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RESEARCH ARTICLE

THE CAPACITY OF THE CIASEM RIVER IN THE BANTARGEBANG INTEGRATED WASTE MANAGEMENT SITE

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ABSTRACT

The annual increase in waste at the Bantargebang Integrated Waste Management Site (IWMS) is proportionally related to leachate produced. The Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) in the Ciasem River in 2018 exceeded the water quality standards, showing the incapacity to accommodate further pollution. Therefore, this research aimed to assess capacity of the Ciasem River as the receiving water body for Integrated Wastewater Treatment Plant (IWTP) using capacity analysis based on mass balance. The results showed that the temporal water quality has been polluted since 2019 and was projected to continue until 2023, particularly regarding BOD, COD, Total Suspended Solid (TSS), and Total Nitrogen (N-Total). Spatially, high concentrations of BOD, COD, and TSS were observed upstream of the Ciasem River and increased in outfall of IWTP. At the confluence of the Cikeuting River with the Ciasem River, the concentrations of BOD, COD, and TSS showed significant changes due. Although the high concentrations of BOD and COD suggested organic matter decomposition through biological and chemical processes, there was significant no reduction in acidic pH, resulting in low toxicity for Mercury and Cadmium. These results showed that the Ciasem River has lost its capacity, particularly regarding BOD, COD, TSS, and Total Nitrogen, persisting from 2019 until 2023.

KEYWORDS

Capacity, Bantargebang landfill, municipal waste management, leachate

1. INTRODUCTION

Solid waste management in developing countries' metropolitan regions has become a challenge for large cities seeking to create sustainable, healthy, and inclusive cities and communities for all (Derdera and Ogato, 2023; Li et al., 2022). Solid waste management generates an estimated 1.6 billion tons of carbon dioxide equivalent (CO2-equivalent) greenhouse gas emissions, accounting for approximately 5% of total global emissions (Gunarathne et al., 2024; Kaza et al., 2018). The World Bank estimates that annual worldwide solid waste generation is over 2.24 million metric tons, indicating a per capita growth or a footprint of about 0.79 kg per person daily (Kaza et al., 2018). This condition will present considerable challenges to city governments responsible for controlling solid waste. Solid waste generation is a byproduct of human civilization, with the majority resulting from social and economic activity (Dangi et al., 2023; Derdera and Ogato, 2023).

Today's issues in managing Municipal Solid Waste (MSW) include collection, sorting, transportation, and disposal (Li et al., 2022; Mokhtari and Salemi, 2023). However, the final disposal location, often known as the landfill site, is the most challenging issue confronting metropolitan populations since it affects the microenvironment, public health, and groundwater (Anand et al., 2021; Gunarathne et al., 2024). The final disposal and management of MSW is a significant burden that large cities, such as Jakarta, the capital of the Republic of Indonesia, must bear.

A total of 8,509.18 tonnes/day of waste was generated by DKI Jakarta Province in 2022, according to the data from the (Ministry of Environment and Forestry, 2023). Approximately 1,000 tonnes/day of this waste has been managed by the community and the Jakarta Provincial Environmental Service (DLH DKI Jakarta Province), while the remaining 7,500 tons/day were transported to the Bantargebang Integrated Waste Management Site (IWMS) located in Bekasi City. Waste processing at the Bantargebang IWMS uses the landfill mining method, where waste entering the facility is stacked in predetermined active zones (Kumar et al., 2021).

In the processing and final treatment at the Bantargebang IWMS, various types of liquid waste are generated, including domestic wastewater, wash water from truck cleaning, and leachate. Domestic wastewater such as feces is directed to septic tanks, while grey from washing and kitchen activities is channeled to the Sewage Treatment Plant (STP) equipped with a biofilter system. The treated water is reused for truck wash purposes and leachate is processed at the Integrated Wastewater Treatment Plant (IWTP) in the Bantargebang IWMS. Currently, there are three IWTP units, namely IWTP 1, 2, and 3 with capacity of 200 m^3, 70 m^3, and 200 m^3, respectively. These three IWTP have outlets that flow into the Ciasem River through Zone II (inactive/landfill zone) and Zone III (new waste reception zone) from south to north. Furthermore, the Bantargebang IWMS is also crossed by the Cikeuting River flowing from west to north through landfill mining Zone IV (RDF) and Zone V (inactive/landfill zone) joining the Ciasem River to the north of the Bantargebang IWMS.

