Analysis of river water quality and pollution control strategies in the upper Citarum River

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Abstract. Utilization of the Citarum River varies greatly from household needs, agriculture, livestock to the industrial sector. However, these activities caused pollution along the Citarum River. This research's main objective is to evaluate the quality of surface water in the upstream Citarum River based on Government Regulation No. 82 of 2001 and its pollution control recommendations. The observed river study area was 80 km long. River water quality is measured and observed at 8 sampling points. Analysis of water quality was carried out using the Pollution Index (IP) method. Meanwhile, the formulation of the pollution control strategy used SWOT analysis. Based on field measurements for parameters BOD, COD, and DO in the upstream segment of the Citarum River have exceeded the quality standard for class II Regulation No. 82 of 2001 in almost all sampling locations. Meanwhile, the IP value results at all sampling locations were in the range of 1.23-5.8 or in mild to moderate polluted status. Recommendations given to control water pollution are increasing monitoring of wastewater disposal into rivers, carrying out an inventory and identifying water pollution sources, and determining the carrying capacity of pollution loads.

1. Introduction
The river as a water source has so many benefits for human life, such as for sanitation, transportation, irrigation, and others. However, the quality of river water is also very much needed by social activities around it. The Citarum River, as a cross-administrative river has a very concerning condition with the title as the most polluted river in the world [1]. Over the past 20 years, rapid urbanization and industrial growth have resulted in an increase in untreated waste from many sectors discharged into the Citarum River [2]. Rivers, as a recipient of wastewater, both domestic and industrial wastes, are vulnerable to pollution.

The volume of waste in the upstream segment has reached 500,000 m³/year. This condition causes changes in ecosystem function, ecological status, and pollution in the Citarum watershed [3]. Limited sanitation facilities for residents, industry non-compliance with wastewater disposal regulations, untreated livestock wastewater, and dumping of garbage into rivers have contributed to the decline in river water quality.

Based on a report from Dinas Lingkungan Hidup (DLH) of Bandung Regency in 2017, the status of the Citarum River tributaries' water quality in all locations has been categorized as polluted, whether mild, moderate, or severe [1]. This can be seen from the parameters observed, physics, chemistry, and
microbiology that are still above the quality standards for surface water for class I and class II of Government Regulation No. 82 of 2001 [4]. Total Suspended Solid (TSS) and Biochemical Oxygen Demand (BOD) concentrations are extremely high in Citarum River, but Dissolved Oxygen (DO) concentrations decrease to almost zero along the river [5]. In general, for the case in the upstream Citarum River, the highest concentration of BOD and Chemical Oxygen Demand (COD) parameters is at the location of industrial wastewater receiving bodies [1].

Various efforts to manage and control pollution from the Citarum River and its tributaries need to be done. Referring to the problems, further monitoring efforts are required of the condition of the Citarum River. This monitoring effort aims to provide factual information about the current condition of water quality. One alternative to support this goal's achievement is to determine the water quality and quality status of the Citarum River. To know about the river's water quality status, one can use the STORET Method or the Pollution Index Method.

According to the background of the above problems, the goals of this research is to analyze the quality of river water and the pollution status of the upper Citarum River in Bandung Regency, based on evaluation of water quality according to its designation and determination of water class in accordance with Government Regulation No. 82 of 2001 as well as an assessment of the water quality status of the Citarum River using the Pollution Index Method according to the Minister of Environment Decree No. 115 of 2003. In addition, a formulation of the Citarum River pollution control strategy was also analyzed by using a SWOT analysis. Hopefully, the outputs of this study are used as the basis for water resources management, both by the community and by the local government.

