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GIS-based Analysis of Water Pollution in the Cisadane River, Indonesia

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Abstract. The rapid growth of anthropogenic activities within the river impacts the river holistically. Cisadane River is categorized as one of the few prioritized watersheds that require conservation by the Ministry of Environment. Approximately 246 industries in Tangerang City (one of the regions that are included in the Cisadane Watershed area) are monitored by the Ministry of Environment as there is an extensive amount of toxic industrial waste disposed into the Cisadane River. This watershed is under further observation as it is progressively exposed to water quality degradation. Therefore this study aims to analyze the water quality in the Cisadane River from 2020 to 2021 based on the physical and chemical properties using the geographical information system (GIS) approach. The monitoring station was determined to represent the water quality from upstream to downstream within the dry and wet seasons. The spatial distribution of the water quality was generated into maps using ArcGIS 10.8 software. The result shows that during the dry season in 2020 and 2021, the water quality throughout all zones (headwaters to floodplains) is found to be highly contaminated. Meanwhile, during the wet season in 2020 and 2021, the water quality is highly contaminated in the headwaters zone to parts of the floodplain zone. The remaining floodplain zone had less contaminated water quality.

INTRODUCTION

Water plays a pivotal role in almost all human activities in various sectors. Its significance is bounded by its unlimited quantity. Regardless of how water is found in almost every part of the world, the quantity of freshwater is considerably limited [1]. The rising demand for clean water and the degradation of water quality establish an imbalance between water demand and water supply [2]. Rivers, as one of the surface water resources, are threatened by water quality degradation. Holistically, anthropogenic activities around the river affect the water flowing through the river. Rapid urbanization generates the transition of the hydrological cycles, which leads to the increasing water supply demand [3]. The national water supply had not yet met the standard regarding accessibility, quality, and continuity [4]. Through the national development plan [5], the national government of Indonesia conceptualized various nationwide improvements with the smart city principle. The plan also mentioned urban watershed management as drinking water and sanitation are still two of the many focused aspects. Restoring rivers and lakes water quality is also considered to establish better natural resource capacity [5].

The Cisadane Watershed is one of the watersheds that received intense attention from researchers. This watershed is categorized as one of the few prioritized watersheds that require conservation by the Ministry of Environment. Approximately 246 industries in Tangerang City (one of the regions that are included in the Cisadane Watershed area) are monitored by the Ministry of Environment as there is an extensive amount of toxic industrial waste disposed into the Cisadane River [6]. In the national development plan, the Cisadane Watershed is instructed to be monitored, especially for its contamination level. As studied by Rosarina and Laksanawati [7], the Cisadane River water was

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classified as Class II water based on the national water classifications. The following study by Ramadhawati et al [8] also classified the Cisadane River water as Class II water. Therefore, this study aims to assess the Cisadane River water quality based on Class II water characteristics and map out the spatial distribution of the water quality. According to [9], land use impacts on water quality require comprehensive analysis based on the spatial scales and the occurring seasons. The rising utilization of Geographic Information Systems (GIS) aids researchers in storing and manipulating geographical data that includes various attributes [10], ArcGIS 10.8 is software used to generate spatial distribution maps with physicochemical data as inputs [11].

METHODOLOGY

Study Area

The Cisadane Watershed is located at 6.72 – 6.76°S and 106.58 – 106.51°E with an area of 154,654 hectares. Administratively, this watershed consists of Bogor Regency, Bogor City, Tangerang Regency, South Tangerang City, and Tangerang City. The point source of the Cisadane River is Mount Gede Pangrango National Park and Halimun Salak National Park [12]. The Cisadane Watershed consists of segment ratios ranging between the first to the fifth orders with 282 segments in total [14]. This study assesses the Cisadane River water quality from upstream, transition, to downstream areas using online monitoring provided by the directorate of water pollution control, Ministry of Environmental and Forestry, Republic of Indonesia [13]. There are 5 (Five) monitoring stations in Cisadane river basin, where the distributions are: 2 stations in the upstream area, 1 station in the transition area, and 2 stations in the downstream area. Table 1 shows the locations of each water quality monitoring station.