Leachate is one of the primary issues associated with landfill operations, posing a substantial hazard to rivers in the waste disposal area (Abedi et al., 2023; Czatzkowska et al., 2023). Leachate is a highly hazardous liquid waste resulting from the entry of external water into waste, flushing, and dissolving the materials present in landfill (Hanafiah, 2023; El-Saadony et al., 2023; Mohammed et al., 2023). Specifically, leachate from landfill sites contains organic and inorganic chemical compounds as well as several pathogenic bacteria, that can impact human health, pollute the

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environment, and affect aquatic biota. Additionally, it contains ammonia, lead, and parasitic microorganisms such as water fleas capable of causing skin itching (El-Saadony et al., 2023; Farsad et al., 2023; Gunarathne et al., 2024). Rainwater seeping through the landfill body, as well as physical, chemical, and biological processes occurring within the landfill body, are the primary causes of leachate formation. The difficulties caused by the presence of leachate have long-term consequences; even several years after the landfill was closed, leachate production was still recorded (Podlasek et al., 2023).

This analysis stated that the concentrations of BOD and COD in the Ciasem River in 2018 exceeded the quality standards (Kurniasari and Aprianti, 2020). The pollution index showed a moderately polluted status that worsened downstream reaching a heavily polluted state. This progression suggested that river had reached capacity to accommodate additional waste. Moreover, essential parameters used to determine water quality and the water-holding capacity of the Ciasem River refer to the Minister of Environment and Forestry Regulation of the Republic of Indonesia Number P.59/Menlhk/Setjen/Kum.1/7/2016. This regulation focuses on Leachate Quality Standards for Waste Processing Facilities and Activities, which include pH, BOD5, COD, TSS, N-Total, Mercury, and Cadmium (Farsad et al., 2023). The annual increase in waste conditions has contributed to more leachate discharge, along with other input loads into the Ciasem River. Therefore, this research aimed to assess water quality and capacity of the Ciasem River to accommodate leachate pollutants from the Bantargebang IWMS. The results are expected to serve as recommendations for sustainable management, specifically for the Ciasem River and Bantargebang IWMS.

2. Research Methods

2.1 Research Location

This research was conducted in November-December 2023 at the upstream area of the Ciasem River, the points where effluent from each IWTP enters river (Outfall), as well as the confluence of the Ciasem River and the Cikeuting River. The locations and research stations are shown in Figure 1 and Table 1.