2. Methodology

2.1. Determination of study area and sampling point location

This study's area is in the upper Citarum River and covers an area of 173,433.41 ha and along 80 km. The river flows through Bandung Regency, Bandung City, and Cimahi City. Geographically the Upper Citarum Watershed is located between 107º30' - 108 East and 6º43' LS - 7º15 LS. There are 8 sampling points (SP) as shown in table 1 in the upper Citarum River region. Determination of the monitoring point as the sampling point for river water using a purposive sampling method based on the ease of access, cost, and time in this study.

| No. | Location     | Coordinates                  | Distance (km) |
|-----|--------------|------------------------------|---------------|
| SP1 | Cisanti Lake | 107°39'36.69” BT - 7°12’36.53” LS | 0             |
| SP2 | Wangisagara  | 107°44'55.45” BT - 7°04’24.87” LS | 25.04         |
| SP3 | Majalaya     | 107°45’23.18” BT - 7°03’3,33” LS    | 3.99          |
| SP4 | Sapan        | 107°42’16,94” BT - 6°59’24,45” LS   | 12.00         |
| SP5 | Cijeruk      | 107°38’23,13” BT - 7°00’15,516” LS | 11.22         |
| SP6 | Dayeuhkolot  | 107°37’34,81” BT - 6°59’27,03” LS   | 3.33          |
| SP7 | Burujul      | 107°32’44,69” BT - 6°58’17,20” LS   | 16.16         |
| SP8 | Nanjung      | 107°32’7,45” BT - 6°56’29,21” LS   | 7.71          |
2.2. Method of collecting data
Primary data are data obtained through direct measurements in the field. Primary data were obtained using field survey methods and sampling. Primary data collection was carried out including preliminary surveys and water sampling.

Data collection was conducted in October 2019. The river water sampling method was using the grab sampling method, a momentary sampling method that collected samples at one location and at one point in time [6]. Before the analysis is conducted in the laboratory, preservation is being done so that there are no physical or chemical changes to the sample.

The parameters measured were BOD, TSS, DO, COD, pH, and temperature. The objects of observation at the study location include the upstream Citarum River's condition and community activities around the river.

Meanwhile, the secondary data used in this study are data that can support primary data analysis. Secondary data collection is due to meet data needs that cannot be retrieved directly due to limited funds and time. Secondary data used were the upper Citarum watershed map and field observations.

2.3. Water quality status
This study uses the Pollution Index (IP) method. IP is a simple and easy to apply a method of assessing river water quality. The IP value indicates the level of pollution relative to the water quality standard required at the water source (river) [7]. Water quality index categories based on IP values are as follows:

- $0 \leq \text{Pij} \leq 1.0$ then the status meets the quality standard (good condition)
- $1.0 < \text{Pij} \leq 5.0$ then the status is mildly polluted
- $5.0 < \text{Pij} \leq 10$ then the status is moderately polluted
- $\text{Pij} > 10$ then the status is heavily polluted

The calculation of the Pollutant Index (IP) value is calculated using equation 1:

$$ P_{ij} = \left( \frac{\frac{C_i}{L_{ij}r} + \frac{C_i}{L_{ij}m}}{2} \right)^{1/2} $$ (1)

Where:
- $P_{ij}$: value of pollution index (j)
- $L_{ij}$: concentration of water quality parameters based on water Quality Standard (j)
- $C_i$: concentration of water quality parameter (i)

Where $(C_i / L_{ij}) r$ is the average $(C_i / L_{ij})$ value, while $(C_i / L_{ij}) m$ is the maximum $(C_i / L_{ij})$ value.
2.4. Formulation of strategies to control river water pollution

The data analyzed in formulating a strategy to control river pollution in the Citarum River was determined based on an analysis of water quality, level of pollution load, literature studies and interviews. The data analysis method used in formulating a strategy to control water pollution in the Citarum River is a SWOT analysis (strength, weakness, opportunity, treat). Strategic planning is based on an analysis of strategic factors that include strengths, weaknesses, opportunities and threats in the current conditions. The process of compiling strategic planning goes through three stages of analysis, namely: the data collection stage, the analysis stage and the decision-making stage [8].

Data collection can be done by interviewing related stakeholders and other parties, especially experts who know about Citarum River condition. Then, from the data obtained, internal and external were determined, and a matrix was made. From the matrix analysis, it can be concluded what strategies are appropriate to anticipate weaknesses and threats. Then, the strategy taken can be implemented in policymaking in the field [8].