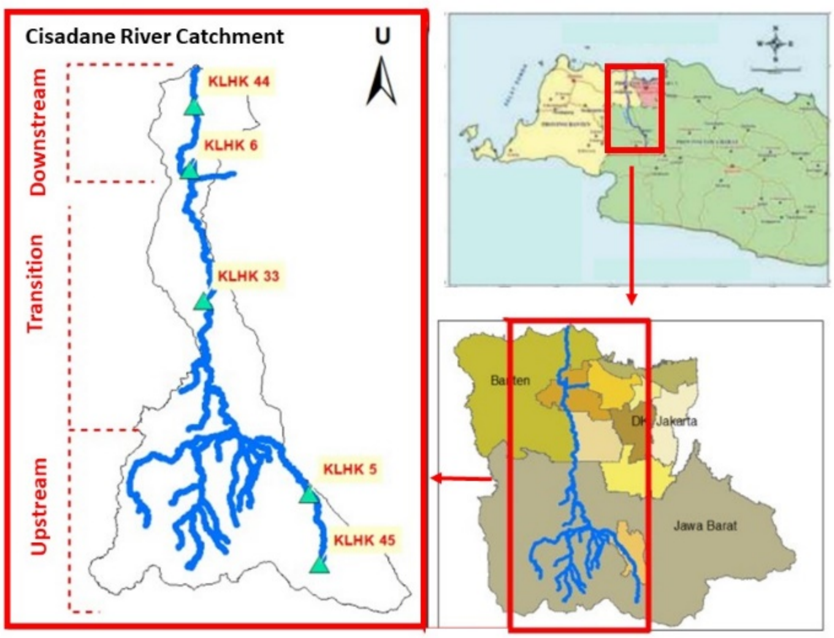


FIGURE 1. Study location of Cisadane River catchment area

TABLE 1. Cisadane River water quality monitoring station [13]

Sampling Station	Longitude	Latitude	Zone	Distance	Location
KLHK 45	106.813618	-6.719268	Upstream		Caringin Cigombong, Bogor, West Java Province
				16.4 km	
KLHK 5	106.798543	-6.618155	Upstream		Empang Weir, Bogor, West Java Province
				49.7 km	
KLHK 33	106.646589	-6.3414285	Transition		Cisauk Water Treatment Plant, Banten Province
				28.9 km	
KLHK 44	106.632888	-6.0629218	Downstream		Kalibaru, Tangerang Regency, Banten Province
				15 km	
KLHK 6	106.627260	-6.1540267	Downstream		Pasar Baru Weir, Tangerang City, Banten Province

Water Quality Data and Assessment

Water quality data for the following parameters are obtained from the online monitoring facility provided by the Ministry of Environment (Table 2). The physical parameters consist of temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and turbidity. While the chemical parameters are pH, Nitrate (NO_3^-), Ammonia (NH_3), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO).

