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Analysis of Non-Point Source (NPS) Pollutant Load and Water Capacity of Bolango River, Gorontalo Province

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Abstract: This study analyzes the non-point source (NPS) pollution load and water carrying capacity of the Bolango River in Gorontalo Province, Indonesia. The river is experiencing water quality degradation due to various human activities, particularly in the upstream and midstream regions. Water samples were collected at six locations along the river during five different periods, with key parameters such as pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate (NO_3), Total Phosphate (TP), and Total Suspended Solids (TSS) measured. A simulation model, Qual2KW Version 5.1, was employed to estimate the river's carrying capacity and validate the pollutant load. Results show that TSS levels frequently exceed regulatory limits, particularly in downstream segments, with the highest concentration recorded at 645 mg/L. BOD and COD levels remained within acceptable limits, although some points demonstrated high values due to agricultural and domestic waste discharge. The findings suggest that pollution control strategies should focus on managing agricultural runoff, domestic wastewater, and solid waste, particularly in critical segments of the watershed. Immediate intervention is needed to address the TSS exceedances and mitigate further environmental degradation. This study provides important insights for developing sustainable watershed management practices for the Bolango River.

Keywords: Carrying capacity; Bolango River; Non-Point Source (NPS); Pollution load

Introduction

Watersheds (DAS) are crucial ecological systems that act as natural basins for collecting, storing, and channeling water and sediments towards a common outlet, such as lakes or seas (F. Lihawa, 2017). These systems, due to their ecological and hydrological significance, provide a structured unit for managing water and related resources. The processes within watersheds are affected by both natural inputs, such as rainfall, and human-induced outputs, such as water discharge. Hydrological processes are key components in watershed ecosystems, and understanding the hydromorphometric characteristics of a watershed is crucial for effective management (Anwar et al., 2011; Ayalew et al., 2024; Getu Engida et al., 2021; Kamaraj et al., 2024; Yin et al., 2023). Human activities, such as land-use changes, have a profound impact on watershed functionality, and addressing these impacts is essential for ensuring sustainable water management (Salote et al. 2022).

The upper region of a watershed, commonly referred to as the headwater, plays a significant role in water retention and distribution. However, its capacity is influenced by land-use patterns, which, if altered, can significantly affect the hydrological response of the watershed (Anwar et al., 2011; Ayalew et al., 2024). These changes can directly impact the quality of water,

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making the monitoring and management of land use a key aspect in watershed management (Hermawan & Wardhani, 2021; Liu et al., 2021; Rodrigues et al., 2018; Scott et al., 2024). Research has shown that agricultural activities contribute to high levels of total phosphorus (TP) in river water, with agricultural land contributing an average of 5.39 kg.ha-1.a-1, which is 1.5 times higher than the contribution from residential land (Min et al., 2022). The impact of non-point source (NPS) pollution is a significant concern globally, as exemplified by studies in China where NPS accounted for up to 81% of nitrogen and 93% of phosphorus pollution (Ongley et al. 2010; Allgeier et al. 2018; Li et al. 2023; Liu et al. 2021; Min et al. 2022). These findings highlight the growing importance of NPS pollution as a critical factor in water quality degradation within watershed ecosystems.

The Bolango River watershed in Gorontalo Province, Indonesia, spans approximately 52,494 hectares and plays a critical role in the region's hydrological and ecological balance (BWS, 2022). Apart from flooding, the Bolango River faces declining water quality due to various human activities. Over the past five years, monitoring by the Gorontalo Provincial Environmental and Forestry Office has revealed that the river's water quality ranges from lightly to moderately polluted. Parameters exceeding the established thresholds include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), *Escherichia coli* (E. coli), and total coliform. In 2022, water quality data indicated BOD levels of 2.35 mg/L, COD levels of 13 mg/L, TSS levels of 156 mg/L, E. coli concentrations of 8,160 MPN/100mL, and total coliform concentrations exceeding 24,200 MPN/100mL (Dinas Lingkungan Hidup dan Kehutanan, 2022). These elevated levels are primarily attributed to untreated wastewater discharges, industrial effluents, and improper solid waste disposal by local communities.

The pollution sources in the Bolango River watershed are diverse, with upstream areas affected by forest conversion into agricultural land, while the central zone is impacted by agricultural activities, industrial waste, and domestic wastewater. Previous studies have indicated that the Bolango River is already under considerable environmental stress. For instance, (Lakoro, 2017) found that the river was heavily polluted, with 18 different genera of macroinvertebrates identified across the Arthropoda, Annelida, and Mollusca phyla, serving as biological indicators of poor water quality. These studies underscore the need for a comprehensive assessment of the watershed's pollution load to determine its pollution carrying capacity. The ability of a river system to absorb pollutants without exceeding water quality standards is critical in maintaining the ecological balance and ensuring the river's capacity to support biodiversity and human activities (Firmansyah et al., 2021).

Research on pollution load and water carrying capacity has been conducted in various watersheds both in Indonesia and globally. However, specific studies focusing on the Bolango River have yet to be carried out. This study seeks to fill that gap by assessing the non-point source pollution load and the water carrying capacity of the Bolango River, providing insights into sustainable watershed management for the region. Non-point source pollution, unlike point-source pollution, is diffuse and arises from multiple land-use activities across the watershed. Such pollution is more challenging to manage, as it is not confined to a single discharge point but spreads across the landscape. Previous studies, such as that by (Min et al., 2022) in the Chaohu River watershed, China, demonstrated the critical role that agricultural land use plays in exacerbating water pollution. They emphasized that addressing land-use patterns is key to mitigating NPS pollution. Similarly, the present study will explore the distribution of NPS pollution in the Bolango watershed, with a focus on land-use variations.

The research will also examine how land-use changes in the Bolango watershed contribute to water quality degradation. For instance, (Bai et al., 2020) demonstrated that changes in land use, particularly agricultural expansion, are strongly correlated with increases in pollutant loads. Similarly, (Zhou et al., 2023) found that agricultural NPS pollution in the Yellow River Basin played a dominant role in determining water quality outcomes, emphasizing the need for targeted land management strategies. Given these findings, this study will assess the land-use patterns within the Bolango watershed and their relationship with the non-point source pollution load, contributing to a broader understanding of how to manage and mitigate the impacts of such pollution on water quality.