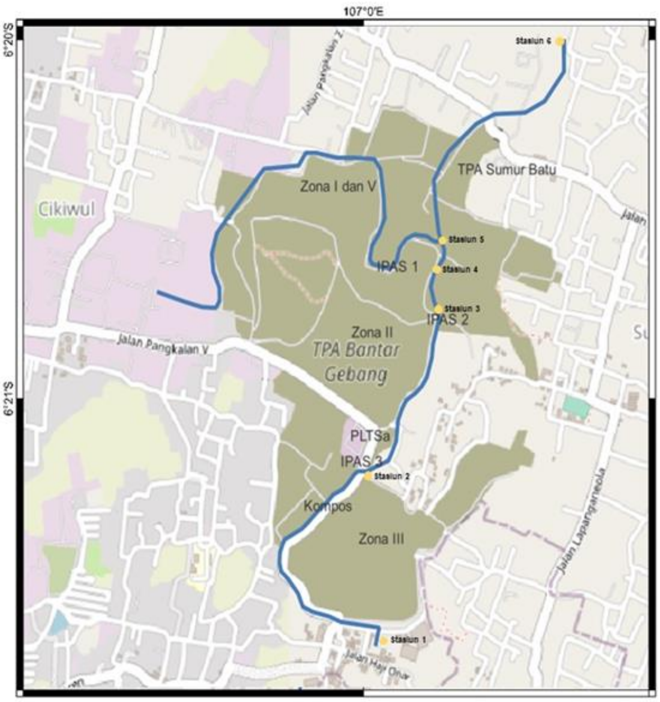


Figure 1: Locations and Research Stations

Table 1: Water Quality measurement station

No	Station	Location	Description
1	Station 1	Upstream of the Ciasem River	influence of activities upstream of the Ciasem River, preceding the Bantargebang IWMS
2	Station 2	IWTP Outfall 3	influence of leachate processing from IWTP 3
3	Station 3	IWTP Outfall 2	influence of leachate processing from IWTP 2
4	Station 4	IWTP Outfall 1	influence of leachate processing from IWTP 1
5	Station 5	The confluence of the Cikeuting River and the Ciasem River	The effect of the meeting of two different bodies of water

2.2 Data Collection

The secondary data used in this research included monitoring report carried out by the Bantargebang IWMS from 2019-2023.

2.3 Data Analysis

Water quality analysis of the Ciasem River was conducted by comparing the data collected with quality standards according to Government Regulation Number 22 of 2021 (Annex VI, Class 2). Capacity analysis was carried out using calculations of the pollution load capacity as stated in the Minister of State for the Environment's Decision Number 110 of 2003. However, the pollution load capacity can be determined using the mass balance method. This entails using a mathematical model to calculate the average downstream concentration originating from point and non-point sources of pollution. Furthermore, the calculation can be used to determine the percentage change in flow rate or pollutant load. In cases where several flows converge to produce a final flow, or when the quantity of water and the mass of constituents are calculated separately, a mass balance analysis is required to determine the quality of the final flow through calculations.

$$CR = \frac{(\Sigma C_i Q_i)}{\Sigma Q_i} = \frac{\Sigma M_i}{\Sigma Q_i}$$

Description:

CR = average concentration of constituents for the combined flow

Ci = constituent concentration in the i-th stream

Qi = flow rate of the stream i

Mi = Mass of a constituent in flow i

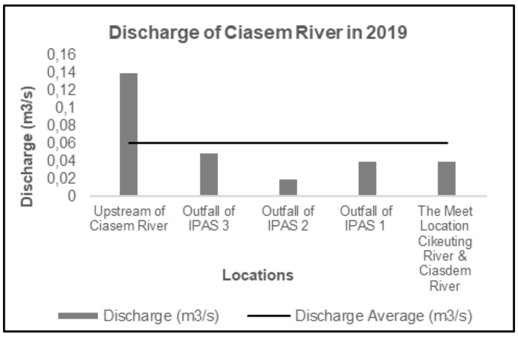
3. Results and Discussion

3.1 The Ciasem River at the Bantargebang IWMS

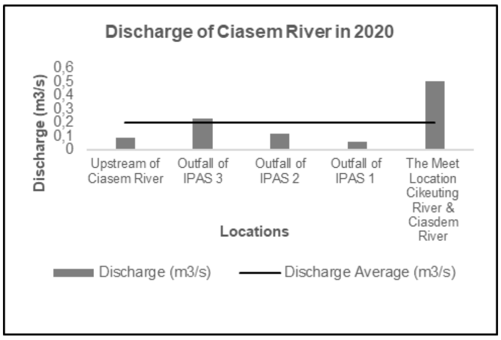
The Ciasem River is located within the Bantargebang IWMS area, flowing through Zone II (inactive/landfill zone) and Zone III (new waste reception zone) from the south to the Bekasi River in the north, after joining the Cikeuting River. Based on secondary data obtained from discharge measurements from 2019 to 2023, the Ciasem River discharge during the period is as follows:

Table 2: The Ciasem River Discharge

Location	Debit (m^3/s)					
	2019	**2020**	**2021**	**2022**	**2023**	**Rata-Rata**
Upstream of the Ciasem River	0,14	0,09	0,018	0,425	0,59	0,25
IWTP Outfall 3	0,05	0,23	0,04	0,088	0,74	0,23
IWTP Outfall 2	0,02	0,12	0,0825	0,311	0,28	0,16
IWTP Outfall 1	0,04	0,06	0,164	0,418	1,11	0,36
Meeting of S. Cikeuting & S. Ciasem	0,04	0,5	0,02	0,911	0,9	0,47
Average	**0,06**	**0,20**	**0,06**	**0,43**	**0,72**	**0,30**