TABLE 2. Water quality data and standard of monitoring locations

Year	Season	Parameter	Standard	Location				
				KLHK 45	KLHK 5	KLHK 33	KLHK 44	KLHK 6
2020	Dry	Temperature	22 - 28^{o}C	-	25.5	-	-	29.6
	Wet			-	26.5	27.2	-	29.5
2021	Dry			-	26.8	28.7	-	29.5
	Wet			25.6	27.0	23.6	28.7	29.3
2020	Dry	Turbidty	25 NTU	-	179.9	-	-	2.3
	Wet			-	120.7	83.9	-	8.8
2021	Dry			-	15.4	31.4	-	10.7
	Wet			45.5	17.0	60.8	46.0	12.1
2020	Dry	EC	0.5 - 800 uS/cm	-	12.5	-	-	16.2
	Wet			-	13.3	873.8	-	12.2
2021	Dry			-	13.7	59.2	-	17.5
	Wet			11.4	15.6	88.8	21.8	11.5
2020	Dry	TDS	1000 mg/L	-	108.7	-	-	141.3
	Wet			-	115.9	0.16	-	105.7
2021	Dry			-	119.3	0.44	-	152.1
	Wet			99.4	136.0	0.06	193.9	100.0
2020	Dry	pH	6-9	-	3.8	-	-	4.1
	Wet			-	6.2	5.7	-	6.9
2021	Dry			-	7.9	5.9	-	6.6
	Wet			7.5	6.9	7.2	6.8	6.7
2020	Dry	DO	4 mg/L	-	5.7	-	-	5.3
	Wet			-	5.1	6.0	-	2.0
2021	Dry			-	2.7	4.9	-	3.6
	Wet			4.5	1.1	3.8	0.87	3.8
2020	Dry	Ammonia	0.2 mg/L	-	10.9	-	-	75.3
	Wet			-	361.8	703.6	-	0.0
2021	Dry			-	47,688.1	409.4	-	1.1
	Wet			0.04	27,561.6	5.4	0.02	6.6
2020	Dry	Nitrate	10 mg/L	-	4,096.4	-	-	234.7
	Wet			-	3,669.7	7.5	-	369.1
2021	Dry			-	43,469.0	11.1	-	12.9
	Wet			5.3	1,168.4	10.5	12.5	2.2
2021	Wet	BOD	3 mg/L	10.9	-	5.6	8.50	-
2021	Wet	COD	25 mg/L	51.8	-	21.8	33.6	-

Source: [13]

This study assesses the water quality using the STORET Method in accordance with the national standard in [15] described in table 3 and 4. Table 4 shows water utilization classifications are based on guidelines determining water quality status [16]. This study refers to the water usage classification characteristics of Class II water as shown in Table 5.

TABLE 3. STORET scores guideline

Number of Parameters	Score	Parameter		
		Physical	Chemical	Biological
< 10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Average	-3	-6	-9
≥ 10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Average	-6	-12	-18

TABLE 4. STORET Scores Classification

Class	Quality	Score	Description
A	Excellent	0	Meet the quality standard
B	Good	-1 to -10	Lightly polluted
C	Moderate	-11 to -30	Moderately polluted
D	Poor	≥ -31	Highly polluted

TABLE 5. Water Usage Classifications

Category	Usage
I	Drinking water and other equal usage
II	Water recreation, aquaculture, agriculture, and other equal usage
III	Aquaculture, agriculture, and other equal usage
IV	Agriculture and other equal usage

Inverse Distance Weight (IDW) Interpolation Method

The Inverse Distance Weighted (IDW) Method is used to obtain the previously unknown values in specific areas by computerizing the available data [17]. ArcGIS software was utilized in this study using the Inverse Distance Weight (IDW) interpolation method [18]. Inverse Distance Weight (IDW) is a method for interpolation which frequently used in GIS. It is the deterministic method that predicts points with unknown values from the points around them. The concentration values are weighted based on distance; therefore, the nearest point with a known concentration value has a higher weight value [19]. The formula for this method is using equation (1). The IDW method in GIS has several power settings, power is the function that determines the interpolation result.

$$z(x_0) = \frac{\sum_{i=1}^{n} z(x1).d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \quad (1)$$

Where:

$z(x_0)$ = a function of the neighboring observation at the location (x_0),
n = representing the total number of sample data,
i = the nearest neighbors (i- 1,2,3 …n)
r = an exponent that determines the weight assigned to each observation
d = the distance separating the location of prediction (x_0) from the location of observation (x_i).

