
MONITORING OF HEAVY METAL PB POLLUTION IN SEDIMENT AND ASSESSMENT OF WATER QUALITY STATUS USING POLLUTION INDEX IN BABON RIVER, SEMARANG

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ABSTRACT

The Babon River in Semarang provides water for humans, animals, and plants; however, pollution from industrial and domestic activities can negatively impact the ecosystem and human health. This study aimed to determine the levels of Pb heavy metal pollution in sediment, water quality, and pollution index (IP) in the river. Sampling was conducted at three station points: residential areas, industries, and a combination of both types of areas. The analyzed parameters included BOD, COD, DO, pH, temperature, brightness, and Pb content using Atomic Absorption Spectroscopy (AAS). The results of the study showed that Pb sediment concentrations ranged from 4.99-32.24 mg/Kg, still within the USEPA threshold of 47.82 mg/Kg, making it safe or low-risk. Water quality analysis showed decreases in BOD and COD exceeding class II standards and DO in several areas. The Babon River was classified as having a light-pollution status. Continuous monitoring and waste management are crucial to prevent further pollution and maintain aquatic ecosystem sustainability.

KEYWORDS: Babon River, Heavy Metal Pb, Pollution Index, Sediment, Water Quality.

INTRODUCTION

Rivers are aquatic ecosystems that play an important role in human life, especially as a source of water for daily needs[1]. Water is a natural resource that plays an important role in life, serving as a primary component of living beings, including humans, animals, and plants[2].

Water quality indicates the relative condition of water in fulfilling the needs of humans as well as aquatic and river ecosystems and has a significant effect on the sustainability of these functions, making proper river management essential. One of the rivers that plays an important role in Central Java is the Babon River, which flows through Semarang Regency, Semarang City, and Demak Regency. The river is utilized by the community for various activities, ranging from domestic use and agriculture to industrial use. However, increasing human activity along the river, in line with population growth and regional development, has led to declining water quality due to waste disposal from the agricultural, household, and industrial sectors[3].

One of the most dangerous forms of pollution is heavy metal contamination. Lead (Pb) is toxic and can disrupt ecosystem balance and endanger human health[1]. Industrial activities such as textiles, paper, garments, shrimp canning, and electronics around the Babon River are suspected to be the main sources of Pb heavy metals entering the water body. Pb metal released into water is not completely dissolved but instead undergoes a deposition process at the riverbed and accumulates in the sediment[4]. Sediment serves as a habitat for benthic organisms and acts as a site for the absorption of heavy metals through adsorption processes and the formation of complex compounds with organic and inorganic materials. The characteristic of Pb to easily settle and decompose slowly causes its concentration in sediment to increase over time[5].

A water quality evaluation method is required to determine the level of pollution. One method used is the Pollution Index, as regulated in the Decree of the State Minister for the Environment No. 115 of 2003. This method compares the results of water quality parameter measurements with applicable quality standards. With this approach, the river water quality status can be classified and used as a reference in efforts to control pollution and improve environmental quality. River management can begin by identifying activities with the potential to pollute the river, measuring river water quality and the river pollution index based on the applicable quality standards, identifying points along the river with high pollution levels, measuring the river's assimilation capacity, and developing ways to reduce pollution loads and conserve the river[6].

This study aimed to determine the concentration of heavy metal Pb originating from industrial waste at the mouth of the Babon River, measure the pollution level using the pollution index method, and identify the main sources of pollution.

RESEARCH METHODS

The materials used included heavy metal Pb, aquatic environmental conditions with parameters (DO, pH, turbidity, temperature, BOD, COD), and Pollution Index. The tools and materials used were GPS for determining coordinate points of research stations, 1-liter plastic bottles for sample containers, a cool box for storing samples, pH Meter, DO Meter, roll meter for measuring distances at the research location, Secchi disk for measuring water depth, 20 cm × 30 cm ziplock plastic bags for sediment sample storage, writing tools and camera for recording results and documentation, 100 ml beaker glass for measuring the volume of water samples in BOD testing, and Atomic Absorption Spectrophotometer (AAS) for measuring heavy metal concentrations.