In addition to understanding land-use impacts, it is crucial to determine the Bolango River's carrying capacity for pollutants. This involves calculating the maximum allowable pollutant loads that the river can assimilate without compromising water quality standards. (Zuo et al., 2023) highlighted the importance of integrating land-use planning with water quality management, suggesting that by aligning these two aspects, it is possible to reduce the pollution load and enhance a river's ecological health. The Bolango watershed, with its varied land-use patterns and growing anthropogenic pressures, presents a complex case for evaluating the carrying capacity for pollutants. By employing a pollution load model and calculating the river's assimilative capacity, this research aims to provide actionable insights for policymakers to implement sustainable watershed management strategies.

Overall, this research aims to address critical gaps in the understanding of non-point source pollution dynamics and carrying capacity within the Bolango River watershed. By focusing on the specific conditions of the Bolango watershed, this study contributes to a growing body of literature on watershed management in Indonesia. Previous studies have laid the groundwork for understanding the general impacts of land-use changes on water quality (Bai et al., 2020; Zhou et al., 2023), but this research offers a localized perspective that is critical for formulating tailored management strategies. Ultimately, the results of this study are expected to inform decision-making processes regarding land-use management, pollution control, and water resource sustainability in the region.

Given the background discussed, it is essential to undertake a comprehensive analysis of the pollution load from non-point sources and the water carrying capacity of the Bolango River. Such an assessment will provide valuable data for informing water quality management and ensuring the long-term sustainability of the watershed. This research will not only contribute to the existing body of knowledge but will also offer practical solutions for mitigating the impacts of non-point source pollution in the Bolango watershed.

Method

Study Area and Sampling Method

This research was conducted on the Bolango River, located within the Bolango watershed in Gorontalo Province, Indonesia (Figure 1). The sampling method employed is purposive sampling, selected for its suitability in capturing pollutant load variation based on different land-use types across the watershed (Firmansyah et al., 2021). The purposive sampling approach was critical as it allowed for targeted sampling that reflects the influence of various land-use patterns on non-point source (NPS) pollutant loads. The sampling locations were determined by considering ecological and topographical factors, representing forest areas, agricultural land, and residential zones, which are known to contribute differently to NPS pollution.

A total of six sampling sites were selected, strategically positioned to represent the upper, middle, and lower reaches of the Bolango River. These locations were chosen to reflect diverse environmental conditions, including forested areas (upstream), dryland agriculture (midstream), and residential zones (downstream). Sampling was conducted five times at each location to account for temporal variations, ensuring that data collection covered different periods to capture comprehensive pollution trends. The geographical coordinates of each sampling site are detailed in Table 1, while the segment lengths between the sites are also indicated to provide a clearer understanding of the spatial distribution of the sampling locations**.**

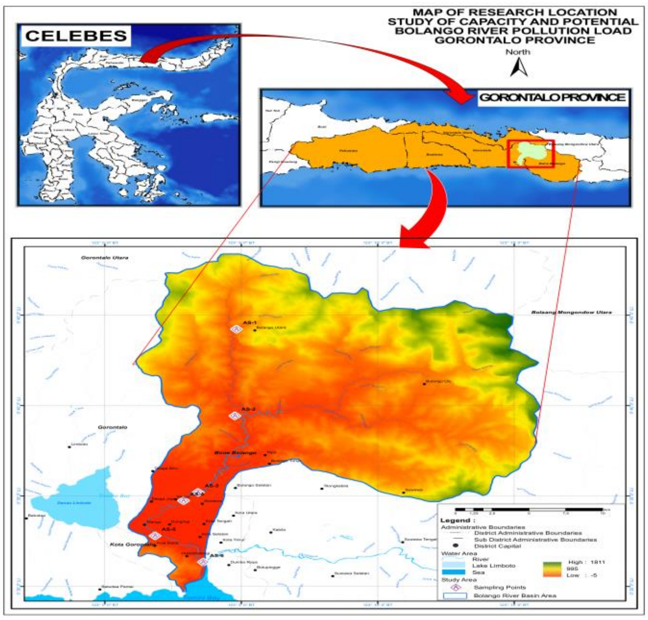


Figure 1. Map of Sampling Point

Table 1. Sample Locations of Bolango River

Code	Location	Coordinat	Length (km)	Land Use
AS-1	Tuloa Village, Bulango Utara District	E: 123°4′27,488″ N: 0°44′ 31,505″	0.00	Forest
AS-2	Bunuo Village, Bulango Utara District	E: 123°4′45,906″ N: 0°39′ 26,295″	15.60	Dryland Agriculture
AS-3	Village Bulotadaa Barat, Sipatana District	E: 123°3′18,986″ N: 0°35′ 13,135″	28.10	Ricefield
AS-4	Hulawa Village, Telaga District	E: 123°2′48,230″ N: 0°34′ 42,488″	29.78	Residential Zone 1
AS-5	Buliide Sub- District, Kota Barat District	E: 123°1′50,447″ N: 0°32′ 48,053″	36.21	Residential Zone 2
AS-6	Tenda Sub- District, Hulondalangi District	E: 123°3′36,608″ N: 0°31′ 20,874″	41.41	Residential Zone 3

Pollution Parameters and Analytical Methods

The pollution parameters analyzed in this study include pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphate (TP), Total Suspended Solids (TSS), and Nitrate (N). These parameters were measured following the water quality standards set by the Indonesian Government Regulation No. 22/2021, Annex VI (Peraturan Pemerintah RI Nomor 22 Tahun 2021 Tentang Perlindungan Dan Pengelolaan Lingkungan Hidup; Lampiran II Tentang Pedoman Penyusunan Formulir Kerangka Acuan, 2021). The parameters were selected based on their relevance to assessing non-point source pollution and their importance in determining the river's water-carrying capacity.

Simulation Model

The Qual2KW Version 5.1 model was used to assess the pollution load and water-carrying capacity of the Bolango River. This model simulates the impact of NPS pollution from various land-use types on river water quality. Based on the simulation results, the river's carrying capacity for pollution was calculated, taking into account local conditions in the Bolango watershed.

Validation of Simulation Results

The validation of the Qual2KW simulation results was performed by comparing the observed concentrations of the pollution parameters with the simulated values. The model's accuracy was evaluated using the Root Mean Square Error (RMSE) criterion. The RMSE is calculated using the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X}_i)^2}{N}} \quad (1)$$

Where:
X_i = Observed values
$\bar{\bar{X}}_i$ = Simulated values
N = Number of observations
An RMSE value of ≤ 1 indicates good model accuracy.