RESULT AND DISCUSSION

Physicochemical Water Quality

Both the dry season in 2020 to the rainy season in 2021, the water temperature of the Cisadane River has a low value in the upstream area and slowly increases downstream. As shown in Figure 2a, the temperature value is progressively increasing where the coverage of higher temperature values is wider at the end of 2020 compared to the beginning of 2020. The same thing will happen in 2021. The increase in temperature values occurs due to the climate change crisis that continues to occur where the surface temperature of water bodies is also affected. It can also be seen in Figure 2a that the temperature tends to increase even though it has entered the rainy season. This happens because the observation period during the rainy season is the early period of the rainy season so high temperatures can still be felt during that period.

According to Saalidong et al. [20], pH concentration in water influences various water quality parameters, one of which is metal concentration. In addition, this parameter affects chemical reactions between acid and base. The most acidic water condition was found during the dry season in 2020 (Figure 2b), and in the wet season, the water turned to a more neutral condition in the upstream zone and more basic in the downstream zone (Figure 2c). During the wet season of 2021 (Figure 2d), overall, the water transitioned into a more neutral to basic condition. The transition was driven by precipitation as rainfall has a more neutral pH naturally. The obtained data were later mapped out using the ArcGIS 10.8 software which resulted in the following maps.

KLHK 44 station contains anthropogenic activities originating from settlements, home industries, and roads. Visually reviewing land use, there is waste originating from anthropogenic activities both domestically and industrially in the watershed. In the rainy season, the waste can be carried away by rainwater runoff and flow into rivers. This is thought to be the cause of high temperatures, increased turbidity levels, decreased DO concentrations, and high TDS levels. Given the data obtained during the rainy season, the lack of sunlight penetrating into the deeper layers of the river water is thought to be another effect of the high turbidity of this region (Figure 3).

The average Total Dissolved Solids (TDS) in 2021 is considerably higher than in 2020. This increase is driven by the disposal of industrial waste, changes in water balance, and saltwater intrusion. Given that the higher TDS values were found in the downstream area where the water flows through Tangerang City, it was coherent that the increase in population within the city might plays a role. The obtained data were later mapped out using the ArcGIS 10.8 software which resulted in the following maps. TDS concentration rises during the wet season of 2021, specifically in the downstream zone due to saltwater intrusion from the rising sea levels and excessive groundwater pumping. The high value of TDS during the wet season of 2021 (Figure 4a) indicates that the river requires monitoring and thorough management to enhance the life cycle of aquatic species without eliminating certain species.