The materials used in this study included river water samples as the research object and distilled water for the instrument calibration. The measurement of the COD (Chemical Oxygen Demand) variable uses several reagents including potassium dichromate ($K_2Cr_2O_7$), concentrated sulfuric acid (H_2SO_4), silver sulfate (Ag_2SO_4), and ferroin indicator solution. The measurement of the BOD (Biological Oxygen Demand) variable uses reagents such as manganese(II) sulfate ($MnSO_4$), potassium hydroxide–potassium iodide solution (KOH-KI), and sodium thiosulfate ($Na_2S_2O_3$). The reagent for measuring the heavy metal Pb includes concentrated nitric acid (HNO_3) for sample preservation, as well as a standard solution of heavy metal Pb ($Pb(NO_3)_2$).

Research Procedure

The research method applied in this study was a survey with quantitative analysis. Data collection was conducted using purposive sampling based on certain considerations or criteria relevant to the research objectives. The research was conducted from January to February 2025 at the Babon River in Semarang. The research location is shown in Figure 1.

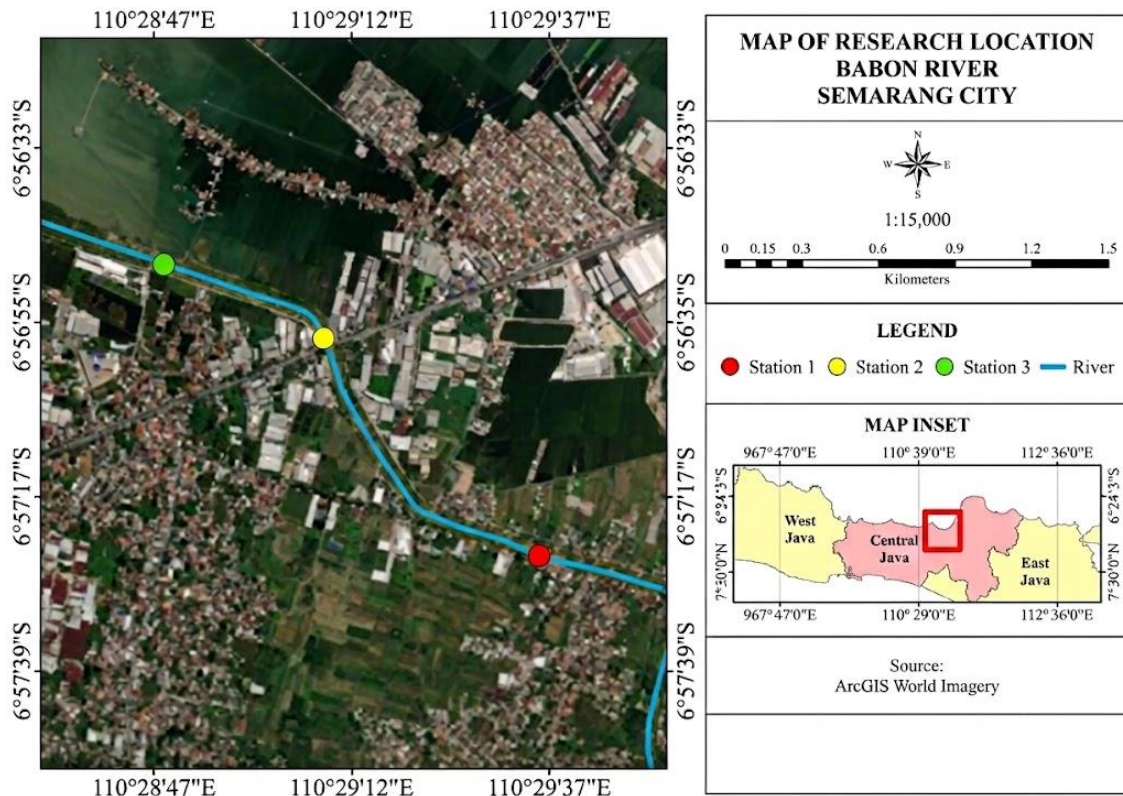


Figure 1. Research Location.