Result and Discussion

Study Site Description

The land morphology of the Bolango watershed (DAS) is predominantly characterized by hilly and undulating terrain. Areas at elevations between 250 and 1,000 meters above sea level (masl) dominate the watershed, covering an area of 31,946.7 hectares, or 66.7% of the total watershed area. These regions are primarily distributed in the Dulamayo and Mongiilo sub-watersheds. Lowland areas, with elevations ranging from 0 to 250 masl, cover 15,915.5 hectares and are found in the lower part of the Bolango watershed. Meanwhile, areas at elevations above 1,500 masl occupy 425.5 hectares, primarily in the upstream sections of the watershed.

The forest area within the Bolango watershed is divided into several categories: protected forests (9,621.56 ha), national parks (22,435.99 ha), other land uses (19,341.75 ha), and limited production forests (514.82 ha). Land use within the watershed includes primary dryland forests (11,032.76 ha), secondary dryland forests (28,067.24 ha), shrubland (5,555.18 ha), settlements (586.53 ha), water bodies (106.83 ha), swamps (0.065 ha), dryland agriculture (507.52 ha), mixed dryland agriculture (3,132.13 ha), and rice paddies (3,475.71 ha). The slope conditions vary, with flat terrain (0–8%) covering 5,202 ha, gently sloping areas (>8–15%) covering 624 ha, hilly terrain (>15–25%) covering 178 ha, and steep slopes (>25%) covering 45,910 ha.

Table 2 provides an overview of the conditions at each sampling location, including segment length, distance from the downstream section, elevation, discharge, depth, and flow velocity.

Table 2. Description of Sampling Locations

Sample Point	Segment Length (km)	Distance from Downstream (km)	Elevation (masl)		Discharge (m3/s)	Depth (m)	Flow Velocity (m/s)
			Upstream	Downstrean			
AS-1	0	0		183	2.51	0.633	0.441
AS-2	15.60	7.80	183	41	2.68	0.3	0.439
AS-4	12.50	21.85	41	15	6.56	0.583	0.013
AS-5	1.68	28.94	15	15	6.58	3.0	0.692
AS-6	6.43	33.0	15	10	6.60	3.67	0.351
AS-7	5.20	38.81	10	5	6.61	3.67	0.446

Bolango River water quality

The pollution load analysis of non-point source (NPS) pollution in the Bolango River was conducted at six sampling locations. Water samples were collected in five different time periods to account for temporal variation. The parameters analyzed included pH, Biological Oxygen Demand (BOD), Chemical Oxygen

Demand (COD), Nitrate (NO_3), Total Phosphate (TP), and Total Suspended Solids (TSS).

Table 3. Water Quality Analysis of Bolango River

Parameter	Unit	Analysis Results							Quality Standard
		AS-1	AS-2	AS-3	AS-4	AS-5	AS-6	AS-7	
pH									
Sampling 1	-	6,5	7	6,5	5,5	6,5	5,5	6,5	6-9
Sampling 2	-	6.5	7	6.5	6.5	7	5.5	6.5	
Sampling 3	-	6.8	6.7	6.7	7	6.5	6.5	6.7	
Sampling 4	-	7.5	7.5	6.9	6.5	6.5	6.5	6.7	
Sampling 5	-	6.5	7	6.5	5.5	6.5	5.5	6.5	
Min		6.5	6.7	6.5	5.5	6.5	5.5	6.5	
Max		7.5	7	6.9	7	7	6.5	6.7	
BOD									
Sampling 1	mg/l	1,0	1,03	1,07	1,08	1,11	1,13	1,14	3
Sampling 2	mg/l	1.02	1.03	1.08	1.08	1.12	1.13	1.13	
Sampling 3	mg/l	0.99	1	1.06	1.08	1.11	1.17	1.2	
Sampling 4	mg/l	0.96	1.01	1.03	1.03	1.07	1.21	1.27	
Sampling 5	mg/l	1.21	1.25	1.31	1.43	1.59	1.64	1.65	
Min		0.96	1	1.03	1.03	1.07	1.13	1.13	
Max		1.21	1.25	1.08	1.43	1.59	1.64	1.65	
COD									
Sampling 1	mg/l	3,71	3,15	3,68	3,61	3,50	3,57	3,71	25
Sampling 2	mg/l	5.84	5.84	5.94	5.84	5.84	6.51	6.51	
Sampling 3	mg/l	4.70	4.42	4.49	5.13	5.13	5.13	5.23	
Sampling 4	mg/l	9.24	9.13	9.41	8.53	8.24	9.50	9.69	
Sampling 5	mg/l	9.16	9.09	9.73	8.49	8.17	9.27	9.58	
Min		3.71	3.15	3.68	3.61	3.50	3.57	3.71	
Max		9.24	9.13	9.73	8.53	8.24	9.50	9.69	
Total Phosphate									
Sampling 1	mg/l	0.17	0.19	0.19	0.19	0.19	0.19	0.19	0.2
Sampling 2	mg/l	0.07	0.09	0.09	0.10	0.11	0.11	0.11	
Sampling 3	mg/l	0.07	0.07	0.08	0.08	0.08	0.09	0.08	
Sampling 4	mg/l	0.05	0.07	0.07	0.09	0.09	0.09	0.1	
Sampling 5	mg/l	0.17	0.19	0.19	0.19	0.19	0.19	0.19	
Min		0.05	0.07	0.07	0.08	0.08	0.09	0.08	
Max		0.17	0.19	0.19	0.19	0.19	0.19	0.19	
TSS									
Sampling 1	mg/l	55	15	58	265	172	77	49	50
Sampling 2	mg/l	69	14	68	283	196	108	60	
Sampling 3	mg/l	78	11	72	301	216	145	104	
Sampling 4	mg/l	88	49	77	316	249	158	111	
Sampling 5	mg/l	97	645	85	395	298	194	120	
Min		55	11	58	265	172	77	49	
Max		97	645	85	395	298	194	120	
Nitrate									
Sampling 1	mg/l	1,08	1,14	1,18	1,18	1,27	1,12	1,59	10
Sampling 2	mg/l	4.95	5.29	4.98	5.21	5.22	5.15	5.09	
Sampling 3	mg/l	4.95	5.04	4.79	4.81	4.97	4.74	5.21	
Sampling 4	mg/l	6.14	5.95	5.94	5.56	5.86	5.40	4.89	
Sampling 5	mg/l	5.35	5.58	5.59	5.55	5.59	5.45	5.61	
Min									
Max									

Source: laboratory analysis results, 2024
Description: Surface Water Quality Standards (Class II), PP Number 22/2021 Attachment VI

pH Levels

The pH measurements ranged from 5.5 to 7.5 across the seven sampling locations. All values remained within the acceptable range of 6 to 9, as established by the Indonesian Government Regulation No. 22/2021. The lowest pH values were recorded at AS-4 and AS-6

(5.5) during the first and fifth sampling rounds, indicating potential acidification in these locations. The highest pH values were observed at AS-1 and AS-2 (7.5) during the fourth sampling. These variations may be attributed to biological activities such as the decomposition of organic matter or domestic and industrial pollution.

