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Potential Pollution Loads of the Cikembar Sub-Watershed to the Cicatih River, West Java, Indonesia

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Abstract: The Cicatih River in the Cikembar sub-watershed, located in Sukabumi Regency, flows along the upstream of the Cikembar sub-watershed and Palabuhan Ratu Bay. For decades, the river has served as a vital water resource, catering to various needs such as domestic use, agriculture, livestock, fisheries, industry, mining, tourism, and hydroelectric power. Recently, the Sukabumi Regency Government made the pollution of coastal and river areas one of the priority issues on sustainable development initiatives for the Sukabumi Regency. This highlights the importance of managing the Cicatih River, one of the main rivers in the regency. This research aims to analyze the potential pollution loads in the Cikembar sub-watershed to the Cicatih River by assessing its water quality status and potential pollution loads from four main sectors: domestic, agricultural, livestock, and industrial. The water quality was calculated based on the Pollution Index method. The potential pollution load from different sources was analyzed using various emission factor calculations. For each pollutant source, the following parameters were analyzed: total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), Total-N (nitrogen), and Total-P (phosphorus). Results showed that the condition of the Cicatih River is slightly polluted. The parameter exceeding its maximum threshold is BOD. The largest contributor to the potential pollution load of BOD is the domestic sector (53%), while the agricultural sector is the least (2%). In the domestic sector, Bojongkembar Village is the largest contributor to the potential pollution load. The results of this analysis can be used to develop strategies for managing the overall Cikembar sub-watershed.

Keywords: Cikembar sub-watershed; water quality status; pollution load; Cicatih River

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1. Introduction

Water pollution has been one of the global challenges for many countries [1]. The decline of river water quality, including in developing countries, is primarily because of urbanization, inadequate waste management policies, or basic infrastructure; this situation has repercussions for human health and for the ecosystem structure and function [2,3]. On the island of Java, Indonesia, particularly in the western part, pollutants entering the watershed and its rivers have been well documented [4]. However, in the southern part, where it is occurring at a rapid pace, development is often unavailable or has not been studied yet. Such a condition has brought attention to investigating and quantifying how urbanization, leading to land use change, affects streams.

One of the important watersheds in the southern part of the West Java Province is the Cikembar sub-watershed. Its significance lies in its role as a primary contributor to the Cicatih River, a vital water body that sustains local communities of Sukabumi Regency for agricultural activities and diverse ecosystems downstream [5]. The increasing pressures of human activities and rapid development within the Cikembar sub-watershed have sparked concerns regarding potential pollution loads that could significantly degrade the water quality of the Cicatih River. Understanding the pollution potential of human activities and their impact on water quality in this watershed is imperative for devising sustainable management strategies to preserve the ecological balance and safeguard human well-being.

The sources of pollution within the Cikembar sub-watershed encompass a wide spectrum of anthropogenic activities. For example, agriculture, particularly its traditional practices, plays a pivotal yet contentious role, contributing substantial amounts of pesticides, fertilizers, and sediment runoff into the waterways, subsequently polluting coastal waters [6]. The evolving landscape due to urbanization and industrialization introduces a complex array of pollutants, including domestic sewage, industrial effluents, and improper waste disposal practices. The combined effects of these activities necessitate a comprehensive investigation to delineate the sources and quantify the potential pollution loads that find their way into the Cicatih River, thereby discerning the dynamics influencing its water quality.

A recent Sukabumi Regency Strategic Environmental Study shows two strategic sustainable developments related to watersheds in Sukabumi Regency—West Java, which is located in the southern part of Java Island: the pollution of coastal and river areas and land use changes [6]. The growing changes in land use in Sukabumi Regency catchments have increased the risk of river pollution. In the last decade, increased areas for the industrial sector (45.50%), settlements (27.71%), and sand mining (64.50%) were the most significant land use changes in Sukabumi Regency. Land use changes occur in the watershed in Sukabumi Regency due to population and density increases, including urbanization [5]. Furthermore, water quality management practices in the Cikembar sub-watershed are currently fragmented and insufficient to address the multifaceted challenges posed by diverse pollution sources. While localized regulations and community-driven initiatives exist, they often lack the cohesive approach required for effective management. The absence of integrated strategies and inadequate monitoring exacerbates the situation, posing risks to the sustained health of the Cicatih River [5].

The use of water quality indices as a tool to evaluate the status of water quality in rivers has been introduced in the last four decades [4,7,8]. For instance, it has been successfully used to identify the water quality status in the Citarum River, Indonesia [9], or the Erdao Songhua River, China [10]. In this study, the Pollution Index (PI) specifically developed by the Ministry of Forestry and Environment of Indonesia was used to analyze water quality status as it has been formally applied across the country [9]. Similar to water quality indices, there are many studies on the non-point source pollution load modeling [11]. The calculation of the pollution loads was performed to investigate the amount, sources, and impact of Total-P (phosphorus) entering the Dongting Lake in China Field [12] and asses Total-N (nitrogen) and Total-P pollution loads in the upper Yellow River [13].

Considering the above-mentioned conditions, the principal objective of this study has two folds namely these were (1) to analyze the water quality status using Indonesia's Pollution Index and (2) to identify potential pollution loads from five main sectors, such as domestic, agriculture, livestock, industry, and commercial, in the Cikembar sub-watershed to the Cicatih River. The analysis was conducted on five key parameters: total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), Total-N, and Total-P. Prior to this study, information on the potential pollution load in the catchment from various pollutant sources was not available. This information is needed by the local government of Sukabumi Regency to determine priority locations and programs to improve the Cicatih River water quality. Therefore, this research contributes to scholarship on water quality management in developing countries by examining water quality status and pollution loads in a rapidly growing area in the southern part of the West Java Province.

2. Materials and Methods

2.1. Study Area Description

The Cikembar sub-watershed, located in Sukabumi Regency, West Java, is part of the Cimandiri watershed with a catchment area covering 84.6 km^2, with an elevation range of 150–700 m msl. The largest river in Sukabumi Regency, the Cimandiri River, flows along the Palabuhan Ratu Bay and the south of West Java. For decades, the Cimandiri River has been a source of domestic/clean water, agriculture/irrigation, livestock, fisheries, industry, sand mining, tourism, and hydroelectric power. The boundary of the Cikembar sub-watershed, and its monitoring locations are shown in Figure 1.

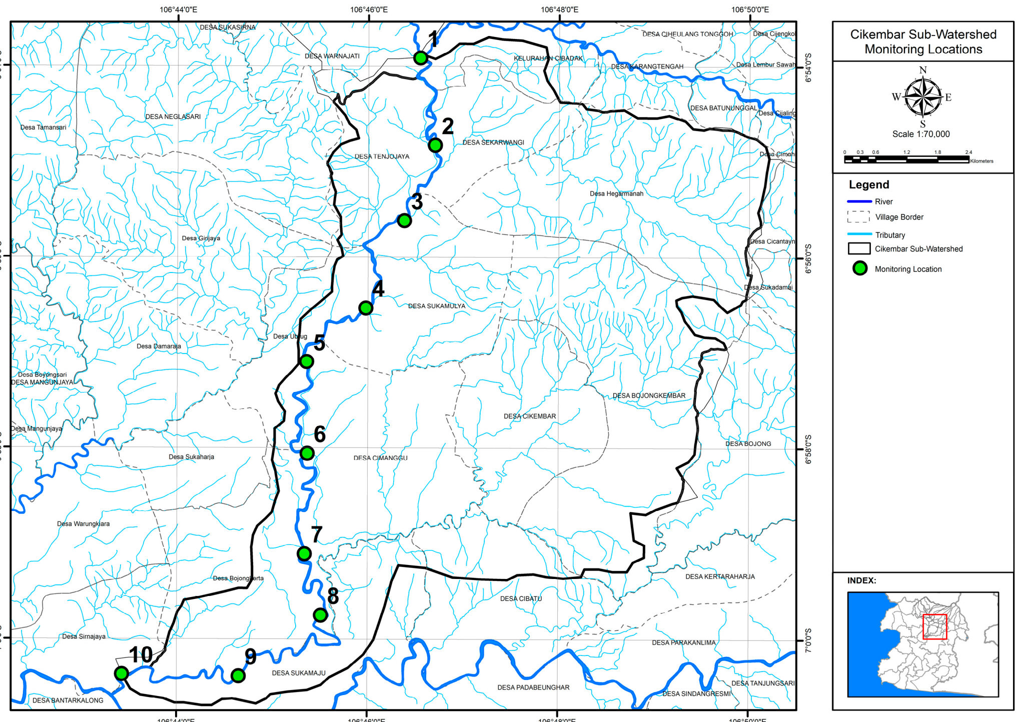


Figure 1. Cikembar Sub-Watershed Monitoring Locations.

Table 1 presents the characteristics of the population, land area, and density in the Cikembar Sub Watershed. Administratively, there are twelve villages with a total population of about 136,874 inhabitants. With regard to populations, Bojongkembar and Hegarmanah had the largest populations with 30,576 persons and 22,779 persons. Meanwhile, Cibatu and Ubrug had the lowest populations, with 2241 persons and 814 persons. Similar to the total population, in terms of total area, Bojongkembar and Hegarmanah are the two biggest villages, spanning 1522.00 ha and 1328.00 ha, respectively, and Cibatu and Ubrug are the two smallest villages, spanning total areas of 215.00 ha and 269.00 ha. Figure 1 also presents the characteristic population density wherein Cibadak (43.51 persons/ha) and Sekarwangi (24.52 persons/ha) are the most densely populated villages, while Tenonjaya and Cibatu are the least densely populated villages in the study area, with 9.38 persons/ha and 3.03 persons/ha [6].