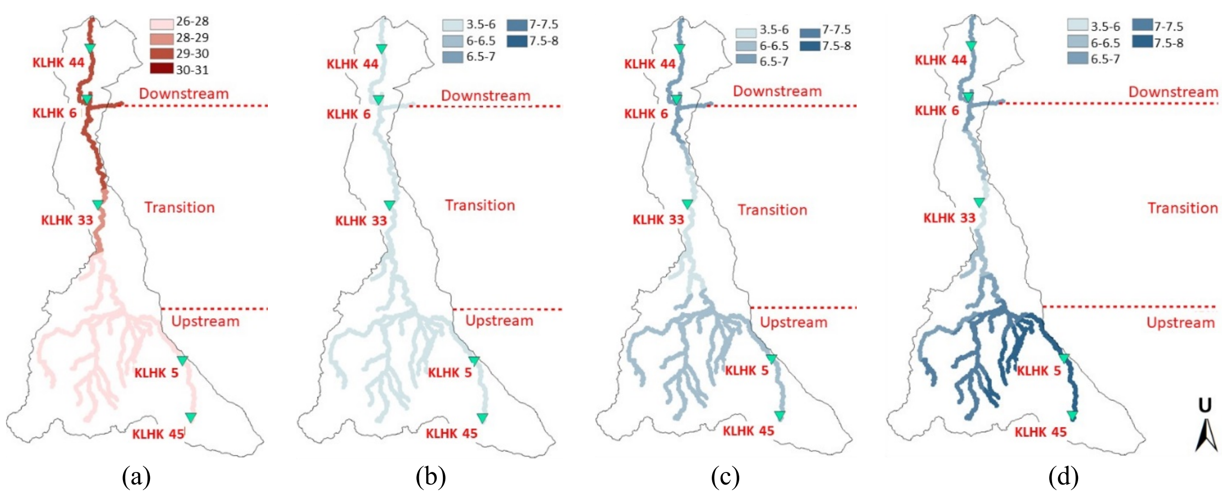
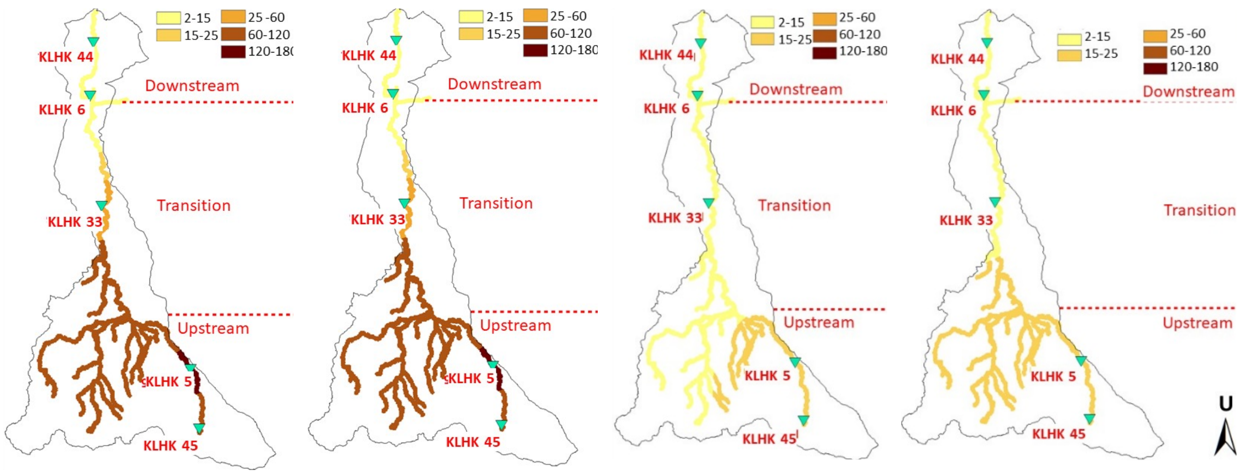


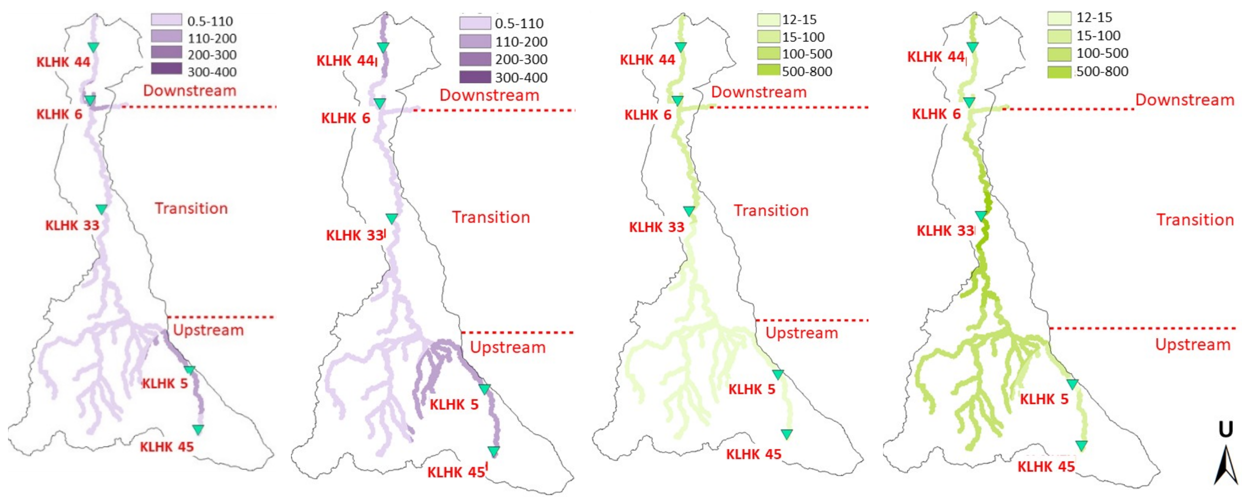
FIGURE 2. Temperature (°C) in 2021 during dry season (a); pH in 2020 of dry (b) and wet (c) seasons; and in 2021 of dry season (d)