The results of the pH pollutant load simulation in the Bolango River are shown in Figure 2.

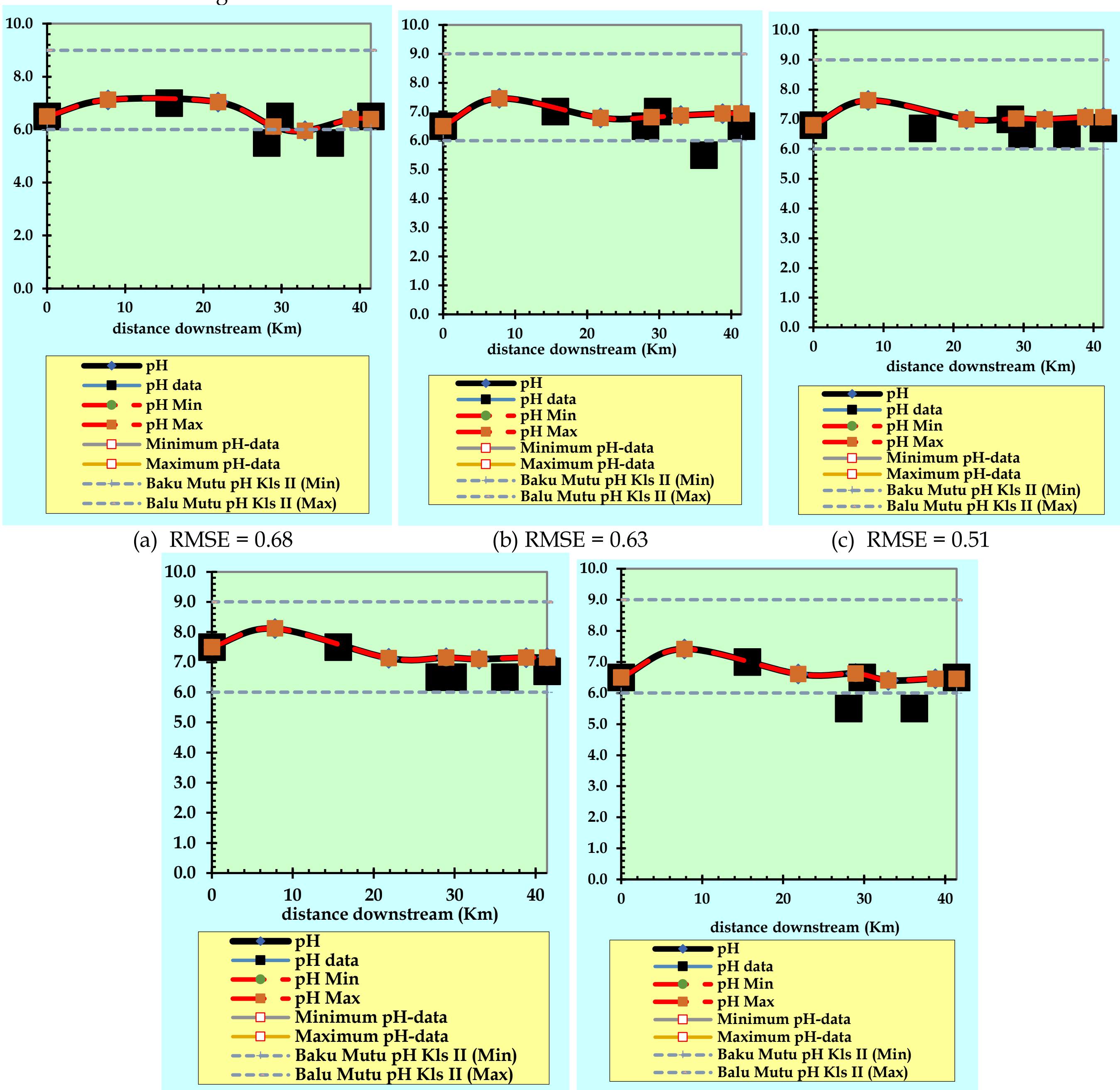


Figure 2. Distribution of pH of Bolango River from upstream to downstream; (a) Sampling 1; (b) Sampling (2); (c) Sampling 3; (d) Sampling 4; (e) Sampling 5

BOD (Biochemical Oxygen Demand)

BOD levels across all sampling locations ranged from 0.96 to 1.65 mg/L, significantly below the threshold of 3 mg/L. AS-7 exhibited the highest BOD concentration (1.65 mg/L) during the fifth sampling, likely due to heightened microbial activity at this location. In contrast, AS-4 demonstrated relatively stable BOD levels with minimal variation, suggesting more consistent water conditions. While all BOD values were below the permissible limit, elevated levels at specific sites warrant further monitoring, especially during the rainy season when pollutant runoff is more likely (Zuo et al. 2023; Elida et al. 2020; Mqingwana et al. 2024; Tisnasuci et al. 2021).