In terms of the average annual rainfall, the Cikembar Sub Watershed was grouped into three categories, ranging from 2950 to 3200 mm/year for the 375.48 ha, between 3200 and 3450 mm/year for the 6580.79 ha, and between 3450 and 3700 mm/year for the 1508.17 ha, as presented in Table 2 below [6].

Table 1. Population, Land Area, and Density of Villages in Cikembar Sub Watershed.

No.	Villages	Number of Population (Persons)	Area (ha)	Population Density (Persons/ha)
1	Hegarmanah	22,779	1328.00	17.15
2	Ubrug	2241	215.00	10.42
3	Bojongkerta	8374	637.00	13.15
4	Cibadak	7266	167.00	43.51
5	Sekarwangi	11,232	458.00	24.52
6	Tenjojaya	4653	496.00	9.38
7	Sukamulya	10,023	795.00	12.61
8	Bojongkembar	30,576	1522.00	20.09
9	Cikembar	16,262	795.00	20.46
10	Cimanggu	15,736	1094.00	14.38
11	Cibatu	814	269.00	3.03
12	Sukamaju	6918	515.00	13.43
	Total	136,874	8291.00	16.84

Table 2. Characteristic of Rainfall in Cikembar Sub Watershed [6].

No.	Categories	Area (ha)
1	2950–3200 mm/year	375.48
2	3200–3450 mm/year	6580.79
3	3450–3700 mm/year	1508.17

Table 3 presents land use in the study area on ten different classifications, namely forest, industry, gardens/plantations, settlement area, grass/empty land, irrigation rice fields, rainfed rice fields, shrubs, moorland/field, and body of water. Overall, the land use of Cikembar Sub Watershed was dominated by rainfed rice fields with 695.378 ha of the total area, followed by the second and third largest: gardens/plantations and moorland with 3891.972 ha and 1631.324 ha, respectively. Meanwhile, industry and forest were the two smallest proportions of land use in the study area, with 31.292 ha and 58.591 ha. The third smallest proportion was body of water, which was 90.461 ha of the total land use area [6].

Table 3. The Characteristics of Land Use in Cikembar Sub Watershed.

No.	Categories	Area (ha)
1	Forest	58.591
2	Industry	31.292
3	Gardens/Plantations	3891.972
4	Settlement Area	1459.163
5	Grass/Empty Land	89.714
6	Irrigation Rice Fields	314.786
7	Rainfed Rice Fields	695.378
8	Shrubs	201.752
9	Moorland/Field	1631.324
10	Body of water	90.461

2.2. Methodology

2.2.1. Water Quality Status

In Indonesia, water quality status refers to the Decree of the State Minister of the Environment on the Guidelines for Determining Water Quality Status. In this decree, river quality status in Indonesia should be determined using the PI method as described in Section 1. Therefore, in this study, the PI method was used [14].

This method assesses water quality by evaluating various parameters such as pH, dissolved oxygen (DO), BOD, COD, TSS, and specific pollutants like heavy metals and nutrients.

Each parameter is assigned a score based on its derivation from set standards or thresholds. These scores are then aggregated to calculate an overall PI for the water body. The PI categorizes water quality into different uses like drinking, aquatic life, or irrigation.

In this study, the water quality status of the Cicatih River is categorized as Class II, as it is generally considered suitable for specific purposes such as irrigation, industrial cooling, or controlled waste disposal. This classification indicates that the water, despite some level of pollution, can be used for certain non-drinking purposes after appropriate treatment or management.

The PI is calculated using the following equation:

$$PI = \sqrt{\frac{\left(\left(\frac{C_i}{L_i}\right)^2_{maximum} + \left(\frac{C_i}{L_i}\right)^2_{average}\right)}{2}} \quad (1)$$

where:

C_i = quality of specific parameter (i) based on water quality sampling
L_i = maximum threshold value for parameter (i)
PI = Pollution Index
i = parameter 1, 2, 3...

Once the value of PI is obtained, the categories of water quality status is analyzed based on the following: $0 \leq PI \leq 1.0$: meet the quality standards (good condition); $1.0 < PI \leq 5.0$: slightly polluted; $5.0 < PI \leq 10$: moderately polluted; and $PI > 10$: heavily polluted.

2.2.2. Potential Pollution Load

Potential pollution load refers to the number of pollutants that could be introduced into an environment, including rivers. By estimating potential pollution loads, policymakers and environmental scientists can develop strategies to mitigate and control pollution effectively. Accurately assessing potential pollution loads is essential for maintaining the health and sustainability of our ecosystems and ensuring the well-being of human populations.

Assessing potential pollution loads involves emission factors, land-use planning, and pollution dispersion models. In this research, the potential pollution load of various sectors, namely domestic, agriculture, livestock, and industrial, will be calculated using available emission factors.

Domestic Sector

The potential pollution load of the domestic sector in a watershed is influenced by the population, emission factors, city equivalent ratio, and load transfer coefficient. The potential pollution load for the domestic sector is calculated using the following formula [6]:

$$\text{The Domestic Sector Pollution Load} = \text{Total Population} \times \text{Emission Factor} \times \text{City Equivalent Ratio} \times \text{Load Transfer Coefficient} \quad (2)$$

The total population in the Cikembar sub-watershed is calculated using the percentage of the settlement area of each village in the watershed area to the total area of settlements in Sukabumi Regency. The percentage is then multiplied by the total population of Sukabumi Regency.

The potential pollution load in the domestic sector is calculated on five key parameters: TSS, BOD, COD, Total-N, and Total-P. These five parameters are water quality parameters with a probability of $\geq$80% causing water pollution [6,15]. Emission factors of these five parameters from household activities are shown in Table 4 below. These emission factors were calculated based on the study by Iskandar [16], taking into account multiple measurements along the Ciliwung River:

1. Assessment of river water quality across 35 locations for various parameters.
2. Analysis of river flow at 25 locations along the Ciliwung River.
3. Collection of sludge samples from 10 locations in the Ciliwung River for DO.

Table 4. The Domestic Sector Emission Factor [6].

Parameter [1]	Emission Factor (g/Person/Day)
TSS	38
BOD	40
COD	55
Total-N	1.95
Total-P	0.21

Note: [1] In Indonesia, these are the five parameters with their emission factors available for domestic sector.

After this, water quality modeling was employed to calculate emission factors by establishing correlations between water quality and pollution sources (domestic, livestock, farming, and industries) along the river within their respective catchment areas. The calibration results for the parameter of BOD show a correlation value of 0.898.

The findings of this study conducted on the Ciliwung River hold particular significance, especially concerning the emission factors of various water quality parameters. These emission factors are used in estimating potential pollution loads in the Cicatih River, given the similarity in catchment characteristics between both rivers. Moreover, this study on the Ciliwung River stands as a pivotal resource, being the sole investigation available that determines emission factors for domestic, agricultural, and livestock activities in Indonesia.

The value of the city equivalent ratio is determined by applying villages to certain categories based on city type. Three categories, namely urban, rural, and inland, show their respective equivalent ratios in Table 5 below.

Table 5. City Equivalent Ratio [6].

Area	Value
Urban	1
Rural	0.8125
Inland	0.6250

The value of the load transfer coefficient for each village is determined by calculating the percentage of settlements within the range of 0–100 m, 100–500 m, and >500 m from the Cicatih River in the Cikembar sub-watershed. The percentage is then multiplied by the value of the load transfer coefficient (α), as is shown in Table 6.

Table 6. Load Transfer Coefficient (α) [6].

Value of α	Distance to the River (m)	Sanitary Pattern
1	0–100	Direct disposal to the river
0.85	100–500	Open canal
0.3	>500	Septic tank

When employing the city equivalent ratio, urban areas are delineated as regions inhabited by over 100,000 people, while rural zones encompass populations ranging between 20,000 and 100,000 inhabitants. Inland areas, in this context, refer to locations with populations of fewer than 20,000 inhabitants [14].

Similar to the emission factor calculation, the determination of α (load transfer coefficient) involved water quality modeling, utilizing multiple measurements along the Ciliwung River on river water quality, river flow, and DO measurements [16].

Subsequently, the model was employed to derive the load transfer coefficient by establishing correlations between water quality and pollution sources (domestic, livestock, farming, and industries) within their respective catchment areas [16].

Agricultural Sector

The type of land, area, and harvest period comprise the potential pollution load of the agricultural sector. The potential pollution load for the agricultural sector is calculated using the following formula [16]:

$$\text{The Agricultural Sector Pollution Load} = \frac{\text{Emission Factor} \times \text{Land Area (ha)} \times 10\%}{\text{Harvest Period (day)}} \quad (3)$$

The 10% in the formula indicated the percentage of agricultural waste entering the river.

The emission factor of agricultural waste is shown in Table 7 below.

Table 7. Agricultural Waste Emission Factor [16].

Type of Agriculture	Parameters of Agricultural Waste [1]				
	TSS	BOD	COD	Total-N	Total-P
	Kg/ha/Planting Season				
Rice field	0.4	225	337.5	20	10
Secondary crops	2.2	125	187.5	10	5
Other agricultures	0.6	32.5	48.75	3	1.5

Note: [1] In Indonesia, these are the five parameters with their emission factors available for agricultural sector.