(a)



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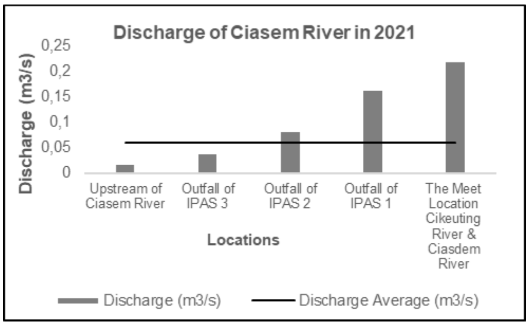

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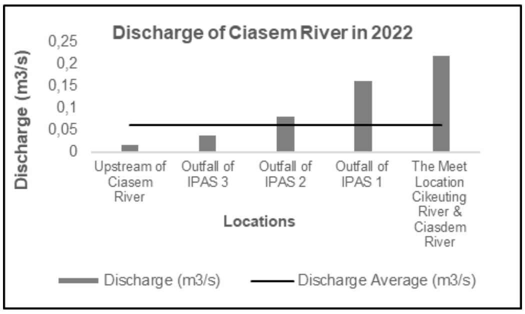

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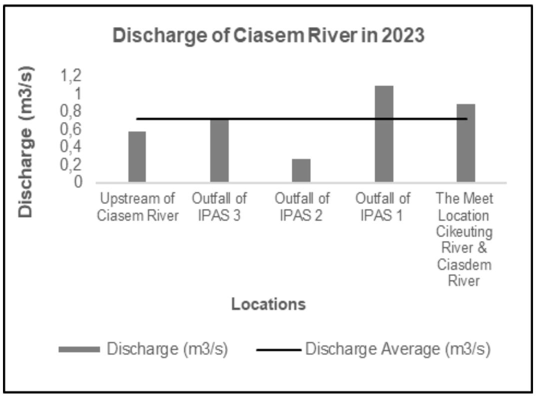

(e)

Figure 2: The Ciasem River Discharge (a) 2019, (b) 2020, (c) 2021, (d) 2022, (e) 2023

The table and graph above show significant fluctuation, specifically in the years 2019 and 2020. Discharge can be calculated using the Bernoulli or the continuity equation, where discharge value is obtained by multiplying the wetted cross-sectional area (the width of river multiplied by the depth) and the flow velocity (Asdak, 2007; Kahn and Salgo, 2014). In 2019, there was a general decrease in discharge due to the influence of waste landslides that reduced the wetted cross-sectional area, leading to river water overflowing onto the roads in the Bantargebang IWMS area. Additionally, these landslides decelerated the flow and provided an opportunity for evaporation, where measurements were taken during the dry season. In 2020, the Bantargebang IWMS made significant improvements, although there were still waste landslides, specifically upstream of the Ciasem River. However, total discharge increased, with substantial input from the Cikeuting River. From 2021 to 2022, there was an increase in discharge along with the input of non-point sources leachate, merging with the Cikeuting River to the north of the Bantargebang IWMS. Furthermore, the discharge of the Ciasem River around the Bantargebang IWMS in 2023 increased, except in the Outfall of IWTP 2, due to the continuous waste landslides. Since 2019, IWTP 1, 2, and 3, which are pollution control devices for leachate from the Bantargebang IWMS, have not been functioning. This is because IWTP 1 and 2 have been buried by waste piles, while IWTP 3 is under renovation between 2022-2023. Consequently, leachate has entered directly through non-point sources into the Ciasem River within the Outfall of IWTP.