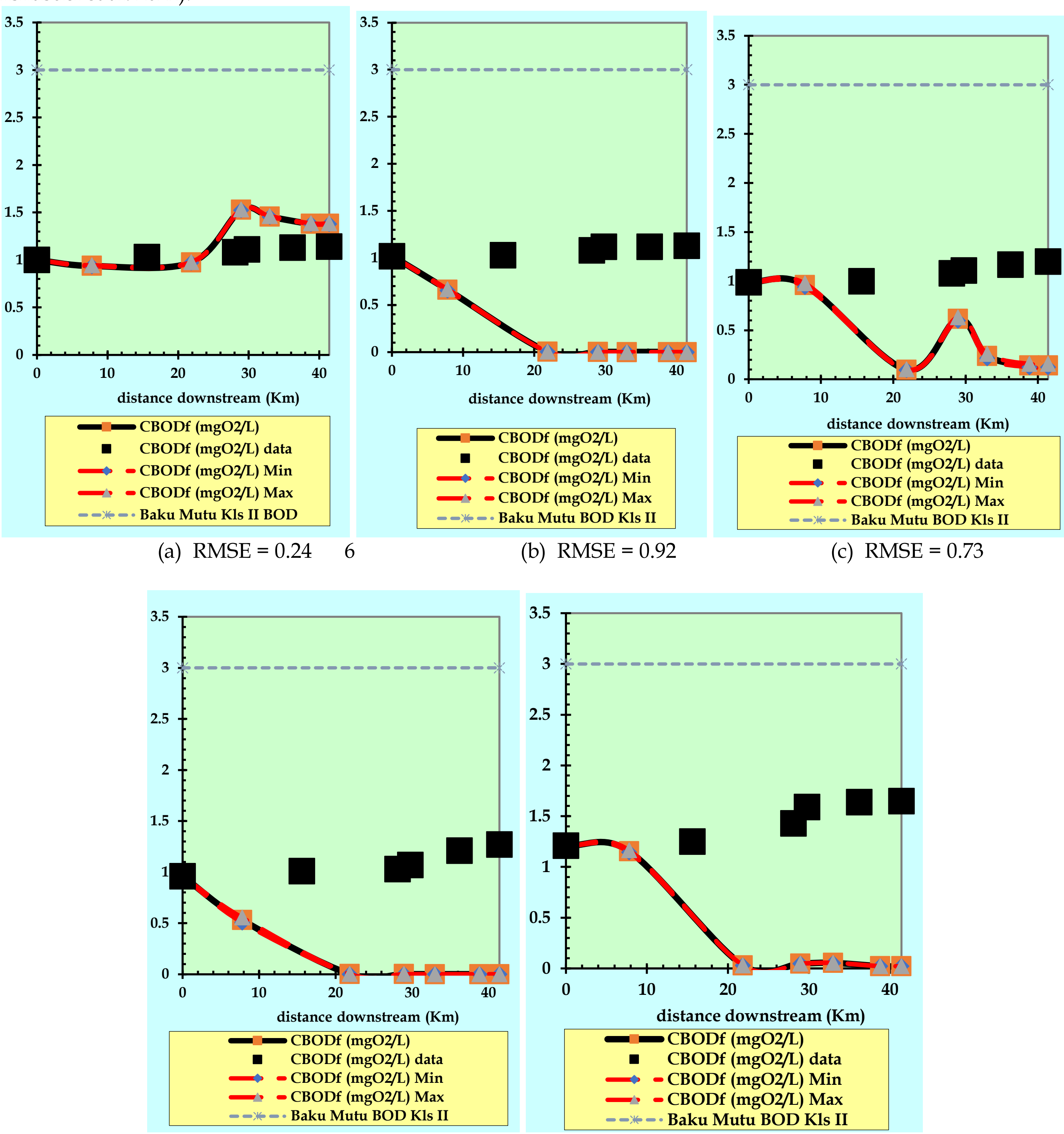


Figure 2. Distribution of pH of Bolango River from upstream to downstream; (a) Sampling 1; (b) Sampling (2); (c) Sampling 3; (d) Sampling 4; (e) Sampling 5

COD (Chemical Oxygen Demand)

COD values displayed notable variation, ranging from 3.15 to 9.73 mg/L across the sampling locations. All COD measurements remained below the permissible limit of 25 mg/L; however, high COD concentrations were recorded at AS-5 and AS-6 (up to 9.69 mg/L), suggesting significant inputs of organic or non-biodegradable pollutants, possibly from domestic or agricultural activities in the surrounding areas (Min et al., 2022). The spatial variation of COD levels is shown in **Figure 3**, with RMSE values ranging from 0.26 to 0.85, indicating some discrepancies between the observed and simulated values.

