Water Quality Monitoring and Evaluation in the Bengawan Solo River Region

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Abstract. The Bengawan Solo River Region with an area of 19,778 km² consists of 96 watersheds with four main watersheds, namely the Bengawan Solo watershed with an area of 15,295.69 km², which has a main river, the Bengawan Solo River which flows from Wonogiri to the downstream area on the north coast of Gresik Regency, Grindulu Lorog Watershed with 1,040,656 km² area, Corong watershed with an area of 815,081 km², and Lamong watershed with an area of 760,292 km². Bengawan Solo River crosses various areas both natural and cultivated areas including forests, rice fields, to settlements and industries, causing changes in water quality from upstream to downstream. The purpose of this study was to determine the level of pollution in the Bengawan Solo River Region from upstream to downstream. This research method is to analyze the parameters of the results of testing water quality samples at several points with the Pollution Index method for second grade water quality then spatially analyzed. The results showed that of the 29 monitoring points of river water quality in the Bengawan Solo River Region, 17% were heavily polluted, 59% were moderately polluted, 24% were light polluted, and 0% were meeting quality standards. Therefore, efforts are needed to manage the river based on its water quality by maintaining the capacity of the river against pollution loads that can be received by water bodies.

1. Introduction
Indonesia has diverse natural resources, one of which is river resources. The majority of Indonesia’s population lives near water, both along rivers and lake shores. Bengawan Solo River is the largest river on the Java Island and flows water from river drainage area (DPS) covering ± 16,100 km². The use of Bengawan Solo River water is for irrigation, pump, fulfillment of water needs for households which are currently completed from local water company supply (PDAM) and community wells or directly from rivers.

The river has an important role in maintaining ecological and environmental sustainability (Wu et al., 2018). In recent years, water pollution remains a challenging issue in the world and can threaten the sustainability of urban systems (Mishra et al., 2015). The volume of wastewater produced in urban areas has increased substantially because of rapid growth of the human population, commercial activities, industrial production, as well as changes in water consumption behaviour (Ismail and Abed, 2013). The water quality decreases affecting The Bengawan Solo River has been known since the industries developed in the Sukoharjo-Karanganyar region. The pollution index increase reached its peak in October, 2018 when the water quality in Bengawan Solo River (Jurug area) was so severe
that caused this river could not be used as raw water for drinking water supply. Some sewer lines connect directly to the Bengawan Solo River and its tributaries.

Previous research has been limited to the assessment of current water quality conditions using water quality sampling in every month. This monitoring program includes all prominent rivers entering and leaving Surakarta City, which is considered to be the worst-quality river section. The further studies regarding the conditions of pollution in Bengawan Solo River haven’t been conducted because the monitoring that have been carried out only for comparing the quality of the various parameters with the class quality standard. Next, the approach of water quality management strategies is the water quality index which has proven to be an efficient and useful method for assessing water quality (Hasan et al., 2015). The purpose of this study was to determine the level of pollution in the Bengawan Solo River from upstream to downstream areas.

2. Materials and Methods

2.1 Study Area

This study focuses on the upstream Bengawan Solo River, starting from the Wonogiri Basin Outlet to the Bengawan Solo River meeting with other tributaries. The coordinate of universal transverse mercator is 483453.11887 X, 9163604.4745 Y – 681667.85893 X, 9204367.72126 Y. The river is divided into upstream and downstream areas. The upstream catchment drains an area of 6.072 km² with Wonogiri Basin as its outlet, downstream with an area of 6.273 km² and Madiun River covers with an area of 3.755 km². Water quality sampling is conducted at 29 monitoring points regularly every month. Locations of water quality monitoring points can be seen in Table 1 and Figure 1.

Table 1. Location of water quality monitoring in Bengawan Solo River.

| Jurug   | Kali wingko | Arjowinangun | Keboimas |
|---------|-------------|--------------|-----------|
| Serenan | Jarum       | Arjosari     | Blawi     |
| Waduk cengklik | Kedungpipit | Sekayu     | Malo     |
| Kali premulung | Mungkung   | Napel       | Karanggeneng |
| Bacem   | Kemiri waduk rowo | Cepu  |
| Peren   | Ahmad Yani  | Bojonegoro   |
| Nguter  | Ketonggo    | Boboh       |

