harum Program. *Jurnal Pengelolaan Sumberdaya Alam Dan Lingkungan (Journal of Natural Resources and Environmental Management)*, *12*(4), 706–719. https://doi.org/10.29244/jpsl.12.4.706-719

Pramaningsih, V., Suprayogi, S., & Purnama, I. L. S. (2020). Pollution Load Capacity Analysis of BOD, COD, and TSS in Karang Mumus River, Samarinda. *Indonesian Journal of Chemistry*, *20*(3), 626. https://doi.org/10.22146/ijc.44296

Pratama, R., Nugroho, K., & Lestari, D. (2021). Mathematical modeling for water pollution in Citarum River, Indonesia. *Environmental Monitoring and Assessment*, *193*(9). https://doi.org/10.1007/s10661-021-09302-5

Pratiwi, Y., Rejo, A., Fariani, A., & Faizal, M. (2021). Source of Carbon Dioxide Emissions Equivalent to Plant-Based Control Concept with Dynamic System in Prabumulih City, South Sumatra Province. *IOP Conference Series: Earth and Environmental Science*, *810*(1), 012051. https://doi.org/10.1088/1755-1315/810/1/012051

Purba, Y. S., Sulandari, U., Lelitasari, L., & Arjuni, D. (2023). Analysis of Water Pollution in The Musi River Due to Community and Industrial Activities Using Onlimo. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 651–656. https://doi.org/10.29303/jppipa.v9iSpecialIssue.5967

Purnama, S., Suryadi, F. X., & Hidayat, A. (2019). Pollution carrying capacity of Code River, Yogyakarta. *Jurnal Ilmu Lingkungan*, *17*(2), 210–222. https://doi.org/10.14710/jil.17.2.210-222

Ramadhan, F., & Yuliani, R. (2023). Evaluation of carrying capacity and pollution load of the Brantas River using the Storet method. *Jurnal Pengelolaan Sumber Daya Alam Dan Lingkungan (Journal of Natural Resources and Environmental Management*, *13*(1), 45–56. https://doi.org/10.29244/jpsl.13.1.45-56

Ramos-Merchante, A., & Prenda, J. (2018). The Ecological and Conservation Status of The Guadalquivir River Basin (s Spain) Through The Application Of A Fish-based Multimetric Index. *Ecological Indicators*, *84*, 45–59. https://doi.org/10.1016/j.ecolind.2017.08.034

Romadona, I. I., Andawayanti, U., & Nur Cahya, E. (2020). Analysis of inundation reduction in drainage channels in the coastal area of the City of Palu with environmental insights. *IOP Conference Series: Earth and Environmental Science*, *437*(1), 012034. https://doi.org/10.1088/1755-1315/437/1/012034

Safitri, A. D., Purwana, R., & Utumo, S. W. (2024). The Potential of Spring Water Analysis for Drinking Water at Ujung Gagak Village, Kampung Laut Subdistrict, Cilacap Regency. *Jurnal Penelitian Pendidikan IPA*, *10*(SpecialIssue), 139–146. https://doi.org/10.29303/jppipa.v10iSpecialIssue.7620

Samsuri, N., Shah, N. A., & Zulkifli, N. (2025). Knowledge, Attitude, And Their Impact On Household Solid Waste Disposal Practices In Selangor line). *Selangor Business Review*, *10*(1), 78–99. http://sbr.journals.unisel.edu.my/ojs/index.php/sbr

Sosiawan, R., Samawi, M. F., & Demmallino, E. B. (2024). The capacity of the ciasem river in the bantargebang integrated waste management site. *Water Conservation & Management*, *8*(4), 389–395. https://doi.org/10.26480/wcm.04.2024.389.395

Supardiono, S., Hadiprayitno, G., Irawan, J., & Gunawan, L. A. (2023). Analysis of River Water Quality Based on Pollution Index Water Quality Status, Lombok District, NTB. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1602–1608.

https://doi.org/10.29303/jppipa.v9i3.4591

Supardiono, S., Rahayu, R. N., Isrowati, I., & Ernawati, E. (2023). Analysis of Water Quality in The Srigangga River Flow, Central Lombok. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 254–259. https://doi.org/10.29303/jppipa.v9iSpecialIssue.6394

Sutanto, H., Prasetyo, D., & Nuraini, A. (2022). Analysis of Ciliwung River water quality based on physical, chemical, and biological parameters. *Jurnal Ilmu Lingkungan*, *20*(3), 215–226. https://doi.org/10.14710/jil.20.3.215-226

UNEP. (2016). *A snapshot of the world's water quality: Towards a global assessment*. United Nations Environment Programme.

Wahyuni, N., & Putra, M. A. (2023). Relationship between community activities and the decline in water quality in the middle section of the Musi River. *Jurnal Penelitian Dan Pengelolaan Lingkungan (Journal of Environmental Research and Management*, *10*(2), 101–112. https://doi.org/10.33005/jppl.10.2.101

Wang, F., Zhang, P., Yan, W., Jia, M., Su, X., Wang, J., & Tian, S. (2023). Riverine organic pollution source and yield from the whole Changjiang river network: Effects of urbanization under changing hydrology. *Journal of Hydrology*, *620*, 129544. https://doi.org/10.1016/j.jhydrol.2023.129544

Yanti, E., Aprihatin, Y., & Armaita. (2024). Analysis of River Environmental Pollution Factors. *Jurnal Penelitian Pendidikan IPA*, *10*(2), 465–470. https://doi.org/10.29303/jppipa.v10i2.6821

Yi, Y., & Li, Z. (2024). The impact of environmental regulation on water resources carrying capacity in the Yangtze River Economic Belt. *Journal of Water and Climate Change*, *15*(7), 3361–3376. https://doi.org/10.2166/wcc.2024.194

Zhang, Z., Hu, B., & Qiu, H. (2022). Comprehensive evaluation of resource and environmental carrying capacity based on SDGs perspective and Three-dimensional Balance Model. *Ecological Indicators*, *138*, 108788. https://doi.org/10.1016/j.ecolind.2022.108788