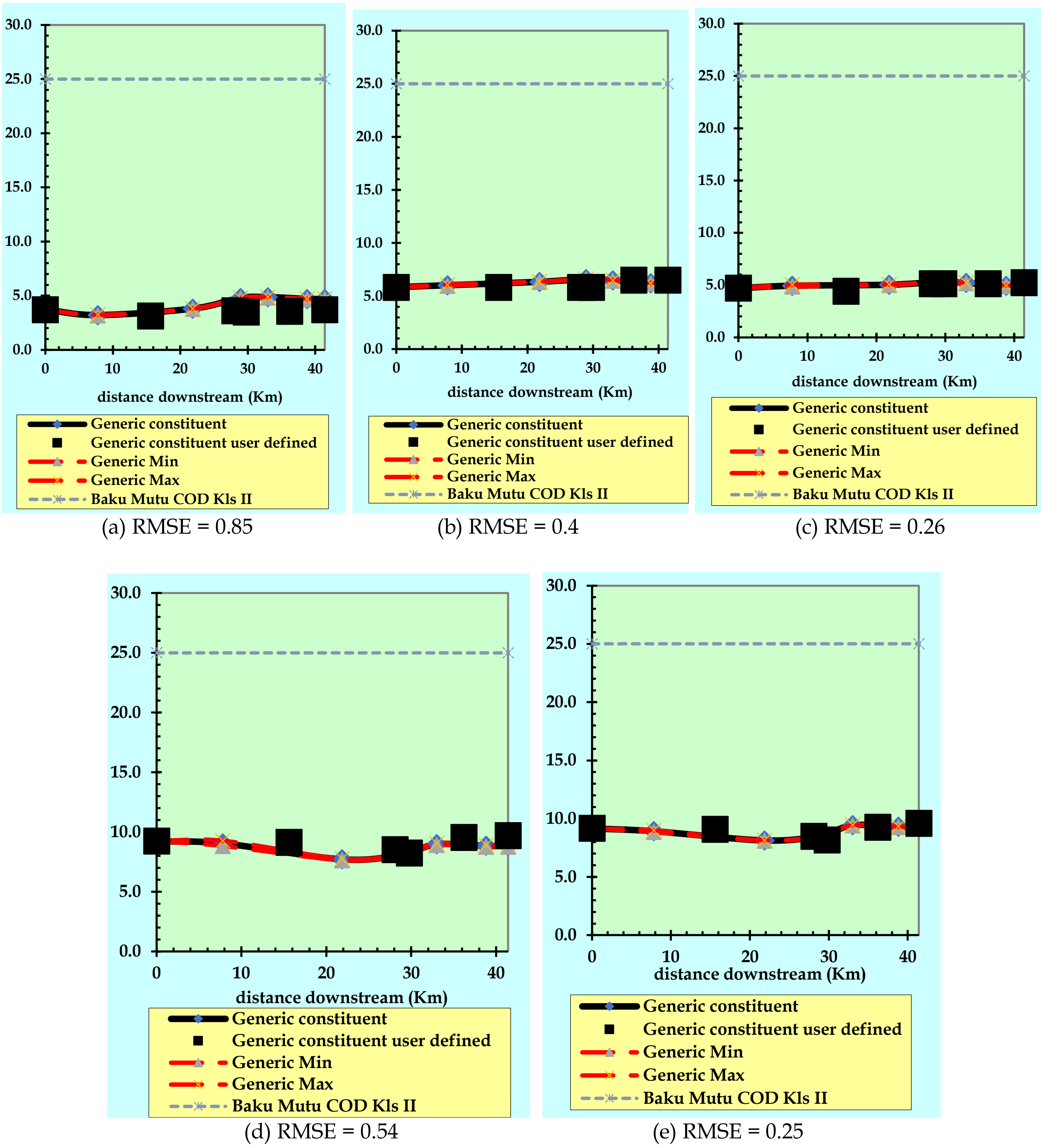


Figure 3. Distribution of COD in the Bolango River from upstream to downstream; (a) Sampling 1; (b) Sampling (2); (c) Sampling 3; (d) Sampling 4; (e) Sampling 5

Total Phosphate (TP)

Phosphate concentrations ranged between 0.05 and 0.19 mg/L, with most sites approaching the regulatory threshold of 0.2 mg/L. The maximum TP concentrations (0.19 mg/L) were observed at AS-1 and AS-2 across multiple sampling periods. The elevated phosphate levels are likely due to agricultural runoff containing fertilizers or untreated domestic wastewater, which can lead to eutrophication in the river (Bai et al., 2020). Given the potential negative impacts of phosphate accumulation on the aquatic ecosystem, it is essential to implement strategies to control phosphate pollution from agricultural and domestic sources. The distribution of TP concentrations along the river is illustrated in **Figure 4**, with RMSE values ranging from 0.37 to 1.52, reflecting the varying accuracy of the model.

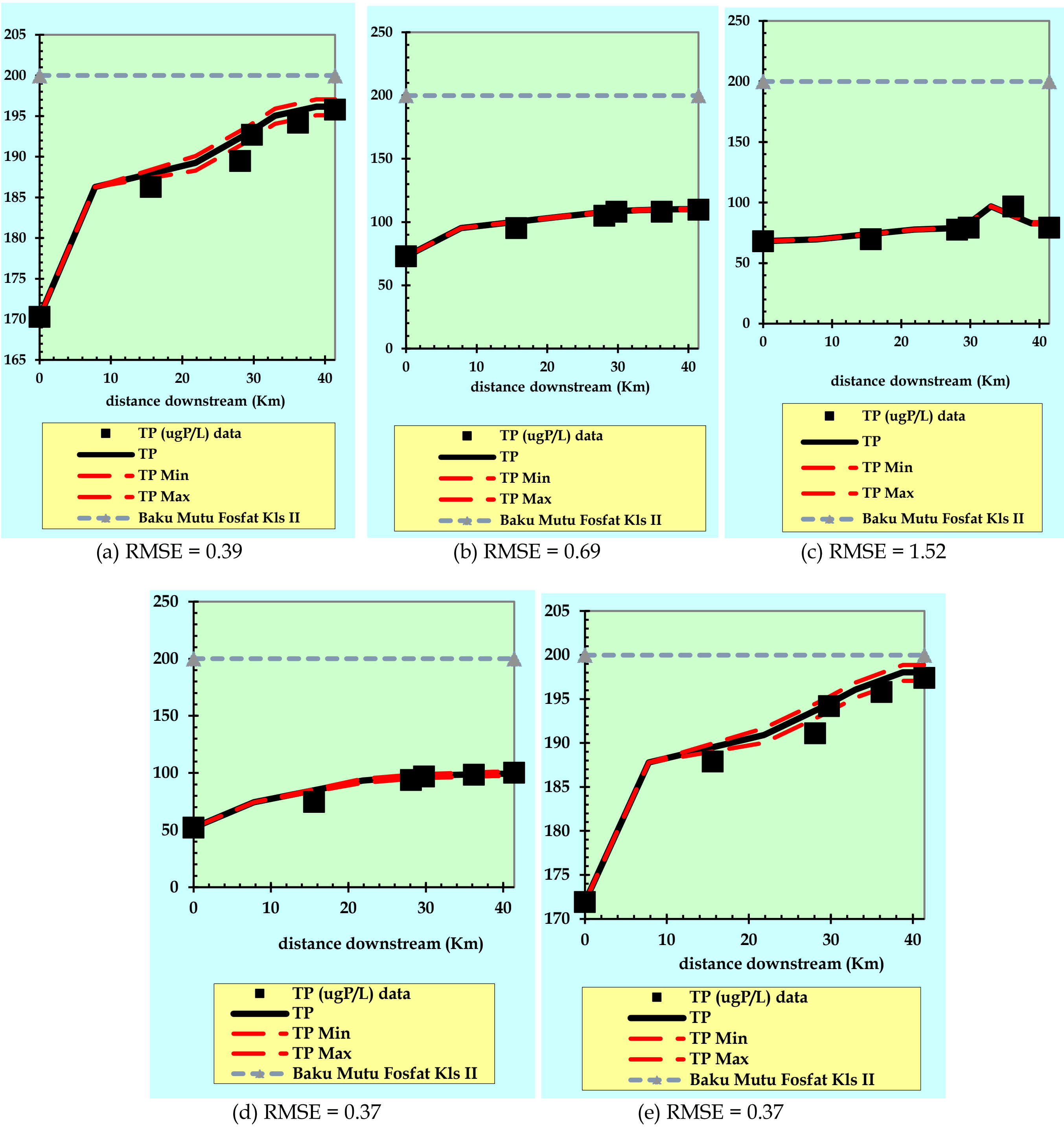
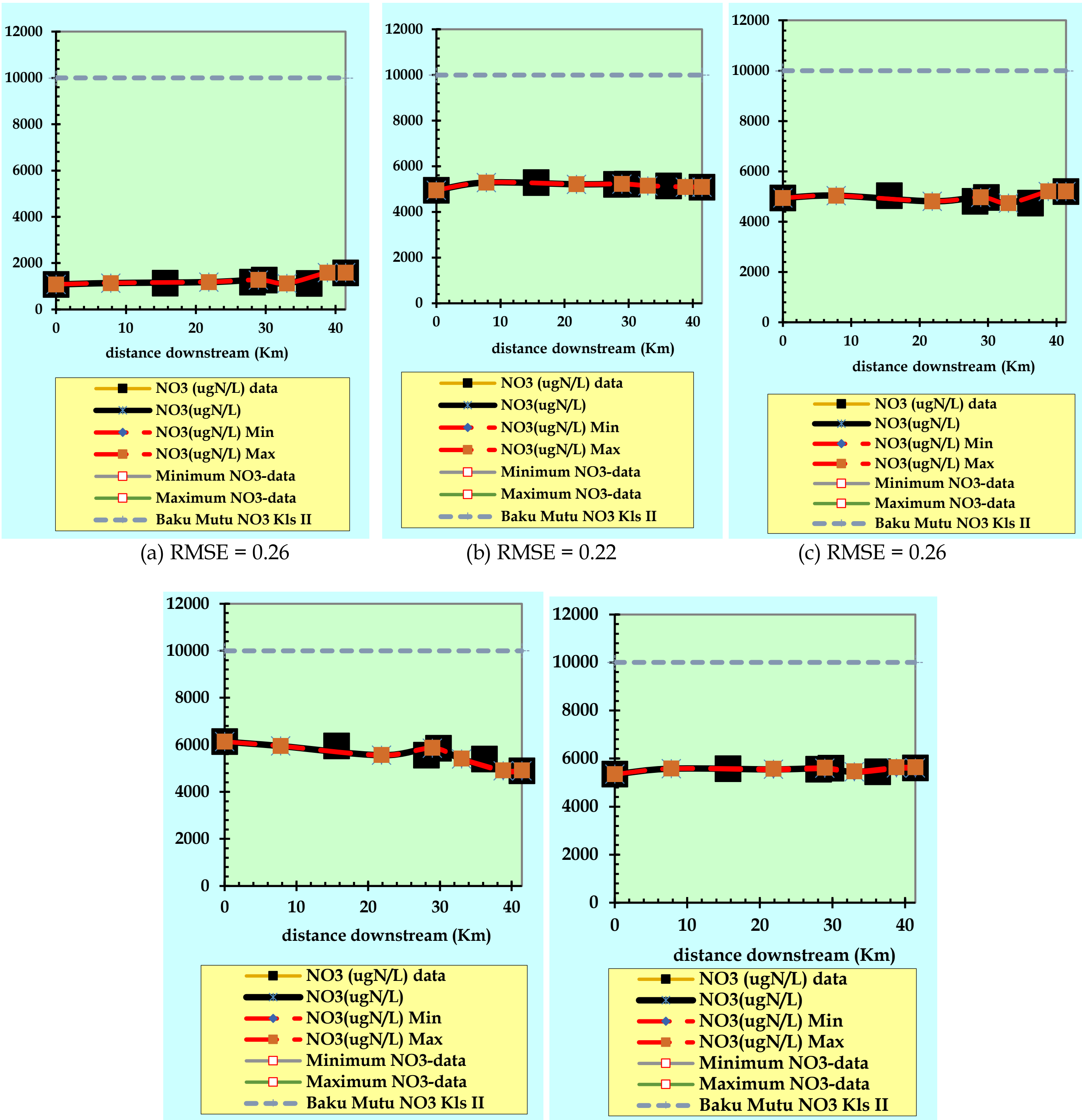