Based on the water classification assembled by Rhoades et al. [21], the average values of EC of the Cisadane River indicate non-saline water (below 700 µS/cm). However, in the transition zone during the wet season of 2020 (Figure 4d), water was considered slightly saline. The obtained data were later mapped out using the ArcGIS 10.8 software which resulted in the following maps. Optimum EC values for aquatic species are between the range of 150 to 500 µS/cm. Therefore, during the wet season of 2020, the water flowing through the transition zone was not optimum for the life cycle of the aquatic species.



(a) (b) (c) (d)

FIGURE 3. Turbidity (NTU) in 2020 during the dry (a) and wet (b) seasons; and in 2021 during the dry (c)and wet (d) seasons.



(a) (b) (c) (d)

FIGURE 4. TDS (mg/L) in 2021 during the dry (a) and wet (b) seasons; and EC (µS/cm) in 2020 during the dry (c), and wet (d) seasons.

Dissolved Oxygen (DO) is influenced by temperature, where oxygen dissolves more effectively in lower temperatures than in higher temperatures [22]. Arend et al. [23] and Lusiana et al. [24] revealed that DO values within the range of 0.3 to 1 mg/L when occurring over a long period of time, increase the death rate of aquatic species. The low DO concentrations in the upstream zone during the wet season of 2021 indicate a low photosynthesis rate done by the phytoplankton in the riverbed. In accordance with the notion constructed by Harvey et al. [22], the disposal of organic waste into the river decreases the DO concentration as the waste requires oxygen to be decomposed. The low DO concentration in the downstream zone is caused by agriculture and aquaculture activities which require the disposal of organic matter.

The discharge of human waste, which is included in the content of black water (wastewater containing feces), increases the concentration of ammonia in the river flow in this area. In addition to waste containing feces, in paddy fields, some communities generally use fertilizers containing urea. Runoff from the area contributes to water pollution due to ammonia

From the dry season of 2020 to the rainy season of 2021, the nitrate content of river water in this region also contributed to the worst value. The poor sanitation system is one of the causes of high nitrate concentrations in an area. The nitrogen content in surface water comes from various sources, including dust in rainwater, domestic sewage systems, industrial wastewater, fertilizers, livestock waste, and so on. Significant increases in nitrate concentrations, as occurred in the observation area of KLHK 5, indicate that there are several sources of pollutants and that the increase is influenced by the nitrification process.