Livestock Sector

The potential pollution load of livestock sector comes from livestock activities, such as animal manure. The following is the formula to calculate potential pollution load for the livestock sector [16]:

$$\text{The Livestock Sector Pollution Load} = \text{Number of Farm Animals} \times \text{Emission Factor} \times 20\% \quad (4)$$

The 20% in the formula indicated the percentage of livestock waste entering the river.

The emission factor of livestock waste is shown in Table 8 below.

Table 8. Livestock Waste Emission Factor [16].

Type of Livestock	Parameters of Agricultural Waste [1]			
	BOD	COD	Total-N	Total-P
	Kg/ha/Planting Season			
Cattle	292	717	0.933	0.153
Sheep	55.7	136	0.278	0.063
Chicken	2.36	5.59	0.002	0.003
Duck	0.88	2.22	0.001	0.005
Buffalo	207	530	2.6	0.39
Horse	226	558	38.083	0.306
Goat	34.1	92.9	1.624	0.115

Note: [1] In Indonesia, these are the five parameters with their emission factors available for livestock sector.

Industrial and Commercial Sector

There are four ways to calculate the pollutant load from point sources [17,18]:

1. Using concentration and discharge of wastewater data to monitor results;
2. If concentration data is available, but discharge data is unavailable from the monitoring results, then the maximum wastewater discharge in the permit is used;
3. If both concentration and discharge wastewater from the monitoring results is unavailable, then pollution load unit (PLU) or Emission Factor (EF) is used;
4. If (1) to (3) is unavailable, the pollution load of the similar sector(s) is used.

The available emission factor of the industrial sector based on a number of employees is shown in Table 9 below.

Table 9. Industrial Sector Emission Factor [17].

Industrial Sector	BOD (g/Day/Employee)
Dyeing	79.1
Other foods	37.9
Metal	10.3
Paper	17.9
Polyester fiber	47.1
Textile	219.2
Laundry	96.4
Machine	4.7
Plastic goods	57.3
Car & motorcycle parts	13.5
Ceramic and tile	2.0
Tannery	144.4
Soap and detergent	50.4
Chemical	1898.2
Metal goods	0.2
Printing	0.6
Glass	0.3
Hospital	123
Hotel	55
Restaurant	17

The potential pollution load for the industrial sector was calculated using the following formula [16]:

$$\text{The Industrial Sector Pollution Load}(\text{kg/day}) = \beta \times \gamma \times \delta \times \text{Qk} \times \text{Ei} \quad (5)$$

with:

β = unit conversion (0.0864)
γ = distance load transfer coefficient (0.3–1.0)
δ = load transfer coefficient discharge ratio (0.1–1.0)
Q_k = discharge (L/s)
E_i = pollutant emission (mg/L).

In applying the equation, the distance-based load transfer coefficient (gamma) is utilized, calculated from the industrial site's proximity to the river. For practical purposes in this study, a gamma value of 0.3 is employed for industries situated over 500 m away, 0.5 for distances between 100 and 500 m, and a gamma value of 1 for industries within 100 m of the river.

Regarding the discharge ratio-based load transfer coefficient (alpha), its value is determined by the industry's discharge recycling practices. A higher recycle ratio correlates with a lower alpha value. In this particular study, identified industries aren't engaged in discharge recycling, resulting in an alpha value of 1 across all industries.

The potential pollution load for the industrial sector could be calculated using another formula [17]:

$$I,i = Ci \times V \times OpHrs/1000000 \quad (6)$$

with:

I,i = load/pollutant emission i (kg/year)
Ci = industrial waste concentration (mg/L)
V = wastewater discharge flow rate (L/h)
OpHrs = number of operating hours per year (h/year)
1000000 = conversion factor (mg/kg).

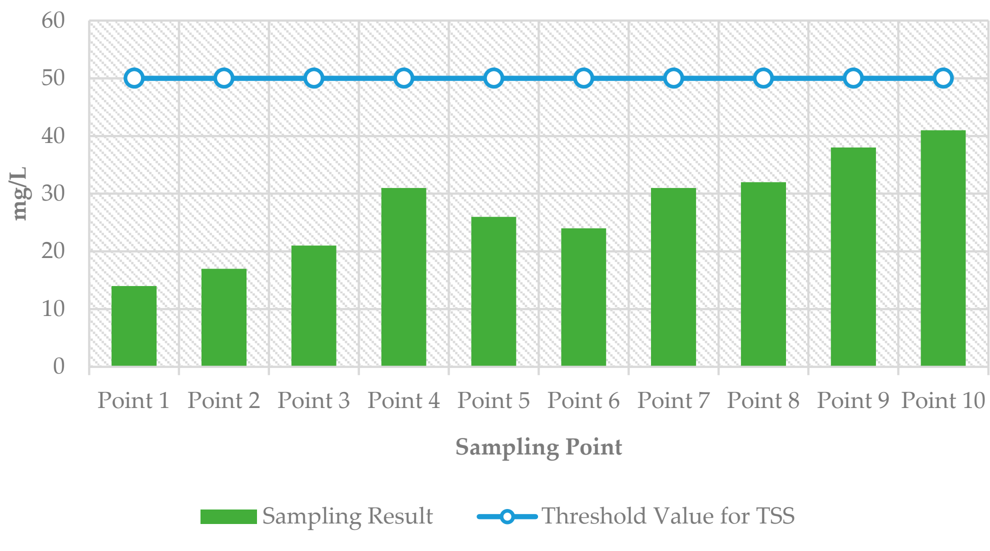
3. Results and Discussion

3.1. Water Quality Status

As mentioned earlier, the water quality status of the Cicatih River is determined using the PI method, which was calculated based on the water quality sampling in 10 locations along the Cicatih River. The results of the samplings for various water quality parameters and their comparisons with respective threshold values are presented in Figure 2.

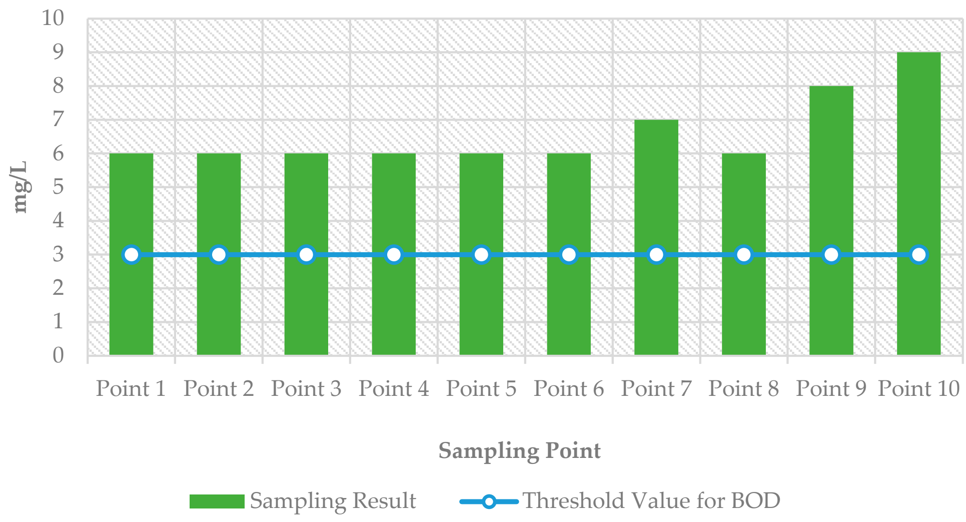
According to the Ministry of the Environment of Indonesia, water quality status juxtaposes the level of water quality conditions in a water body at a certain time with respective water quality standards [16]. This study calculates the water quality status using the Pollution Index (PI value) method and data derived from the water quality measurements of 10 different sampling locations. The results are shown in Table 10.

The results show that the condition of the river in the Cikembar sub-watershed is slightly polluted. Even though the river is still in the early category of pollution, this is an alarming condition due to the growing housings and industries in the catchment. In most rivers in Indonesia, river pollutions are mainly caused by domestic and industrial activities. For example, in Cimahi Catchment, the sub-catchment of Citarum, domestic activities have contributed 43% of the total river pollution in its respective catchment [16], and in the overall Citarum Catchment, domestic activities have contributed 85% of the total river pollution [19]. Therefore, the government of Sukabumi Regency should regularly monitor the water quality of the river and implement necessary policies to ensure that housings and industrial development in the catchment area will not increase its pollution level.