Heavy Metal Pb

The method for Pb metal analysis in this study used an Atomic Absorption Spectrophotometer (AAS), which operates based on the principle of absorption of radiation by free atoms of metal elements [7]. AAS has high sensitivity and is capable of detecting metals at very low concentrations ($\mu\text{g/L}$ to mg/L). Sediment samples were digested using a wet destruction method with strong acids such as HNO_3 and H_2SO_4 , which dissolve metals from the sediment matrix for accurate analysis [8]. The samples underwent a digestion process to separate heavy metals from organic compounds. The concentration of Pb in the sediment samples was calculated using a Buck Scientific 205 Atomic Absorption Spectrophotometer (AAS) according to SNI 6989.8:2009, which regulates the testing method for heavy metals Pb using AAS.

Water Quality Class

This is based on Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. Water quality was classified into four classes as follows:

Table 1. River Class Cluster.

Variable		Class			
		I	II	III	IV
DO	mg/L	6	4	3	1
pH	-	6-9	6-9	6-9	6-9
COD	mg/L	10	25	40	80
BOD	mg/L	2	3	6	12
Brightness	cm	10	4	2,5	-
Water temperature	°C	Dev 3	Dev 3	Dev 3	Dev 3

Each class has its own designation based on Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management:

- Class I: Water designated for drinking and/or other uses that require water quality equal to this use.
- Class II: Water designated for use in water recreation facilities/infrastructure, freshwater aquaculture, livestock farming, irrigation for crops, and/or other uses that require water quality equal to these uses.
- Class III: Water designated for use in freshwater aquaculture, livestock farming, irrigation for plants, and/or other uses that require water quality equal to these uses.
- Class IV: Water designated for irrigation of crops and/or other uses that require water quality equal to these uses.

Water Quality Status

Based on the Regulation of the State Minister for the Environment Number 115 of 2003 concerning Guidelines for the Determination of Water Quality Status.

Table 2. River pollution category clusters.

No	PI	Category
1	$0 \leq PI \leq 1$	meet quality standards
2	$1 \leq PI \leq 5$	lightly contaminated
3	$5 \leq PI \leq 10$	moderately polluted
4	$PI > 10$	heavily polluted

PI calculation can be considered to directly describe the level of pollution using the Pollution Index equation[9]:

$$PI_j = \sqrt{\frac{\{Ci/Lij\}^2_M + \{Ci/Lij\}^2_R}{2}}$$

Description:

- PI_j = pollution index for allocation (j)
- C_i = concentration of water quality parameters (i)
- L_{ij} = concentration of water quality parameter (i) as specified in the water quality standard for intended use
- M = maximum
- R = average

RESULT AND DISCUSSION

The concentration of lead (Pb) in sediment, determined through Atomic Absorption Spectroscopy (AAS), ranged from 4.99 to 32.24 mg/kg (Figure 2). Both samples were below the 47.82 mg/kg threshold established by the Sediment Quality Guidelines of the United States Environmental Protection Agency (USEPA). Lead is typically emitted from industrial activities, including battery and ammunition manufacturing, wire production, metal alloy creation, and paint production. The Pb concentration in the sediment is affected by industrial and domestic waste from adjacent communities. [5]. Predominantly, the waste is domestic, containing organic compounds and heavy metals from sources such as discarded electronics, paint, combustion ash, and Pb-containing pesticides[10]. Prolonged exposure of aquatic organisms to heavy metals, which are also consumed by humans, poses potential health risks, including kidney damage and nervous system disorders, even at low concentrations[11]. Therefore, it is crucial to monitor Pb levels to prevent them from exceeding the critical thresholds that could harm aquatic ecosystems. Regular waste management and monitoring of heavy metal content in the Babon River are essential to prevent further degradation of the water quality[4].