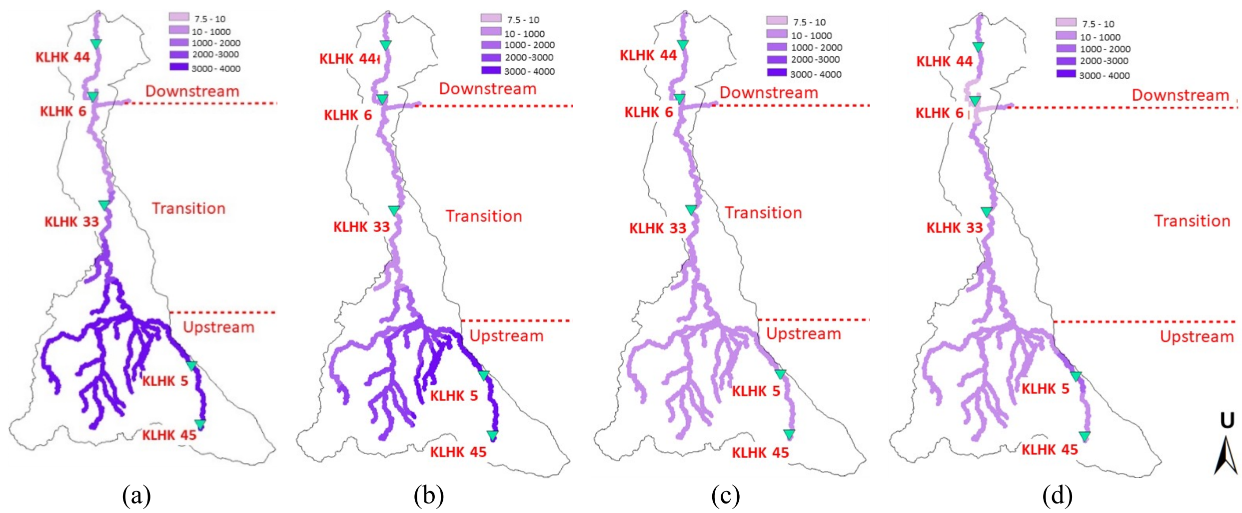


FIGURE 5. Nitrate (mg/L) in 2020 during dry (a) and wet (b) seasons; and in 2021 during dry (c) and wet (d) seasons.

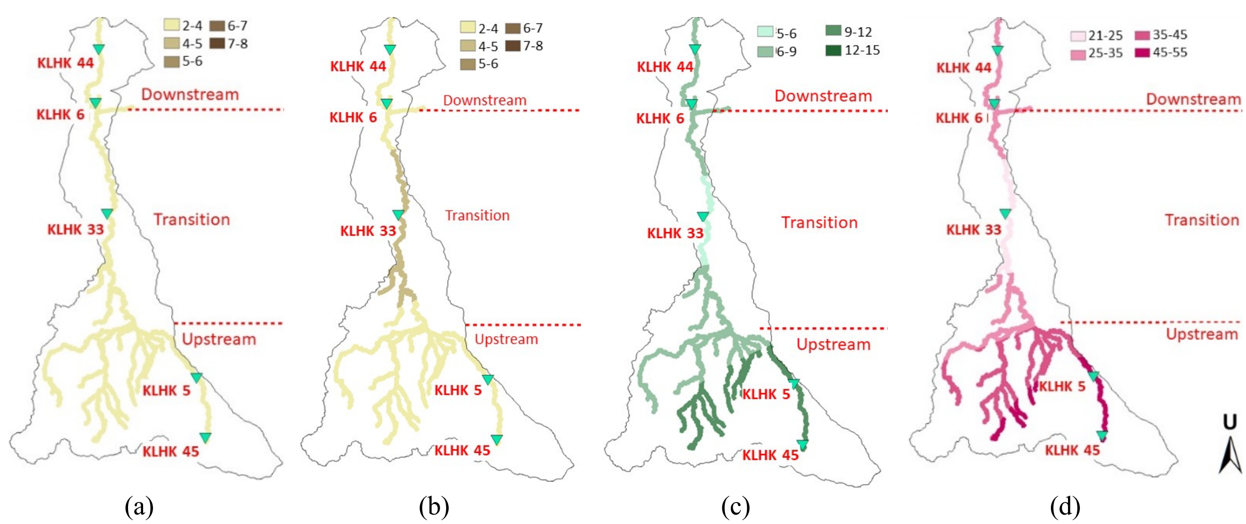


FIGURE 6. DO (mg/L) in 2020 during the wet season (a) and in 2021 during the dry season (b); BOD (mg/L) in 2021 during the wet season (c); COD (mg/L) in 2021 during the wet season (d)

The high value of Biochemical Oxygen Demand (BOD) decreases DO concentration in the water. Additionally, when a high value of BOD is present in the water body, water is unable to self-purify effectively [25]. A high concentration of BOD indicates water pollution which is driven by water temperature, type of waste, and the condition of the water body as a whole. The highest Chemical Oxygen Demand (COD) value was found in the upstream zone during the wet season of 2021. Meanwhile, the lowest value of COD was found in the transition zone during the wet season of 2020.