3. Results and discussion

3.1. River water quality analysis

Citarum River is classified in class II of water quality according to the regulation. Table 2 shows the results of monitoring the water quality of the upstream Citarum River.

| No | Parameter | Units | SP1 | SP2 | SP3 | SP4 | SP5 | SP6 | SP7 | SP8 | Water Quality Standard for Class II of PP No. 82/2001 |
|----|-----------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----------------------------------------------|
| 1  | pH        |       | 7.75| 8.53| 7.5 | 7.62| 7.75| 7.64| 7.68| 7.56| 6-9                                           |
| 2  | Temp      | °C    | 25.2| 29.7| 31.6| 32.9| 28.6| 30.4| 28.6| 28.5| Deviation 3                                   |
| 3  | TSS       | mg/l  | 17  | 22  | 21  | 25  | 30  | 124 | 124 | 60  | 50                                           |
| 4  | DO        | mg/l  | 9.9 | 6.83| 4.23| 1.12| 3.32| 2.15| 0.84| 0.5 | 4                                            |
| 5  | BOD       | mg/l  | 4.6 | 4   | 12  | 36  | 30  | 58  | 37  | 36  | 3                                            |
| 6  | COD       | mg/l  | 10  | 8.9 | 23  | 74  | 64  | 144 | 66  | 77  | 25                                           |

The results of measuring the pH of the upper Citarum River show that the water's pH at SP1 to SP8 is ranging from 7.75 to 8.53. Therefore, still within the range of class II river water quality standard. Water with a pH value range of 6.5 - 7.5 is normal for surface water that meets life requirements [9].

For BOD concentration, it is ranged from 4 mg/l in SP2 to 58 mg/l in SP6. Meanwhile, the water quality standard is 3 mg/l. The maximum level of BOD$_3$ allowed for drinking water and supporting aquatic organisms is 3.0-6.0 mg/l [10]. BOD concentration is directly associated with DO concentration high value of BOD shows a decline in DO concentration [11]. In this study, the highest DO values are in the upstream area and tend to decrease downstream, while BOD value is low upstream and increasing downstream. The highest DO concentration is in SP1 with 9.9 mg/l, and the lowest is in SP8 with 0.5 mg/l. Water condition can be categorized as good and has a low level of pollution if its dissolved oxygen (DO) level is greater than 5 mg/l [12]. COD concentrations result also similar to BOD. The lowest COD concentration is 8.9 mg/l at SP2, and the highest is 144 mg/l at SP6. Meanwhile, the water quality standard for COD concentration is 25 mg/l.

In the upstream area, which is around the SP1 and SP2 areas, it is still dominated by agricultural, rice fields and forest areas. Meanwhile, starting from SP3, many industrial areas, especially textile industries, discharged their waste directly into the Citarum River. This has resulted in a degrade of water quality of the Citarum River. The highest concentration of BOD is in SP6, which is a densely populated area. In addition, there are several communal WWTP as well as Bojong Soang WWTP and Cisirung WWTP around there. SP6 also has the highest COD concentration because in SP6, there is an accumulation of
COD pollutant loads from previous points. COD concentrations were accumulated from industrial waste types of textiles and dyes, which were widely found in the SP3, SP4, and SP5 areas. A wide usage of chemical and organic fertilizer and discharge of sewage affect COD level, while the high COD pointing to a deterioration of the water quality is attributed to the discharged of municipal effluent [13]. Industrial waste contains organic material which is difficult to decompose. Starting from SP6 to SP8, water flow is also relatively low. This also caused low DO concentration. Rapidly moving water tends to contain a lot of dissolved oxygen whereas stagnant water contains less [14]. For TSS concentration, it is varied from 17 mg/l in SP1 to 124 mg/l in SP 5 and SP 6. TSS pollutant loads are caused by natural factors such as landslides or sediment transport from rivers due to water flow and anthropogenic factors or human activities. The high TSS concentration is because river water contains a lot of silt and fine sand and microorganisms carried from soil erosion to water bodies [6].