Table 3: The Ciasem River Water Quality 2019-2023

Location	Concentration						
	pH	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	N Total (mg/l)	Mercury(mg/l)	Cadmium (mg/l)
2019							
Upstream	7,6	146	193	198	11,5	0,0001	0,001
IWTP Outfall 3	7,8	1.133	1.487	582	12,0	0,0001	0,001
IWTP Outfall 2	8,0	1.044	1.403	212	11,8	0,0001	0,001
IWTP Outfall 1	8,5	760	1.094	30	12,5	0,0001	0,001
The confluence of the Cikeuting & Ciasem River	7,0	560	985	84	13,0	0,0001	0,001
2020							
Upstream	7,5	365	493	834	19,3	0,0001	0,001
IWTP Outfall 3	7,4	298	396	384	22,2	0,0001	0,220
IWTP Outfall 2	8,2	371	505	106	28,3	0,0001	0,001
IWTP Outfall 1	8,0	311	488	332	24,4	0,0001	0,001
Meeting of S. Cikeuting & S. Ciasem	8,0	223	302	124	17,2	0,0001	0,001
2021							
Upstream	6,8	510	676	1.048	10,3	0,0001	0,001
IWTP Outfall 3	7,2	813	1.066	844	10,3	0,0001	0,001
IWTP Outfall 2	7,5	827	1.086	612	50,9	0,0001	0,001
IWTP Outfall 1	7,5	807	1.057	518	10,3	0,0001	0,001
Meeting of S. Cikeuting & S. Ciasem	7,6	705	929	414	28,1	0,0001	0,001
2022							
Upstream	7,0	596	781	36	10,3	0,0001	0,001
IWTP Outfall 3	7,9	889	1.161	34	10,3	0,0001	0,001
IWTP Outfall 2	7,6	1.089	1.423	60	10,3	0,0001	0,001
IWTP Outfall 1	8,8	1.197	1.566	60	10,3	0,0001	0,001
Meeting of S. Cikeuting & S. Ciasem	7,5	922	1.209	36	10,3	0,0001	0,001
2023							
Upstream	7,7	535	699	350	10,3	0,0001	0,001
IWTP Outfall 3	7,2	1.153	1.506	300	10,3	0,0001	0,001
IWTP Outfall 2	7,7	218	285	46	10,3	0,0001	0,001
IWTP Outfall 1	7,9	807	1.054	278	10,3	0,0001	0,001
Meeting of S. Cikeuting & S. Ciasem	7,9	771	1.007	194	88	0,0001	0,001

The results showed that the pH value and the concentration of heavy metals such as Mercury and Cadmium still complied with the quality standards according to Government Regulation of Indonesia No. 22 of 2021 (Annex VI, Class 2). To analysis stated that the toxicity of heavy metals including Mercury and Cadmium would increase at low pH levels (Moore, 1991). Therefore, the toxicity of heavy metals in the Ciasem River can be considered low. The concentrations of BOD and COD parameters at all locations as well as times consistently exceed the quality standards. This phenomenon has been occurring since 2017 and Tahun 2018, where BOD and COD concentrations in the upstream, middle, and downstream parts of the Ciasem River have exceeded the quality standards (Fadhilah and Fitria, 2020; Kurniasari and Aprianti, 2020). The high concentrations of BOD and COD show the amount of oxygen required for the biological and chemical decomposition of organic matter. This can disturb and cause death to aquatic organisms (Effendi, 2003). The TSS parameter also exceeds the quality standards at several locations, while the N-Total shows varying concentrations. The study in N-Total can be found in the form of inorganic and organic nitrogen (Effendi, 2003). Inorganic nitrogen includes ammonia (NH3), ammonium (NH4), nitrite (NO2), nitrate (NO3), and nitrogen molecules (N2) in the form of gas, while organic nitrogen consists of proteins, amino acids, and urea.

IWTP 1, 2, and 3, which are pollution control devices for leachate from the Bantargebang Final Disposal Site (IWMS) since 2019, have ceased to function. Specifically, IWTP 1 and 2 are buried under waste piles, while IWTP 3 is being renovated in 2022-2023. This phenomenon has led to the direct discharge (non-point source) of leachate into the Ciasem River, although remaining concentrated at the respective Outfall of each IWTP. In 2018, stated that the effectiveness of IWTP 1, 2, and 3 averaged 79.8% TSS, 97.1% BOD, and 97.2% COD (Fadhilah dan Fitria, 2020). These results showed that IWTP 1, 2, and 3 were still operating optimally. With the non-functioning IWTP, the water quality management of the Ciasem River depends on the performance of the communal wastewater treatment plant, located approximately 2 kilometers north of the Bantargebang IWMS.