(**a**)

Figure 2. *Cont.*



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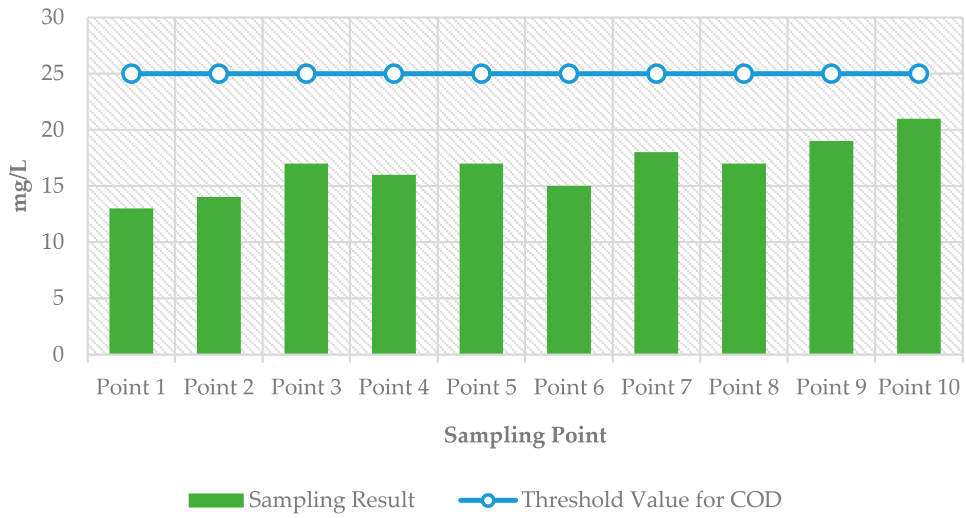

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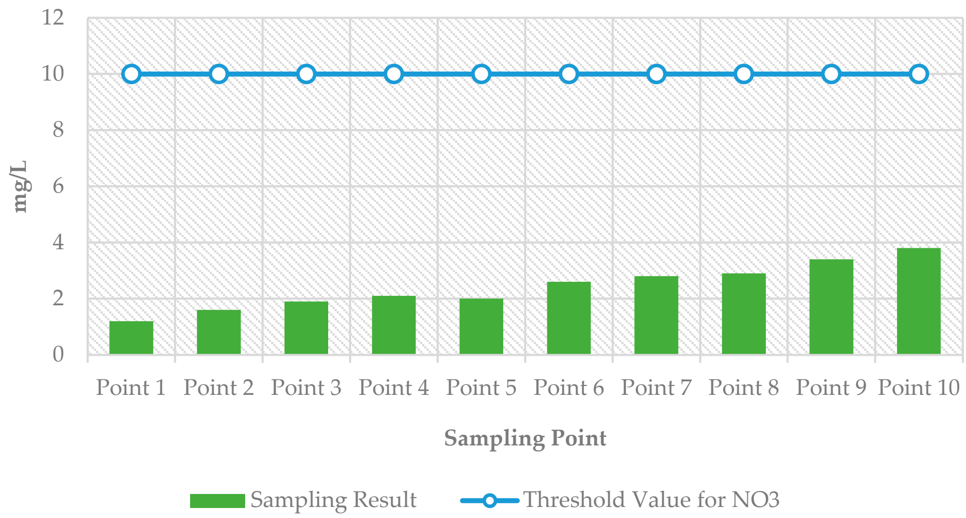

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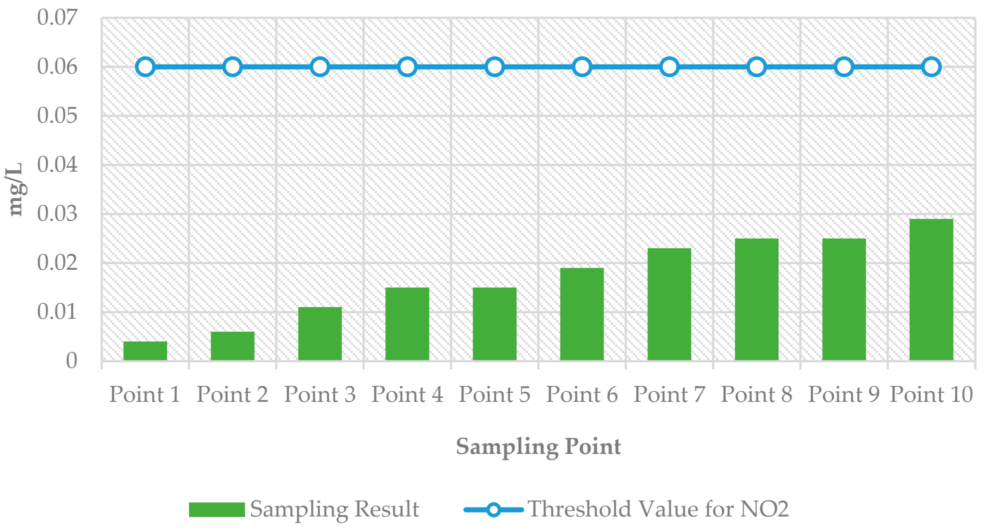

(**e**)

Figure 2. Water quality of Cicatih Rivers for various parameters (**a**) TSS; (**b**) BOD; (**c**) COD (**d**) Parameter NO_3; (**e**) NO_2.

Table 10. Water Quality Status of the Rivers in Cikembar Sub-watershed.

Monitoring Location	PI Value	Description
Cicatih River Point 1	1.82	Slightly polluted
Cicatih River Point 2	1.81	Slightly polluted
Cicatih River Point 3	1.82	Slightly polluted
Cicatih River Point 4	1.82	Slightly polluted
Cicatih River Point 5	1.82	Slightly polluted
Cicatih River Point 6	1.82	Slightly polluted
Cicatih River Point 7	2.06	Slightly polluted
Cicatih River Point 8	1.83	Slightly polluted
Cicatih River Point 9	2.28	Slightly polluted
Cicatih River Point 10	2.47	Slightly polluted

3.2. Potential Pollution Load

3.2.1. Domestic Sector

As indicated in the methodology section, the potential pollution load of the domestic sector was based on the total population in the Cikembar sub-watershed area. Figure 3 shows the settlement areas in the Cikembar sub-watershed, marked in light-brown color. The total area of settlements in Sukabumi Regency is 28,663.45 ha, with a population of 2,725,450. Based on calculation results, the largest population came from Bojongkembar Village (30,576 inhabitants), with 136,874 inhabitants in the Cikembar sub-watershed.

The Cikembar sub-watershed comprises two area categories: urban and rural areas. There are three villages falling into the category of urban areas: Cibadak, Sekarwangi, and Tenjojaya. Other remaining villages are included in the rural category. The calculation of the value of the load transfer coefficient begins with calculating the area of settlements within 0–100, 100–500, and >500 m ranges from the Cicatih River in the Cikembar sub-watershed. Based on the calculation results, most settlement areas are beyond 500 m distance.

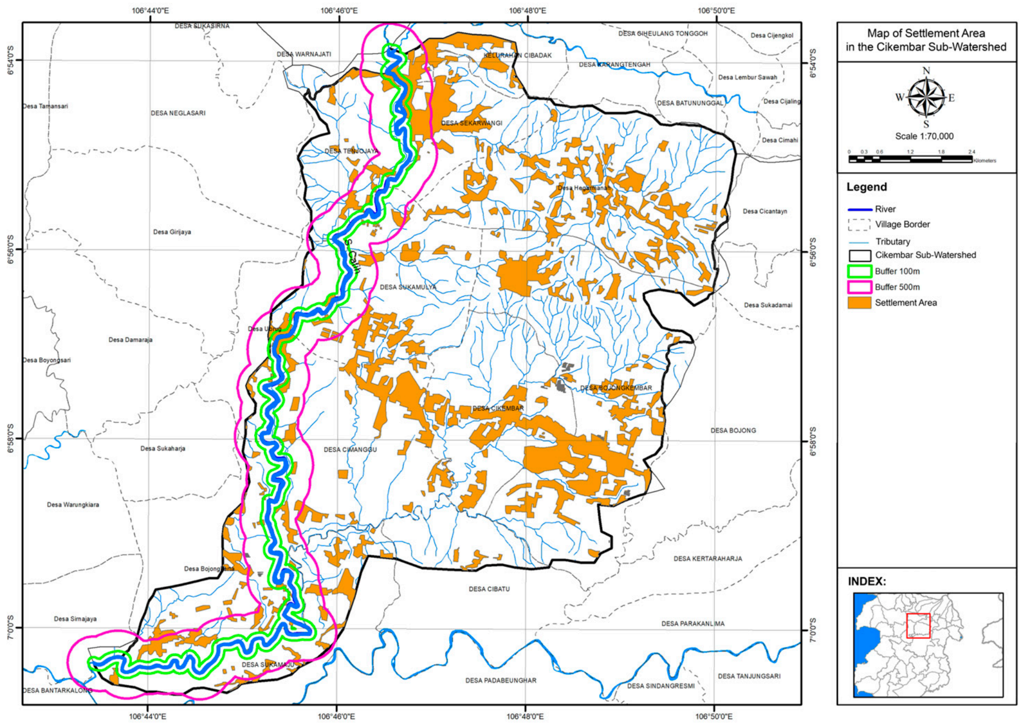

Figure 3. Settlement Area in the Cikembar Sub-Watershed.

The potential pollution load from the domestic sector is directly proportional to the number of populations. The value of the emission factor, city equivalent ratio, and the load transfer coefficient also affect the value of the potential pollution load from the domestic sector. High area category (urban) and close settlement to the river lead to the domestic sector's high potential pollution load discharged into the river [16,20]. The results of the calculation of the potential pollution load of the domestic sector in the Cikembar sub-watershed are shown in Table 11, and the contribution of each village to the potential pollution load of the domestic sector in the Cikembar sub-sub-watershed is shown in Figures 4 and 5.

Table 11. Potential Pollution Load of the Domestic Sector in the Cikembar Sub-watershed.