3.2. Water quality status
Analysis of water quality status is conducted based on the guidelines for determining water quality status set by the Regulation of Ministry of Environment number 115 of 2003 using the Pollution Index (IP). A river is said to be polluted if it cannot be used according to its normal designation. Table 4 is the calculation result for the Pollution Index in the Upper Citarum River.

| No | Location      | IP value | Status       |
|----|---------------|----------|--------------|
| SP1| Cisanti Lake  | 1.43     | Mildly polluted |
| SP2| Wangisagara   | 1.23     | Mildly polluted |
| SP3| Majalaya      | 2.94     | Mildly polluted |
| SP4| Sapan         | 4.87     | Mildly polluted |
| SP5| Cijeruk       | 4.53     | Mildly polluted |
| SP6| Dayeuhkolot   | 5.79     | Moderately polluted |
| SP7| Burujul       | 5.04     | Moderately polluted |
| SP8| Nanjung       | 4.93     | Mildly polluted |

The calculation results found that all parts of the upper Citarum River based on the parameters BOD, COD, TSS, DO, and pH if using class II quality standards as benchmarks have been polluted. In the upstream or Cisanti Lake, it is classified as mildly polluted. As for locations in Wangisagara, Majalaya, Sapan, Cijeruk and Nanjung also classified as mildly polluted. Meanwhile, two locations, which are Dayeuhkolot and Burujul, were classified as being moderately polluted. The increase in the value score correlates with the increase in the value of the pollutant parameters at each monitoring point, and this also is correlated with the increase in population and the industrial sector as the dominant source of pollutants that contributed to the most parameters concentration such as COD, BOD, and TSS[15,16].

3.3. Formulation of river water pollution control strategy
The pollution control strategy used in this study is the SWOT analysis. The SWOT factor selection is intended to obtain factors that relatively give a higher degree of importance compared to other factors. The scope stipulated in this strategy formulation includes 7 things, which are: inventory and identification of water pollutant sources, calculation of the load capacity of water pollution, determination of wastewater quality standards, stipulation of policies for water pollution control, licensing, monitoring of water quality, guidance and supervision, and provision of information [7].

Citarum River water pollution control strategies are formulated based on the results of water quality analysis, pollution levels, literature studies and interviews with authorized agencies to obtain
information about efforts to control river water pollution so that internal and external factors can be identified in controlling river water pollution.

The position of the SWOT diagram for the strategies formulation in this study is in quadrant 3. The quadrant position is a strategic position by facing enormous opportunities but facing several internal obstacles or weaknesses. Another effort that can be done is to minimize internal problems as well as to seize opportunities or by taking advantage of all existing opportunities to minimize all the weaknesses that exist in the management of clean water resources in the upper Citarum River.

The recommendations for the Citarum River pollution control strategy that can be used are as follows:

- Improve the controlling of wastewater disposal into rivers, carry out an inventory and identification of sources of water pollution, and determine the carrying capacity of pollution loads.
- Improve monitoring of river water quality and supervision of the discharge of wastewater into rivers that has the potential to pollute the Citarum River
- Permit to dispose of wastewater into rivers must consider the condition of the Citarum River water pollution load's carrying capacity. Conducting law enforcement against business sectors who violate the regulation of water quality standards
- Provide environmental education and routine outreach to increase public awareness of the environment.

4. Conclusion
The water quality condition of the upstream Citarum River for the BOD concentration at all sampling points from upstream to downstream has exceeded the class II water quality standard based on Government Regulation No. 82 of 2001, while the COD and DO concentration from SP4 to SP8 have exceeded class II water quality. In addition, for TSS concentration also from SP6 to SP8 has exceeded the water quality standard. The status of water quality in the upper Citarum River at SP1 to SP5 and SP8 shows the status of "mildly polluted" while on SP6 and SP7, the status is "moderately polluted".

Based on the SWOT analysis results, recommendations strategies for controlling water pollution in the upper Citarum River is a strategic position by facing enormous opportunities but facing several internal obstacles or weaknesses. Some recommendations for Citarum River pollution control strategies are to increase monitoring of wastewater disposal into rivers, conduct an inventory and identification of water pollution sources, determine the carrying capacity of pollution loads, and also provide environmental education and routine outreach to increase public awareness of the environment.

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