2.2 Sample collection and laboratory analysis

Twenty-nine sampling sites were carefully selected to represent the whole of Bengawan Solo River, covering the main rivers of 4 watershed: Bengawan Solo Watershed which has a main river, the Bengawan Solo River which flows from Wonogiri to the downstream area on the north coast of Gresik Regency, Grindulu Lorog Watershed, Corong Watershed, and Lamong Watershed. The geographical locations of sampling points were recorded at each site which are listed in Figure 1. Water sampling was conducted in 2018 at each site/point. Most of the samples were collected under sunny and cloudy weather conditions. Selected environmental parameters, including surface water temperature (T), pH, and dissolved oxygen were obtained in situ using a pH meter portable that were calibrated prior to sampling. Other samples used for determination of chemical and biological parameters were collected and stored in refrigerator in 4°C to keep the initial characteristics. Water sample preservation used 0.3 mL concentrated H₂SO₄, 4N. Some parameters such as COD, NO₃-N, NO₂-N, Cl, SO₄ and others were filtered using GF/F filters (Whatman).
The detailed method used for the water chemistry analyses can be found in the Table 2.

Table 2. Water quality parameters and mesurement methods (standard methods).

| No | Parameters      | Unit   | Methods                            | Measurement Site |
|----|----------------|--------|-----------------------------------|------------------|
| 1  | Temperature    | ºC     | Thermometer                       | In situ          |
| 2  | Suspended solids | mg/L   | Gravimetric                        | Laboratory       |
| 3  | Dissolved solids | mg/L   | Gravimetric                        | Laboratory       |
| 4  | Discharge      | m³/s   | Calculation                        | In situ          |
| 5  | pH             |        | pH meter                          | In situ          |
| 6  | Dissolved oxygen | mg/L   | DO meter                          | In situ          |
| 7  | BOD            | mg/L   | Winkler & incubation              | Laboratory       |
| 8  | COD            | mg/L   | Refluxs K₂Cr₂O₇                   | Laboratory       |
| 9  | Phosphate      | mg/L   | Spectrophotometer                 | Laboratory       |
| 10 | NO₃-N          | mg/L   | Spectrophotometer (brucine)       | Laboratory       |
| 11 | NO₂-N          | mg/L   | Spectrophotometer (sulfanilic acid) | Laboratory       |
| 12 | Oil & grease   | µg/L   | Gravimetric                        | Laboratory       |
| 13 | Detergent      | µg/L   | Spectrophotometer                 | Laboratory       |
| 14 | Cu             | mg/L   | Atomic Absorption Spectrophotometer (AAS) | Laboratory     |
| 15 | Pb             | mg/L   | AAS                               | Laboratory       |
| 16 | Sn             | mg/L   | AAS                               | Laboratory       |
| 17 | F              | mg/L   | AAS                               | Laboratory       |
| 18 | Cl             | mg/L   | AAS                               | Laboratory       |
| 19 | Total coliform | JPT/100 mL | Total Plate Count (TPC) | Laboratory       |
Data were analysis based on Pollution Index as well as Government Regulation No. 82/2001 (class II), water quality for infrastructure / water recreation facilities, freshwater, animal husbandry and irrigation.

2.3 Pollution Index

Pollution Index is used to determine the level of relative pollution for permitted water quality parameters (Nemerow, 1974). Pollution Index is determined for a particular purpose (river class II) (Regulation of Environmental Ministry, No. 115/2003). The water quality management based on this Pollution Index (IP) can provide input to policy makers (government) in order to assess the quality of water river. The government can take action to improve if there is a quality decrease due to the presence of pollutants. The formula used to calculate Pollution Index (IP):

\[ PI = \sqrt{\left(\frac{C_i}{L_i}\right)^2 + \left(\frac{C_j}{L_j}\right)^2} \]

3. Results and Discussion

3.1 The existing conditions of Bengawan Solo River
Evaluation of the existing condition of the Bengawan Solo River is conducted with comparing the analysis results of physical and chemical parameters from water samples taken with applicable water quality criteria, which refer to Government Regulation No 82/2001. Bengawan Solo River has been determined as a stream with Class 2 criteria based on water quality management and water pollution control regulations.

3.2 Physical water quality parameters
Two physical parameters temperature and total suspended solid are described. The results of water temperature and total suspended solid measurements are shown in Figure 2(a) and Figure 2(b).

3.2.1 Temperature
In water quality monitoring, temperature is measured in degree Celsius that refers to how cold or warm the stream is. Water temperature values fluctuate from upstream, middle, and downstream zones. Generally, the average temperature ranges from 24°C – 31°C with an overall average of 28°C. The highest temperature value is in Cepu at 2017 (30.68°C) and the lowest values is in Bulakan at 2018 (24.95 °C). The results is in accordance with the opinion of Akoto et al. (2017), which states the temperature of river water in the tropics generally varies between 25°C - 35°C.