District	Village	Potential Pollution Load (kg/Day)				
		TSS	BOD	COD	Total-N	Total-P
Cicantayan	Hegarmanah	210.99	222.10	305.38	10.83	1.17
Warung Kiara	Ubrug	61.18	64.40	88.55	3.14	0.34
	Bojongkerta	167.16	175.96	241.95	8.58	0.92
Cibadak	Cibadak	130.87	137.76	189.42	6.72	0.72
	Sekarwangi	210.78	221.87	305.08	10.82	1.16
	Tenjojaya	121.13	127.51	175.32	6.22	0.67
Cikembar	Sukamulya	129.41	136.22	187.31	6.64	0.72
	Bojongkembar	283.21	298.12	409.91	14.53	1.57
	Cikembar	150.63	158.56	218.02	7.73	0.83
	Cimanggu	222.05	233.73	321.39	11.39	1.23
	Cibatu	7.54	7.93	10.91	0.39	0.04
	Sukamaju	107.96	113.65	156.26	5.54	0.60
Total		1802.93	1897.82	2609.50	92.52	9.96

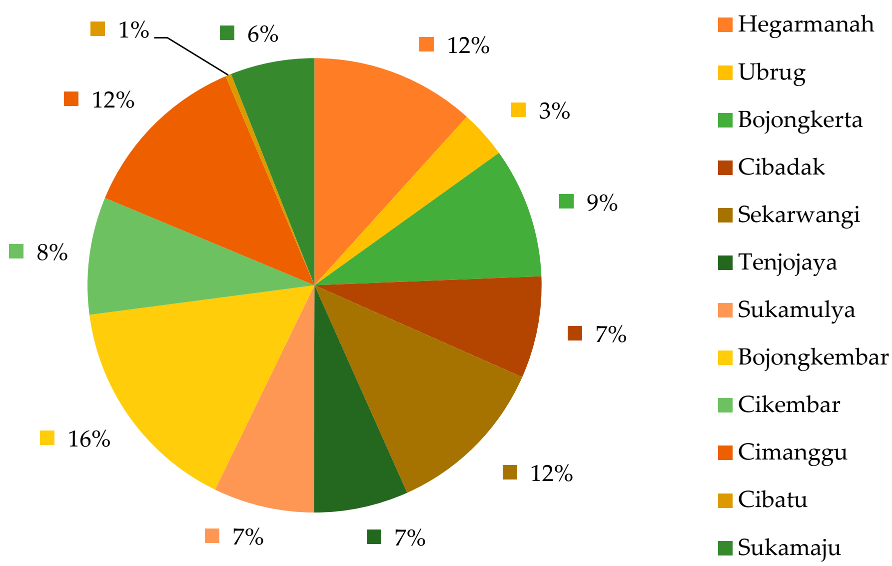

Figure 4. The Contribution of Each Village to the Potential Pollution Load of the Domestic Sector in The Cikembar Sub-Watershed.

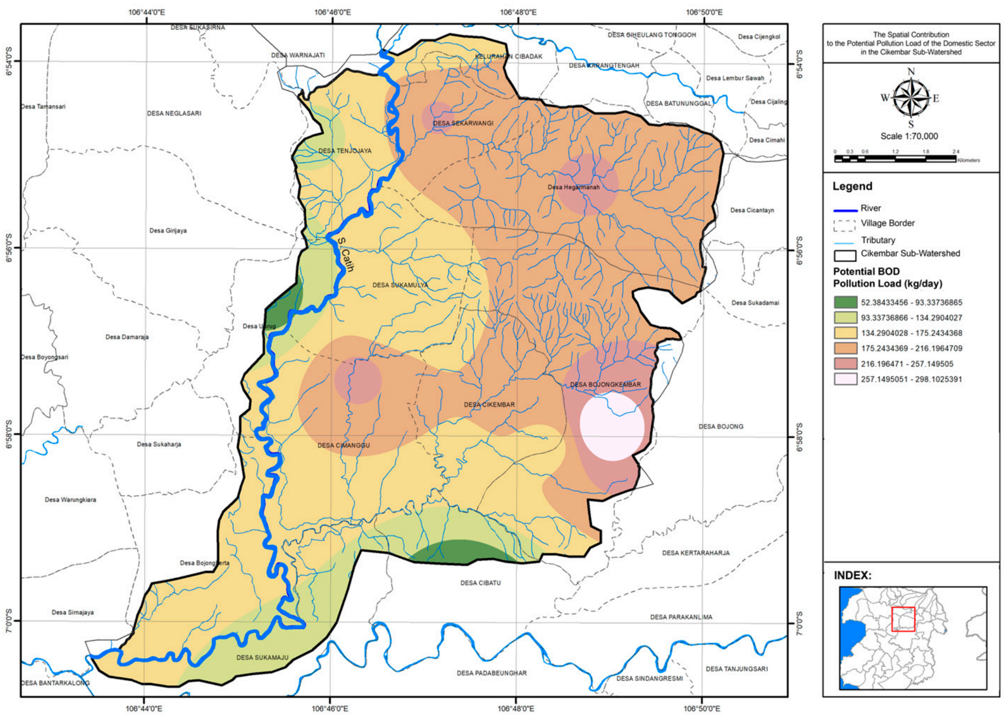

Figure 5. The Spatial Contribution to the Potential Pollution Load of the Domestic Sector in the Cikembar Sub-Watershed.

Based on the calculation, the potential pollution load for the domestic sector in the Cikembar sub-watershed for the BOD parameter is 1897.82 kg/day. This value indicates the potential pollution load from the domestic sector for the BOD parameter entering the Cicatih River daily in the Cikembar sub-sub-watershed.

The same explanation applies to other parameters. Based on the calculation results, Bojongkembar Village is the largest contributor to the potential pollution load of the domestic sector in the Cikembar sub-watershed, with 16% of the total pollution potential, followed by Hegarmanah, Sekarwangi, and Cimanggu Villages, with the same contribution of 12%. Meanwhile, the smallest contributor was Cibatu Village at 1%.

Yusuf [16] presents that the main contributors to the high level of BOD in rivers are domestic and industrial activities. In most of Indonesia's densely populated urban and peri-urban areas, untreated household sewage and wastewater are often discharged directly into the nearby rivers and streams. The same situation applies in most villages in Cikembar sub-watershed, where outlets of wastewater discharge either go directly to nearby river or to water channel leading to nearby rivers. These discharges can contain organic matter, detergents, and other pollutants, contributing to the BOD levels in the river. The organic matter in sewage becomes a food source for bacteria, which consume oxygen during decomposition [21]. Consequently, high BOD levels deplete dissolved oxygen in the water, harming aquatic life, including fish and other organisms. Further, oxygen-deprived water can lead to fish kills and negatively impact the health of the river's ecosystem [21]. In addition, elevated BOD levels can lead to algal bloom. These blooms can further deplete oxygen levels and release toxins harmful to aquatic organisms and human health [22].

3.2.2. Agricultural Sector

The agricultural sector in the Cikembar sub-watershed comprises rice fields and farms. The potential pollution load of the agricultural sector is calculated based on land areas, emission factors, and the number of planting days.

The results of the calculation of the potential pollution load of the agricultural sector in the Cikembar sub-watershed are presented in Table 12, and the contribution of each village to the potential pollution load of the agricultural sector in the Cikembar sub-watershed is shown in Figure 6. The agricultural area in the study area is presented in Figure 7. Rice fields and farm areas are marked in green and red, respectively.

Table 12. Potential Pollution Load of the Agricultural Sector in the Cikembar Sub-watershed.

District	Village	Potential Pollution Load (kg/Day)				
		TSS	BOD	COD	Total-N	Total-P
Cicantayan	Hegarmanah	0.02	4.66	7.00	0.42	0.21
Warung Kiara	Ubrug	0.01	3.45	5.17	0.31	0.15
	Bojongkerta	0.04	20.03	30.05	1.78	0.89
Cibadak	Cibadak	0.00	1.77	2.65	0.16	0.08
	Sekarwangi	0.01	1.09	1.64	0.10	0.05
	Tenjojaya	0.01	0.80	1.20	0.07	0.04
Cikembar	Sukamulya	0.02	5.35	8.02	0.48	0.24
	Bojongkembar	0.03	11.28	16.91	1.01	0.50
	Cikembar	0.02	4.02	6.03	0.36	0.18
	Cimanggu	0.03	9.31	13.97	0.83	0.41
	Cibatu	0.00	0.25	0.37	0.02	0.01
	Sukamaju	0.01	4.92	7.39	0.44	0.22
Total		0.20	66.94	100.41	5.97	2.98

The area of agricultural land is directly proportional to the amount of potential pollution load from the agricultural sector. In addition, agricultural land type, emission factor, multiplier factor, and the length of the growing season also affect the potential pollution load from this sector. Based on the calculation results, Bojongkerta Village has the largest contribution to the pollution load of the agricultural sector produced in the Cikembar sub-watershed, as they have the largest area of agriculture in the catchment.

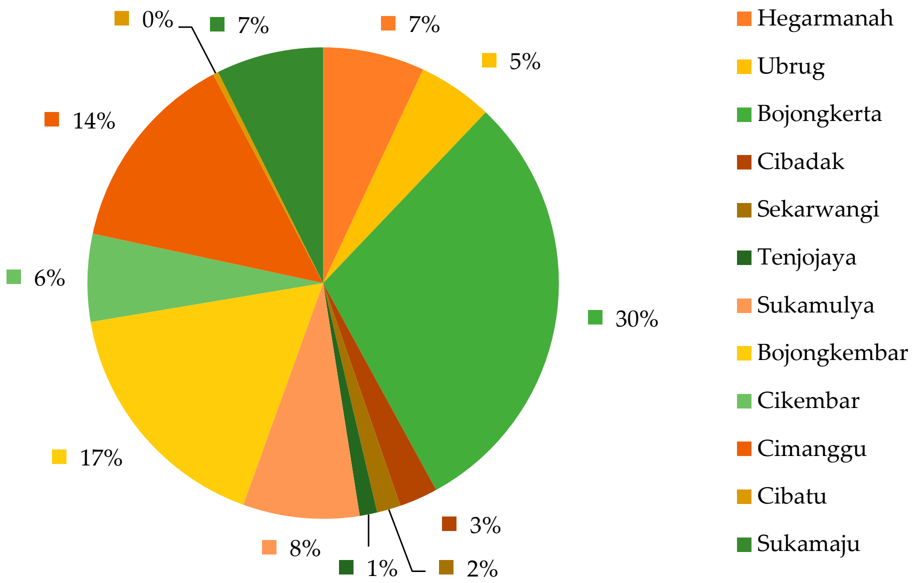

Figure 6. The Contribution of Each Village to the Potential Pollution Load of the Agricultural Sector in the Cikembar Sub-Watershed.