Figure 4. Distribution of Total Phosphate (TP) of the Bolango River from upstream to downstream; (a) Sampling 1; (b) Sampling (2); (c) Sampling 3; (d) Sampling 4; (e) Sampling 5

Nitrate (NO_3)

Nitrate concentrations in the river ranged from 1.08 to 6.14 mg/L, with the highest value recorded at AS-1 during the fourth sampling period. Although the nitrate levels remained below the regulatory limit of 10 mg/L, significant variability was observed, particularly at AS-4 and AS-5. This suggests the presence of substantial nitrate sources, likely from agricultural runoff or domestic wastewater discharges (Ayalew et al. 2024; Yudhistira et al. 2017; Zhang et al. 2022; Zhou et al. 2023). Excessive nitrate levels can contribute to eutrophication and may pose a risk to aquatic ecosystems, especially in downstream sections. **Figure 5** shows the spatial distribution of nitrate concentrations, with RMSE values between 0.22 and 0.67.



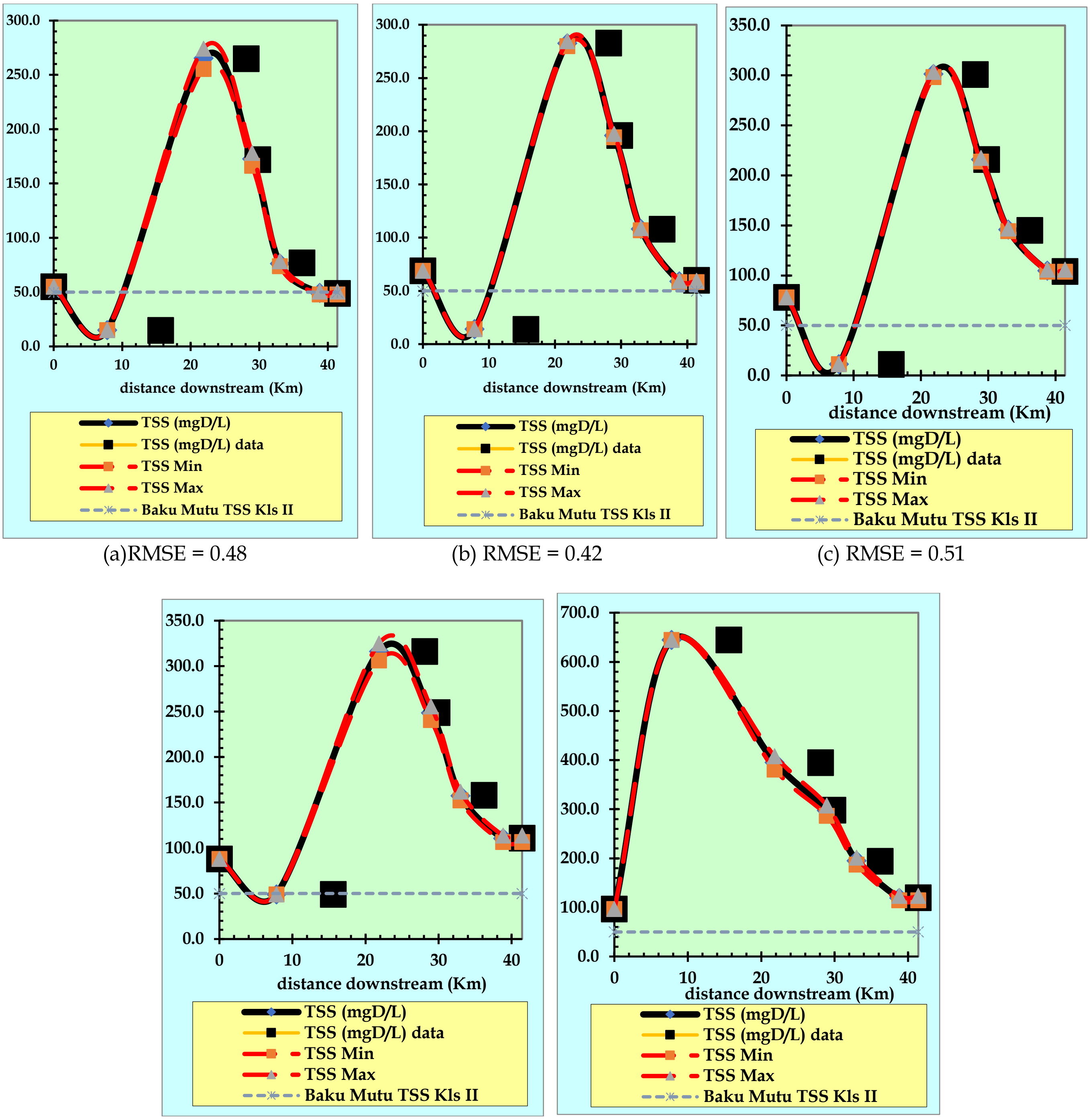
(a) RMSE = 0.26 (b) RMSE = 0.22 (c) RMSE = 0.26