![Figure 2 (a). The water temperature results in Bengawan Solo River.](image-url)
3.2.2 Total Suspended Solids (TSS)
Total suspended solids is a specific measurement of solid all suspended solids, organic and inorganic, by mass which present in a water body. The results showed that the total value of suspended solids (TSS) in Bengawan Solo River averaged between 16 mg/L – 74 mg/L with an overall average value of mg/L. This is caused by the large number of suspended particles consisting of sludge, and, microorganisms due to the deposition and decay of organic materials from residential and industrial wastes. The water quality standard in 2001 states that the maximum level of TSS allowed in class 2 water use is 50 mg/L. From the Figure 2 (b). in Kajangan at 2016, we can see that there is a TSS value which exceeds the quality standard of 74 mg/L.

![Figure 2 (b). The total suspended solids results in Bengawan Solo River.](image)

3.3 Chemical water quality parameters
The chemical parameters which have been measured in this research are pH, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrate (NO$_3^-$), nitrite (NO$_2^-$), total phosphate and oil and grease.

3.3.1 Dissolved oxygen (DO)
DO describe the concentration of oxygen molecular in the water and it depends on the temperature of the water and the biological demand of the system. DO is supplied to water through several methods; direct diffusion of oxygen from the atmosphere, wind and wave action, and photosynthesis. DO in the water is used for aerobic decomposition of organic matter, respiration of aquatic organism and chemical oxidation of mineral, so it tends to change rapidly (Kale, 2016). The results from Figure 3. showed that the level of dissolved oxygen (DO) in Bengawan Solo River at six observations points. The highest DO value is found in Kajangan and Cepu at 2018 (8.43 mg/L), while the lowest DO value is found in Jebres at 2017 and 2018 (3.86 mg/L and 3.53 mg/L). The overall DO value is mg/L. According to Akan et al. (2010), the DO standard determined for the sustainability of aquatic organisms is 5 mg/L. The low oxygen levels describe that the river has been polluted by organic material that is easily biodegradable.

3.3.2 pH
The pH refers to the hydrogen ion concentration in water. The water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH can be affected by chemicals, pH is an important indicator of water (Kale, 2016). The results in Figure 4. showed that the pH value of Bengawan Solo River fluctuates, but it is still in the standard water pH range of 6-9. The average of pH value at the five sampling points in 2016 – 2018 ranged from 6.51 – 7.93 with an
The overall average value of 7.2. The changes in pH at each observation are also caused by fluctuating industrial pollutants.

![Dissolved oxygen parameter in Bengawan Solo River](attachment:Figure_3.png)

**Figure 3.** The results of dissolved oxygen parameter in Bengawan Solo River.

![pH parameter in Bengawan Solo River](attachment:Figure_4.png)

**Figure 4.** The results of pH parameter in Bengawan Solo River.

### 3.3.3 Chemical oxygen demand and Biochemical oxygen demand

The Figure 5 showed the variation of COD parameters in the Bengawan Solo River at each sampling point during the period of 2016 – 2018. The highest COD value is found in Jebres and Bulakan at 2016 (23.10 and 21.90 mg/L) while the lowest value in Jebres at 2017 of 10.11 mg/L. The overall average of COD value is 18 mg/L. The dominant source of BOD and COD pollutants in this river are domestic waste, industrial and home-industry waste. Overall, Bengawan Solo River in terms of COD content is still suitable as a source of raw water for drinking water based on class 2 quality standards which require a maximum COD value of 25 mg/L.

The results showed that the BOD concentrations between the sampling points and period are very diverse (Figure 6). The overall average value of BOD in Bengawan Solo River is above the grade 2 quality standard. According to Akoto et al. (2017), the high BOD value directly reflects the high activity of microorganisms and the content of suspended organic matter in the water.
3.3.4 Nitrate, total phosphate
Nitrate is a form of nitrogen and nutrient compounds that are important for the growth, reproduction, and organisms life. According to Wu et al. (2018), nitrate compound are formed as the end product of the biochemical oxidation of ammonia resulting from the breakdown of protein substances. The results in Figure 7 (a) showed that the levels of nitrate in this river ranged from 0.35 mg/L to 2.81 mg/L, with an overall average value of 1.5 mg/L. The spread profil of nitrate levels at 5 observation points in the period 2016 – 2018 is presented in Figure 7(a).