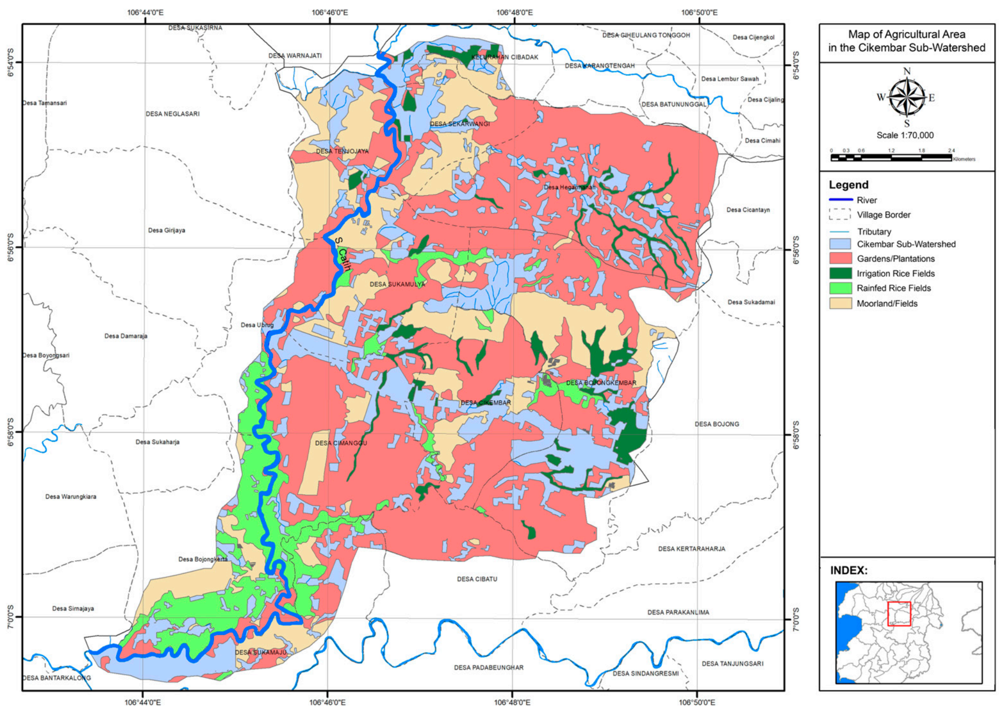

Figure 7. Agricultural Area in the Cikembar Sub-Watershed.

In Sukabumi Regency, farmers use fertilizers, pesticides, and herbicides to increase crop yields. When mismanaged or applied excessively, these chemicals wash into nearby rivers through surface runoff or leach into groundwater, eventually reaching the rivers. This leads to elevated levels of nutrients, such as nitrogen and phosphorus, and various harmful chemicals in the water, which eventually harm aquatic ecosystems and human health [23].

Furthermore, inadequate land management practices, such as inappropriate land clearing and logging, significantly exacerbate river pollution within the Cikembar watershed by intensifying soil erosion. The eroded soil, called sediment, gets carried into rivers during rainfall. This sediment smothers riverbeds and negatively impacts aquatic habitats by reducing the amount of light and oxygen that can reach aquatic organisms [1].

3.2.3. Livestock Sector

The livestock sector in the Cikembar sub-watershed comprises seven types of livestock: cattle, sheep, chicken, duck, buffalo, horse, and goat. The calculation is conducted based on the number of livestock and the emission factor of each type of livestock. The results of the calculation of the potential pollution load of the livestock sector in the Cikembar sub-watershed are shown in Table 13, and the contribution of each village to the potential pollution load and their spatial mapping of the livestock sector in the Cikembar sub-watershed are shown in Figures 8 and 9 below.

Table 13. Potential Pollution Load of the Livestock Sector in the Cikembar Sub-watershed.

District	Village	Potential Pollution Load (kg/Day)			
		BOD	**COD**	**Total-N**	**Total-P**
Cicantayan	Hegarmanah	26.668	64.513	0.134	0.035
Warung Kiara	Ubrug	7.072	16.998	0.030	0.010
	Bojongkerta	3.154	7.841	0.038	0.005
Cibadak	Cibadak	0	0	0	0
	Sekarwangi	0	0	0	0
	Tenjojaya	0	0	0	0
Cikembar	Sukamulya	0	0	0	0
	Bojongkembar	11.596	29.568	0.268	0.030
	Cikembar	256.408	608.766	0.350	0.329
	Cimanggu	0.935	2.428	0.031	0.002
	Cibatu	11.051	27.167	0.091	0.015
	Sukamaju	131.370	313.807	0.317	0.169
Total		448.253	1071.089	1.259	0.595

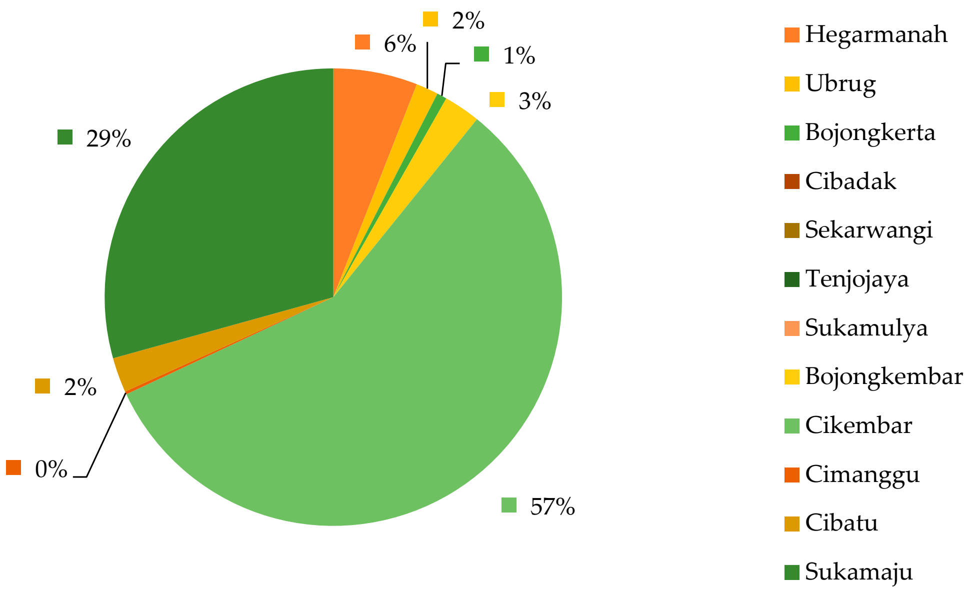

Figure 8. The Contribution of Each Village to the Potential Pollution Load of the Livestock Sector in the Cikembar Sub-Watershed.

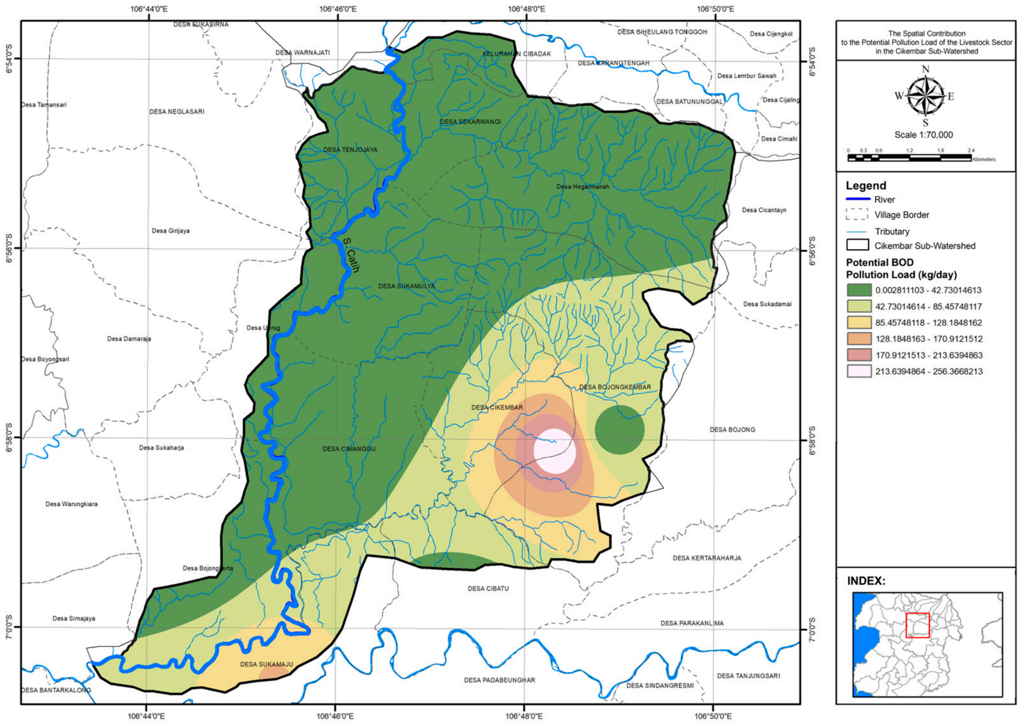

Figure 9. The Spatial Contribution to the Potential Pollution Load of the Livestock Sector in the Cikembar Sub-Watershed.