Water quality assessment using the STORET Method

This study assesses the water quality in each observation station during different seasons using the STORET Method. Overall, the pollution level in the Cisadane River has intensified throughout the years, more extensively in the transition and downstream zones. As this study assessed the water quality in accordance with Class II water characteristics, the Cisadane River water is considered moderately to highly polluted for Class II water utilizations. The STORET value in the upper Cisadane River, precisely at the observation point of the KLHK 45 Station, is -58 which indicates that the condition of the river water is heavily polluted (Table 5). The observation point area of KLHK 45 Station is surrounded by paddy fields and residential areas. The high level of pollution is influenced by land use around the observation point. The assessment of the water quality of the Cisadane River at the KLHK 5 Station in the dry season of 2020 showed a STORET value of -35. This value indicates that the condition of the water at that point is heavily polluted. From the STORET analysis, the parameters that meet the class II water quality standards are the TDS and EC parameters. Meanwhile, the biggest contributors to the worst values were the parameters of pH, turbidity, nitrate, and ammonia.

TABLE 6. STORET scores of Cisadane River in 2020 and 2021

No.	Observation Station	Zone	2020				2021			
			STORET Score		Pollution Status		STORET Score		Pollution Status	
			Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1.	KLHK 45	Upstream	-	-	-	-	-	-58	-	Heavily Polluted
2.	KLHK 5	Upstream	-35	-31	Heavily Polluted	Heavily Polluted	-34	-31	Heavily Polluted	Heavily Polluted
3.	KLHK 33	Transition	-	-68	-	Heavily Polluted	-102	-96	Heavily Polluted	Heavily Polluted
4.	KLHK 44	Downstream	-	-	-	-	-	-86	-	Heavily Polluted
5.	KLHK 6	Downstream	-31	-20	Heavily Polluted	Moderately Polluted	-32	-22	Heavily Polluted	Moderately Polluted

The Intergovernmental Panel on Climate Change (IPCC) [26] stated that climate change increasingly influences precipitation and evaporation in water bodies.

The occurring climate crisis overburdens the prediction of changes in seasons and precipitation rates. By 2050, the negative impacts of the climate crisis are predicted to impact critical rivers in 42% to 79% of areas of the global watersheds. The mentioned negative impacts include the rising evapotranspiration rate, the transformation of spatial patterns, and the rising precipitation rate.

From the water quality assessment, the following alternative strategy solutions are proposed to manage the contamination level along the Cisadane River, such as optimization of the sewerage system [12], development of communal wastewater treatment plants, stormwater management [9], and development a conservation area [27].

CONCLUSION

The Cisadane River water, as assessed using GIS analysis of the water quality distribution map and the STORET Method in accordance with Class II water characteristics, was moderately to highly polluted from 2020 to 2021. The water pollution intensified, especially in the transition to the downstream zones. Overall, the water quality parameters that met the standard for Class II water from 2020 to 2021 were temperature in the upstream zone and total dissolved solids (TDS) along the river. This study found that the concentrations of nitrate throughout the years are in crisis and require further monitoring and management. Causes of the intensifying water pollution are the rapid growth of urbanization, disposal of untreated wastewater, and the occurring climate crisis, which increases the water temperature. To manage the contamination that occurred in the Cisadane River, this study proposes the following alternative strategy solutions: sewerage system optimization, communal water treatment plants, stormwater management, and conservation areas.

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