(d) RMSE = 0.35 (e) RMSE = 0.67

Figure 4. Distribution of Nitrate in the Bolango River from upstream to downstream; (a) Sampling 1; (b) Sampling (2); (c) Sampling 3; (d) Sampling 4; (e) Sampling 5

Total Suspended Solids (TSS)

TSS concentrations exhibited the most significant variation, ranging from 11 to 645 mg/L. The highest TSS value (645 mg/L) was observed at AS-2 during the fifth sampling period, greatly exceeding the regulatory limit of 50 mg/L. Elevated TSS levels at AS-2, AS-4, and AS-5 indicate considerable sedimentation, likely resulting from soil erosion and surface runoff during the rainy season. High TSS levels can reduce light penetration, adversely affecting aquatic photosynthesis, and may transport additional pollutants, such as heavy metals or organic compounds (F. Lihawa, 2017). The spatial distribution of TSS is presented in **Figure 6**, with RMSE values between 0.33 and 0.51.



(a)RMSE = 0.48 (b) RMSE = 0.42 (c) RMSE = 0.51

(d) RMSE = 0.33 (e) RMSE = 0.47

Figure 5. Distribution of TSS of Bolango River from upstream to downstream; (a) Sampling 1; (b) Sampling (2); (c) Sampling 3; (d) Sampling 4; (e) Sampling 5

Potential Pollutant Load

The analysis of potential pollutant loads in the Bolango River identified that the solid waste management and domestic wastewater sectors were the largest contributors to the total pollution load. Solid waste management accounted for 40.93% of the pollution load, while domestic wastewater contributed 26.71%. These findings suggest that pollution management strategies should prioritize improvements in domestic wastewater management and the reduction of solid waste entering the river. Table 4 summarizes the total potential pollutant load of the Bolango River, emphasizing the importance of managing both agricultural and domestic waste sources.

Table 4. Total Potential Water Pollution Load of Bolango River

Parameter						Pollution Load (kg/day)			Total Pollution Load (kg/day)
	Dry Land	Plantation	Ricefield	Waste	Domestic Waste	Farm	Hospital	Fishery	
BOD	6.78	8.12	864.61	92.33	319.26	3,064,292.36	19.07	52,538	3,470.31
COD	10.17	12.18	788.09	126.95	4,389.82	7,568,489.44	26.21	115688	-
Nitrate	0.54	0.66	1.07	-	0.80	31,113.56	-	-	677.04
Total Phosphate	0.27	0.37	23.35	-	16.76	2,146.28	-	-	187.82
TSS	0.13	0.40	1.07	87.71	3,032.96	-	131.75	84000	-

Pollution Load Capacity of Bolango River

The carrying capacity analysis for key pollutants, including BOD, COD, TP, TSS, and nitrate, revealed that TSS levels exceeded the river's capacity in all segments, necessitating urgent intervention. Soil erosion control and waste management improvements are critical for addressing these issues. The carrying capacity results highlight the need for targeted strategies to manage the pollution from anthropogenic activities and mitigate further environmental degradation (Ariani et al. 2021; Firmansyah et al. 2021; Lihawa 2009; Maulana, Lihawa, and Maryati 2020; Wang et al. 2023; Xu et al. 2024).
Table 5 provides the calculated pollutant load and carrying capacity for each segment of the Bolango River. The analysis indicates that the river's capacity to assimilate TSS is significantly exceeded, particularly in downstream sections.

Table 5. Pollution Load Capacity of Bolango River

Parameter	Quality Standards (mg/l)	Average Concentration (mg/l)	Average Discharge (l/second)	Conversion Factor	Maximum Pollution Load (kg/day)	Measured Pollution Load (kg/day)	Pollution load capacity (kg/day)
BOD	3	1.155	8891.429	0.0864	2305	3121610.33	-3119306
COD	25	6.537	8891.429	0.0864	19205	7689530.36	-7670325
Total Phosphate	0.2	0.128	8891.429	0.0864	154	2374.85	-2221
TSS	50	151.37	8891.429	0.0864	38411	87254.03	-48843
Nitrate	10	4.499	8891.429	0.0864	7682	31793.68	-24111

Conclusion

Overall, the water quality of the Bolango River remains within acceptable limits for most parameters, according to national water quality standards. However, significant exceedances of the regulatory limits were observed for TSS, especially in downstream segments. The findings underscore the importance of managing pollution sources, particularly from agricultural and domestic activities, to preserve water quality and prevent further degradation. Improving waste management and implementing erosion control measures within the watershed should be prioritized to protect the river's aquatic environment

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Author Contributions
Author Yetti Mosi as the initiator of the research idea. Fitryane Lihawa played a role in data analysis. Iswan Dunggio played a role in river basin analysis and Fery Novrizal played a role in map making.

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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.

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