The analysis results of phosphate concentrations in Bengawan Solo River at five observations point are presented in Figure 7 (b). The highest value of phosphate concentration is found in Jebres and Napel at 2018 (1.40 mg/L and 1.03 mg/L), while the lowest concentration of phosphate parameter is found in Cepu and Bulakan at 2018 and 2017 (0.02 and 0.03 mg/L). Based on the grade 2 quality standard which requires a maximum phosphate concentration of 0.2 mg/L, it can be concluded that there are 4 sampling points that do not meet quality standards.

3.3.5 Oil and Grease
Oil and grease are present in wastewater and produce similar environmental effects. This matter can cause oxygen depletion, toxic products, and respiration prevention. Oil and grease are contributed to river and reduces the rate of microbial degradation. The spread profil of oil and grease concentration at 5 observation points in the period 2016 – 2018 is presented in Figure 8. The water quality standard established that the maximum concentration of oil & grease allowed in class 2
water use is 1000 mg/L. Thus, Bengawan Solo river still have not suitable to be used as a raw source for drinking water.

Figure 7(a). The results of nitrate parameter in Bengawan Solo River.

Figure 7(b). The results of phosphate parameter in Bengawan Solo River.

Figure 8. The results of oil & grease parameter in Bengawan Solo River.
3.4 Water quality assessment based on the Pollution Index

The Pollution Index (IP) method is used to determine the level of pollution relative to permissible water quality parameters. Pollution Index is determined from the resultant maximum value and the mean value of the concentration ratio per parameter to its standard quality value. The results showed that of the monitoring points of river water quality in the Bengawan Solo River, 17% are heavily polluted, 59% are moderately polluted, 24% are slightly polluted and 0% are meeting quality standards.

4. Conclusions

The results of physical-chemical parameters data analysis can describe the existing condition of water quality along the Bengawan Solo River. The poor status of water quality in this river is indicated by total suspended solids (TSS), biochemical oxygen demand (BOD), total phosphate and oil & grease parameters that still exceed grade 2 quality standards from 5 sampling points and time periods from 2016 – 2018. One of the characteristics of pollution in the Bengawan Solo River is the entry of pollutants sourced from domestic waste, industrial waste, agricultural waste and others containing organic, inorganic, and other components. The amount of pollutant load does not proportional to self purification process, resulting in an an oxygen deficit and decreased water quality.

5. References

[1] Akoto, O., Gyamfi, O., Darko, G. and Barnes, V.R., 2017. Changes in the Water Quality in the Owabi Water Treatment Plant in Ghana. Applied Water Science, Vol. 7 (1), pp. 175–186.

[2] APHA, Standard Methods for Examination Water and Wastewater (American Public Health, 1995)

[3] Government of the Republic of Indonesia, Regulation Government Number : 82 Year 2001 About Water Quality Management and Control Water Pollution, Government Republic of Indonesia, Jakarta (2001).

[4] Hasan, H. H., Jami, N. R. and Aini, N., 2015. Water Quality Index and Sediment Loading Analysis in Pelus River, Perak, Malaysia. Procedia Environmental Sciences, Vol. 30, pp. 133-138

[5] Ismail, A.H., Abed, G.A., 2013. BOD and DO modelling for Tigris River at Baghdad city portion using QUAL2K model. J. Kerbala Univ, Vol. 11 (3), pp. 257-273

[6] Kale, V.S., 2016. Consequence of Temperature, pH, Turbidity and Dissolved Oxygen Water Quality Parameters. International Advanced Research Journal in Science, Engineering and Technology, Vol. 3 (8), pp. 186 – 190.

[7] Ministry of Environment, Decision State Minister of Environment Number: 115 Year 2003 About Water Quality Status Guidelines, Ministry of Environment, Jakarta (2003).

[8] Ministry of Environment, Decision State Minister of Environment Number: 110 Year 2003 About Guidelines for Determining Load Capacity Water Pollution in Water Sources, Ministry of Environment, Jakarta (2003).

[9] Mishra ,B. K., Regmi, R. K., Masago, Y., Fukushi, K., Kumar , P. and Saraswat, C., 2017. Assessment of Bagmati River Pollution in Kathmandu Valley: Scenario-based Modelling Analysis for Suistainable Urban Development. Sustainability of Water Quality and Ecology.
[10] Nemerow, N. I., 1974. Scientific Stream Pollution Analysis. McGraw-Hill, New York.

[11] Wu, Z., Wang, X., Chen, Y., Cai, Y. and Deng, J., 2018. Assessing River Water Quality Using Water Quality Index in Lake Taihu Basin, China. Science of the Total Environment, Vol. 612, pp. 914-922.

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