The concentration of BOD in 2019 showed a significant increase in the Outfall of IWTP 3 (1,134 mg/l) and IWTP 2 (1,044 mg/l). This was followed by a decrease at IWTP 1 (760 mg/l) and the confluence with the Cikeuting River, reaching 560 mg/l. The significant variation is attributed to the increased oxygen resulting from direct aeration due to the elevated flow velocity and the mixing with the discharge of the Cikeuting River. Fluctuations in COD concentrations were similar to BOD, with higher values showing greater amount of oxygen required for the chemical decomposition of organic materials. The researcher at the Cipayung Landfill in Depok City, the concentration of TSS in leachate ranged from 600 mg/l to 900 mg/l (Tri Hutomo, 2012). The TSS concentration in the Ciasem River in 2019 varied from 30 mg/l (Outfall of IWTP 1) to 582 mg/l (Outfall of IWTP 3), showing a natural decrease in leachate entering river. However, the concentrations of N-total, pH values, Mercury, and Cadmium in 2019 still met the quality standards.

In 2020, BOD and COD concentrations in all locations were relatively stable, although the values obtained exceeded quality standards. The highest BOD concentration was at Outfall of IWTP 2 (371 mg/l) and the lowest was obtained at the confluence with the Cikeuting River (223 mg/l), similar to COD results. Meanwhile, the highest TSS concentration was in the Upper Ciasem River at 834 mg/l, which decreased to 106 mg/l at Outfall of IWTP 2 and increased to 332 mg/l at IWTP 1. TSS concentration decreased to 124 mg/l at the confluence location of the Cikeuting River, showing a slowdown in flow and subsequently settling of suspended particles into the sediment. The N-Total concentration ranged from 17.2 mg/l (Confluence with the Cikeuting River) to 28.3 mg/l (Outfall of IWTP 2), exceeding the quality standard of 15 mg/l. Meanwhile, the pH values and concentrations of Mercury and Cadmium remained consistent with the previous year, meeting quality standards.

BOD, COD, and TSS concentrations in 2021 experienced pollution at all locations. The highest BOD and COD concentrations occurred around Outfall of IWTP 1, 2, and 3, surpassing the quality standard at the Upper Ciasem River. The TSS parameter in the upstream river reaches 1,048 mg/l and decreases to 414 mg/l at the confluence location with the Cikeuting

River, where the TSS concentration exceeded quality standard of 50 mg/l. For the N-Total parameter, two locations had higher values, namely Outfall of IWTP 2 (50.9 mg/l) and the confluence of the Cikeuting River (28.1 mg/l). Meanwhile, the pH values and concentrations of Mercury and Cadmium in 2021 still meet quality standards.

Water quality of the Ciasem River around the Bantargebang IWMS in 2022 showed the presence of BOD and COD pollution in all locations. The highest concentrations were observed at around Outfall of IWTP 2, 3, and the confluence of the Cikeuting River. Generally, TSS parameters meet quality standards except for Outfall of IWTP 2 and 1, showing an external source of TSS. For the N-Total Parameters, the pH of Mercury and Cadmium still meets the quality standards.

BOD and COD concentrations in 2023 exceeded quality standards, with the highest concentrations occurring in Outfall of IWTP 3 and 1. Because the measurement in 2023 was carried out during the rainy season, there was an increase in TSS concentration exceeding the quality standard due to runoff, except for Outfall of IWTP 2 (46 mg/l). The highest N-Total concentration of 88 mg/l was around the confluence of the Cikeuting River and Ciasem River. Furthermore, the pH values and concentrations of Mercury and Cadmium still meet quality standards.

3.2 The Ciasem River Capacity

The carrying capacity is the limit of a water resource's ability to accept input of pollution loads without exceeding the water quality criteria for various purposes (Haripavan and Dey, 2023; Huang et al., 2024). The carrying capacity of the Ciasem River is shown in Figure 3.