The discharge of animal waste, particularly from concentrated animal feeding operations (CAFOs) and large-scale livestock farms, is a significant source of river pollution in Indonesia, including in the Cikembar catchment. Animal manures containing minerals like nitrogen and phosphorus are mismanaged in the Cikembar catchment. Thus, they are washed into nearby rivers through rainfall runoff or leach into groundwater [24]. The other sources of contaminants from the livestock activities in Cikembar are pathogens and chemicals. Livestock produces pathogens, such as bacteria, viruses, and parasites, in their waste. In Cikembar, they are mismanaged and treated ineffectively, allowing these pathogens to contaminate nearby rivers, posing risks to human health and aquatic life. As for the chemicals, many farmers in Cikembar use chemicals and pesticides to control pests and parasites. These chemicals potentially enter rivers due to improper treatment of the chemical and pesticide waste [25].

3.2.4. Industrial and Commercial Sector

Based on available data, the potential pollution load for the industrial and commercial sectors is calculated using the number of employees and emission factor. The map of the industrial and commercial area in the Cikembar sub-watershed is shown in Figure 10.

Potential pollution load calculations for industries depend on the availability of respective emission factors. If some industries' emission factors are unavailable, the emission factor of a similar industry was used. For example, to calculate the potential pollution load for pharmaceutical industries, the emission factor for chemical industries was used due to the unavailability of the emission factor for pharmaceutical industries.

The results of the calculation of the potential pollution load of the industrial sector in the Cikembar sub-watershed are presented in Tables 14 and 15, and the contribution of each village to the potential pollution load of the industrial sector in the Cikembar sub-sub-watershed is shown in Figures 11–13.

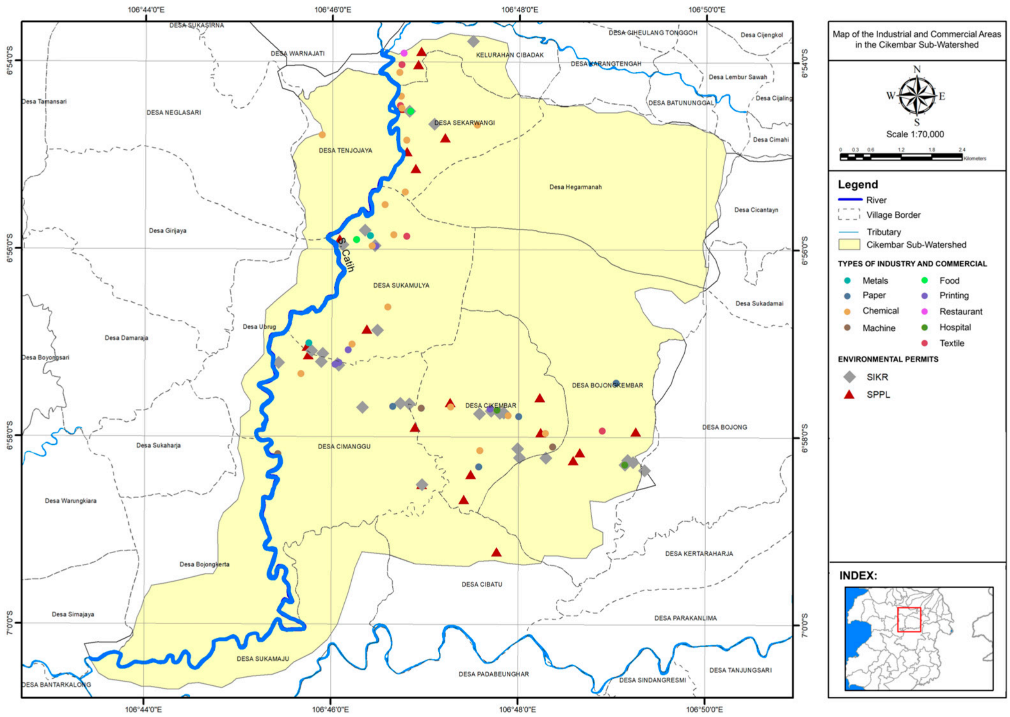

Figure 10. The Map of the Industrial and Commercial Areas in the Cikembar Sub-Watershed.

Table 14. Potential Pollution Load of the Industrial and Commercial Sector in the Cikembar Sub-watershed.

District	Village	Potential Pollution Load (kg/Day)	
		BOD	COD
Cibadak	Cibadak	366.31	549.47
	Sekarwangi	107.62	161.43
	Tenjojaya	28.47	42.71
Cikembar	Sukamulya	494.35	741.52
	Bojongkembar	38.15	57.22
	Cikembar	154.77	232.15
	Cimanggu	1.78	2.67
Total		1191.45	1787.18

Table 15. Potential Pollution Load of the Industrial and Commercial Sector in the Cikembar Sub-watershed Based on Industry Type.

Type of Industry	Potential Pollution Load (kg/Day)	
	BOD	COD
Metal goods	0.17	0.26
Paper	2.69	4.03
Chemical	540.99	811.48
Machine	0.13	0.20
Other foods	0.53	0.80
Printing	0.14	0.20
Restaurant	0.41	0.61
Hospital	8.36	12.55
Car & motorcycle parts	0.16	0.24
Textile	637.87	956.81
Total	1191.45	1787.18

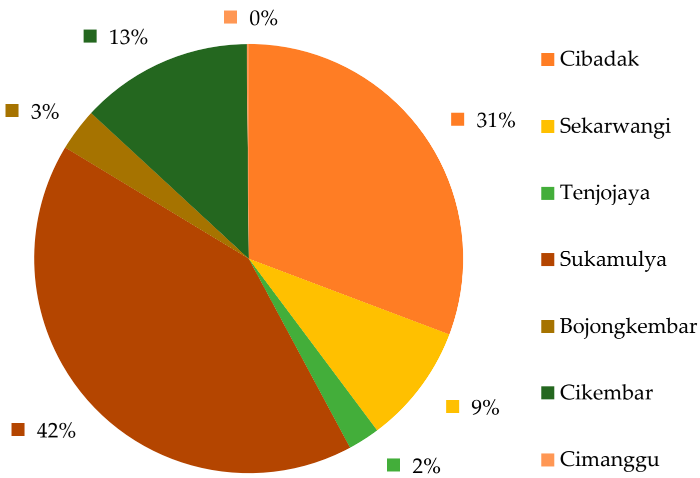

Figure 11. The Contribution of Each Village to the Potential Pollution Load of the Industrial and Commercial Sector in the Cikembar Sub-Watershed Based on Area.

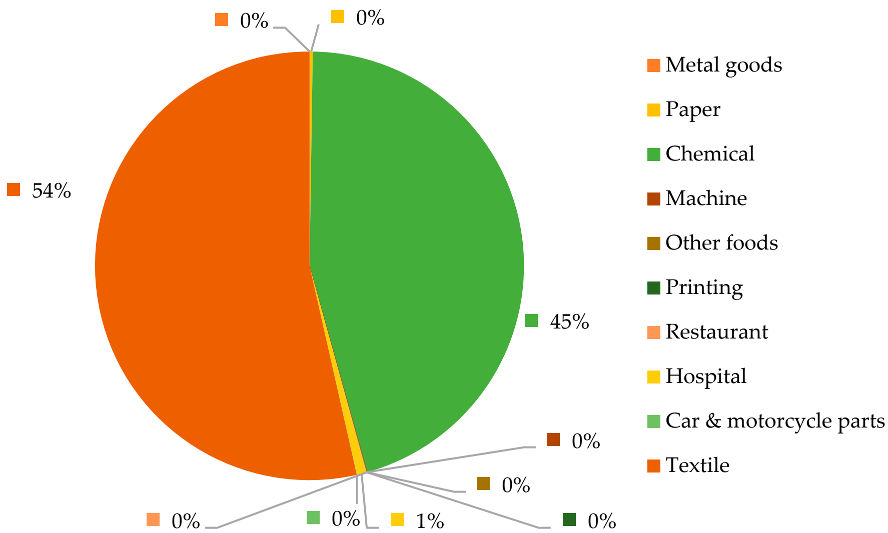

Figure 12. The Contribution of Each Village to the Potential Pollution Load of the Industrial and Commercial Sector in the Cikembar Sub-Watershed Based on Industry Type.

The potential pollution load generated from the industrial and commercial sectors is influenced by the number of employees and industry type; increase in employees results in increased potential pollution load. The results of the calculation show that Sukamulya Village and the textile industry are the biggest contributors to the potential pollution load of the industrial and commercial sectors in the Cikembar sub-watershed. However, due to limited data, only parameters BOD and COD are calculated and discussed in this manuscript.

Textile manufacturing in the Cikembar watershed, and generally in Indonesia, involves using dyes, chemicals, and finishing agents to color and treat fabrics. Wastewater generated from these processes contains various organic compounds and toxic substances. Various reasons may lead to improperly treated wastewater being discharged into rivers, significantly elevating BOD levels [19]. Also, these textile industries use various chemical additives, such as detergents, softeners, and bleach, which harm the environment when discharged to nearby rivers. Some of these chemicals are biodegradable, but others are not, and they can contribute to BOD pollution in the Cicatih River [26].