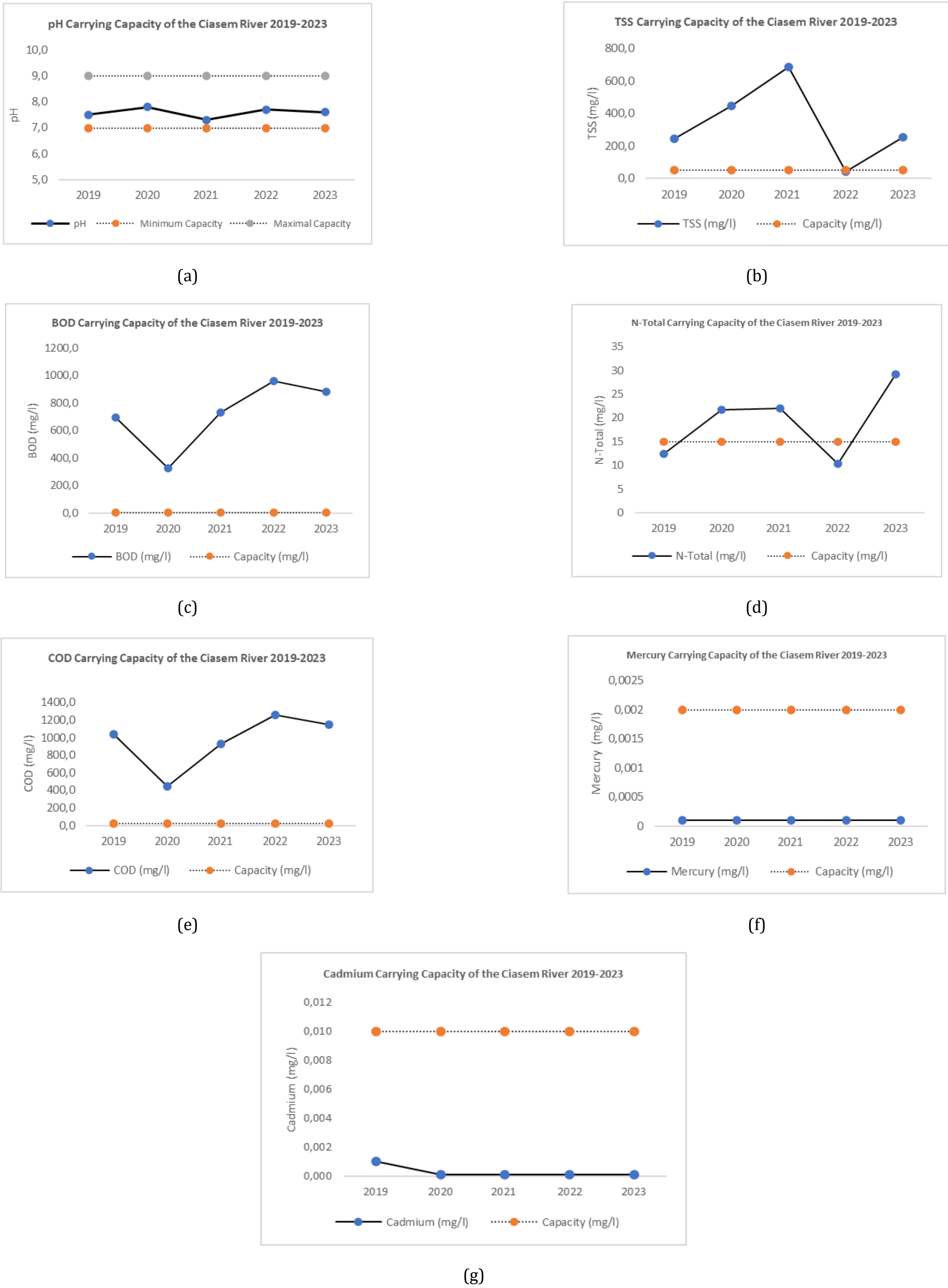

Figure 3: Carrying Capacity parameters (a) pH, (b) TSS, (c) BOD, (d) Total Nitrogen, (e) COD, (d) Mercury, and (e) Cadmium

The results showed the pH buffering capacity in the Ciasem River from 2019 to 2023 met the water quality. A previous research has established that the majority of aquatic organisms thrive in a pH range of 7-8.5, while metal toxicity increases at low pH levels (Novotny and Olem, 1994). Therefore, with the pH buffering capacity still being met, metals such as Mercury and Cadmium in the Ciasem River are within acceptable limits. This showed that wastewater with Mercury concentrations less than 0.0019 mg/l and Cadmium below 0.0099 mg/l can still be discharged into river.

The BOD carrying capacity in the Ciasem River has significantly exceeded the quality standard of 3 mg/l. However, the average concentrations at the final discharge point from 2019 to 2023 were 696.3 mg/l (deficit - 693.3 mg/l), 325.3 mg/l (deficit - 322.3 mg/l), 732.4 mg/l (deficit - 729.4 mg/l), 962.8 mg/l (deficit - 959.8 mg/l), and 880.6 mg/l (deficit - 877.6 mg/l), respectively. Based on the results, an increasing trend was observed in BOD carrying capacity from 2021 to 2023.

The same condition is also evident in the COD carrying capacity of the Ciasem River, which has exceeded the quality standards of 25 mg/l. However, the average concentrations at the final discharge point from 2019 to 2023 were 1,037.5 mg/l (deficit -1,013 mg/l), 448 mg/l (deficit - 423 mg/l), 926.8 mg/l (deficit - 901.8 mg/l),1,260.1 mg/l (deficit - 1,235 mg/l), and 1,150.2 mg/l (deficit - 1,125 mg/l), respectively. This result showed a significant increase in COD carrying capacity from 2021 to 2023.

In this research, the TSS parameter exceeded the carrying capacity of river. However, in 2022, TSS met the carrying capacity at 5.8 mg/l, showing permissible to discharge wastewater with TSS concentrations below 5.8 mg/l. The average concentrations at the final discharge point of N-Total in the Ciasem River met the carrying capacity in 2019 with a value of 12.4 mg/l. Therefore, the discharge of wastewater with N-Total content below 2.6 mg/l is allowed. In 2020 and 2021, N-Total exceeded the carrying capacity with deficits of -6.7 mg/l and -7.0 mg/l, respectively. After meeting the carrying capacity of 10.3 mg/l in 2022, N-Total exceeded the carrying capacity in 2023, with the largest deficit being 29.2 mg/l.

3.3 The Ciasem River Management Recommendations

Several recommendations for management of the Ciasem River can be formulated based on the observed capacity with the parameters pH, BOD, COD, TSS, Total Nitrogen, Mercury, and Cadmium. These include:

- Improvement of IWTP 1,2, and 3;
- Construction or strengthening of sheet piles and enforcing river-level lines to prevent waste avalanches in the Ciasem River;
- Maintenance of the width and depth of the Ciasem River, along with flow speed to preserve river's capacity;
- Coordination with the Bekasi City Government regarding management of the Ciasem River water quality.

4. Conclusions and Recommendations

In conclusion, this research showed that the temporal water quality of the Ciasem River has experienced pollution since 2019 and persisted until 2023, particularly concerning BOD, COD, TSS, and N-Total parameters. Spatially, elevated concentrations of BOD, COD, and TSS have originated upstream of the Ciasem River and increased in the areas surrounding Outfall of IWTP. At the confluence of the Cikeuting River with the Ciasem River, BOD, COD, and TSS concentrations showed significant changes due to the discharge from the Cikeuting River. The high concentrations of BOD and COD showed biological and chemical decomposition of organic matter, without decreasing to acidic pH. Therefore, the toxicity of Mercury and Cadmium remained low, as the water did not become acidic. The Ciasem River had no capacity, particularly for BOD, COD, TSS, and N-Total parameters since 2019 and persisted until 2023. This research showed the need to implement regular monitoring and initiate management practices to mitigate the conditions of the Ciasem River that have exceeded the carrying capacity for certain parameters.

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