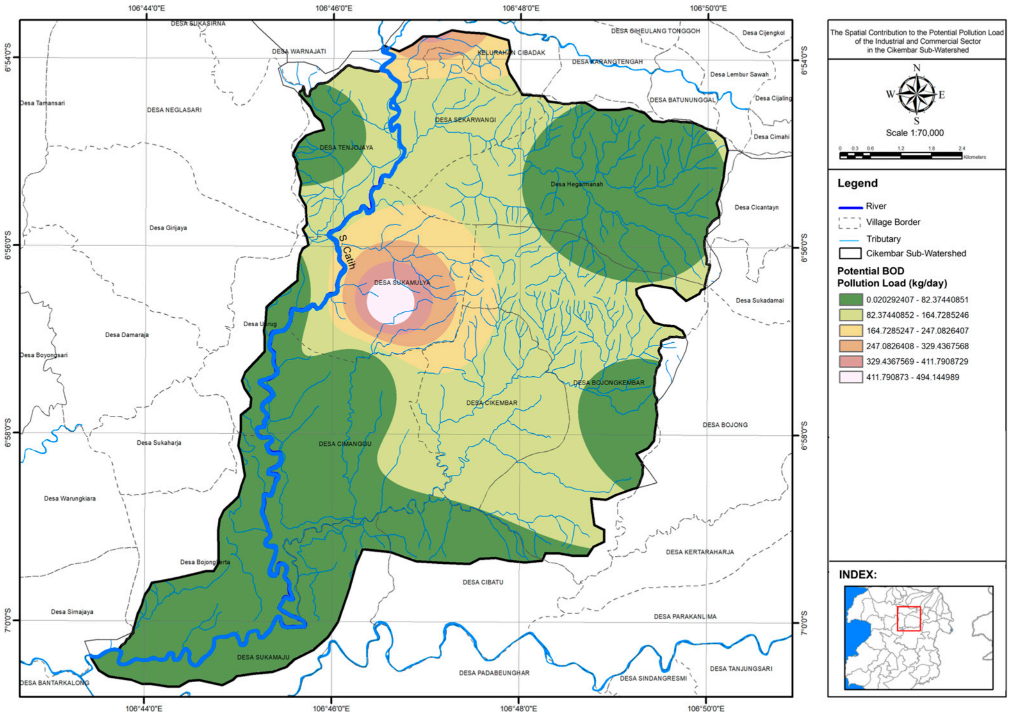

Figure 13. The Spatial Contribution to the Potential Pollution Load of the Industrial and Commercial Sector in the Cikembar Sub-Watershed.

The other major contributor to river pollution from the industrial sector comes from the chemical industries. In the Cikembar watershed, chemical industries can contribute to river pollution, including increasing BOD, in Indonesia through various processes and activities. Chemical manufacturing plants generate wastewater as a by-product of their processes, which contains various organic and inorganic compounds. When these effluents are discharged into nearby rivers without proper treatment, they significantly increase the BOD levels in the receiving water bodies. Further, accidental releases of chemicals or chemical spills from industrial facilities can introduce large quantities of toxic and organic compounds into rivers. These substances harm aquatic life and contribute to elevated BOD levels in the Cicatih River [25].

3.2.5. All Sector

The potential pollution load in the Cikembar sub-watershed is calculated based on four main sectors: domestic, agricultural, livestock, and industrial and commercial. Based on calculation results of the potential pollution load for the BOD parameter, the domestic sector is largest contributor to the pollution of the Cicatih River in the Cikembar sub-watershed. A total of 3604.46 kg of organic material presented in BOD value, enter the Cicatih river in the Cikembar sub-watershed daily from all sectors. The results of the calculation of the potential pollution load of all sectors in the Cikembar sub-watershed are shown in Table 16 and Figure 14 below.

The high levels of the TSS parameter are mainly caused by soil erosion eroding into water bodies. If not addressed, it will increase the turbidity of water and reduce the light that can enter the water, resulting in the death of aquatic organisms [25]. Elevated concentrations of Total-N pose a threat to water quality and certain aquatic organisms due to their potential toxicity. Conversely, heightened levels of Total-P precipitate algal blooms, causing oxygen depletion and light attenuation, thereby disrupting the ecological balance within the food chain and the overall aquatic ecosystem [27,28].

Table 16. The Potential Pollution Load of All Sectors in Cikembar Sub-watershed.

Type of Agriculture	Potential Pollution Load (kg/Day)				
	TSS	BOD	COD	Total-N	Total-P
Domestic	1802.93	1897.82	2609.50	92.52	9.96
Agricultural	0.20	66.94	100.41	5.97	2.98
Livestock	-	448.25	1071.09	1.26	0.60
Industrial and Commercial	-	1191.45	1787.18	-	-
Total	1803.13	3604.46	5568.17	99.74	13.54

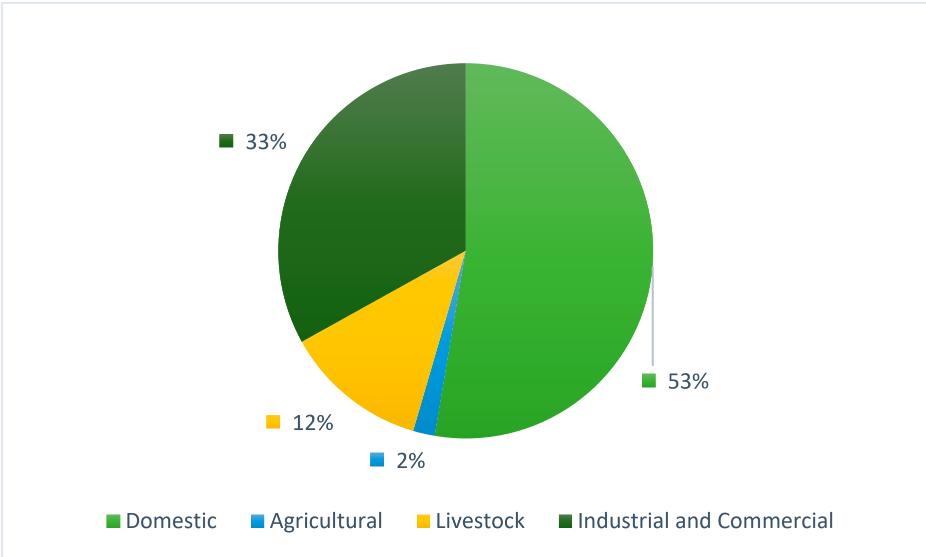

Figure 14. The Contribution of Each Sector to the Potential Pollution Load in the Cikembar Sub-watershed.

Other parameters, such as BOD and COD, are interrelated because they can be used to determine the oxygen content status in the water. The size of the oxygen content in the water can indicate whether the water is polluted [29]. A high BOD parameter value indicates polluted river water [18]. This also happened to the COD parameter. High values of BOD and COD affect the amount of oxygen needed to decompose organic matter that pollutes river water [30]. Increased oxygen consumption depletes the oxygen available in the river water, resulting in insufficient oxygen resources for aquatic organisms. If unresolved, the aquatic organisms will die, thus disrupting the food chain/ecosystem [29].

All explanations show the importance of domestic wastewater management. If the river water remains unattended, water quality deterioration is inevitable. Water quality is one of the most important aspects for the sustainability of water resources. Poor water quality will affect the environmental, social, health, and economic aspects [30], which is also exacerbated by climate change [31].

Bojongkembar Village needs special attention in managing the Cicatih River in the Cikembar sub-watershed because it is the largest contributor to the potential pollution load, especially in the domestic sector. As previously explained, river pollution from the domestic sector is strongly influenced by population. Therefore, discharging domestic wastewater directly or without treatment into the river must be prevented. Domestic waste management efforts can be conducted with a communal WWTP construction program. In addition, settlements near riverbanks must be prevented, and existing ones must be relocated. All these efforts must be made to reduce the potential pollution from the domestic sector and resolve other related problems, such as water-borne diseases, water availability shortage, and flood risk [16].

4. Conclusions

This research shows that the water quality status of the river in the Cikembar sub-watershed is slightly polluted, with BOD parameters exceeding the maximum threshold in all monitoring locations. Based on the results of the potential pollution load calculation for the BOD parameter, the domestic sector (53%) is the largest contributor to the pollution of the Cicatih River in the Cikembar sub-watershed, while the agricultural is the least (2%).

For the domestic sector, Bojongkembar village has the highest BOD contribution, with 16% of the total pollution load in the Cikembar sub-watershed. As for the agriculture sector, the highest pollution contributor is Bojongkerta village, which accounts for 30% of the total pollution load. For the livestock and industrial sectors, the highest contributors of BOD are Cikembar and Sukamulya villages, with BOD contributions of 57% and 42%, respectively. Based on the types of industries in the Cikembar sub-watershed, the main contributors of BOD are textile and chemical industries, with 54% and 45% contributions, respectively.

The potential pollution contribution of each village in the Cikembar sub-watershed to the Cicatih River will be used by the local government of Sukabumi Regency to develop programs to reduce the pollution load for each village.

To optimize the applicability of the findings outlined in this manuscript for diverse stakeholders, pollution load modeling in the Cicatih River will be performed. This will be accomplished through the utilization of Qual2K Version 5.1 and WASP Version 8.32 modeling software, considering variations in river flow during both rainy and dry seasons.

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