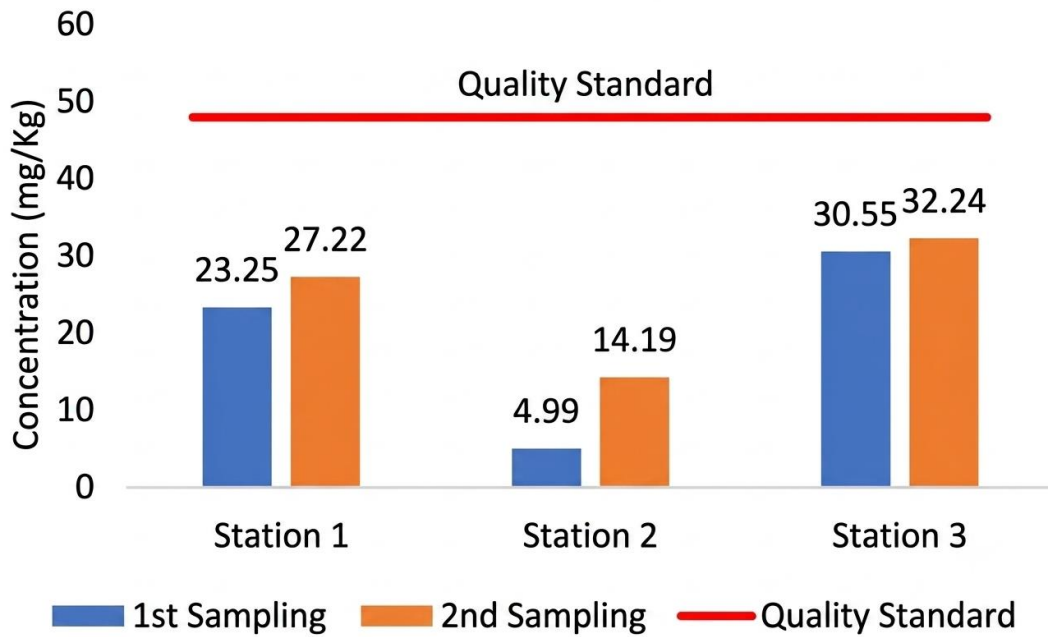


Figure 2. Concentration Pb.

Aquatic Environmental Conditions

This study used water quality variables, including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), pH, and temperature, to describe the environmental conditions of the Babon River. The results of the observations are shown in Table 3.

Table 3. Water quality variable.

Station	Variable					
	DO (mg/L)	pH	Brightness (cm)	Water Temperature (°C)	BOD (mg/L)	COD (mg/L)
1	4,6 – 5,5	9,1	8 – 17,5	26,6 – 28	3,3 – 7,6	70,95 – 220
2	5,1 – 5,7	9,1 – 9,2	23 - 25	26 – 28,9	4 – 9,2	82 - 280
3	4,4 – 4,9	8,9 – 9,2	13,5 – 35	27 – 30	4 – 9,3	75,2 - 310
quality standards	4	6-9	4	Dev 3	3	25

Elevated levels of dissolved oxygen are attributed to post-rainfall conditions, as precipitation enhances water currents and turbulence, thereby facilitating the diffusion of oxygen from the atmosphere into aquatic environments [12]. Furthermore, rapid water flow can dilute waste concentrations, potentially reducing pollutant levels and affecting the dissolved oxygen (DO)

concentrations[13]. In contrast, a decline in dissolved oxygen is associated with the introduction of substantial waste, which significantly escalates oxygen consumption in water, thereby diminishing the dissolved oxygen levels necessary for aquatic life[14]. This reduction in dissolved oxygen can induce stress in aquatic organisms, indicating the onset of an oxygen stress phase in aquatic ecosystems [15]. Such conditions threaten the survival of fish, shrimp, and other aquatic species that depend on specific dissolved oxygen levels for their survival.

The measured pH value is still within the applicable quality standard and is considered good for the growth of aquatic biota. The pH of a body of water is influenced by the water temperature, and waste originating from households, industry, and agriculture entering the water can also affect the pH [16]. A pH value that is too high can disrupt the metabolic processes of aquatic organisms and decrease the availability of essential nutrients in the water.[16]

The brightness indicated in the measurements of the Babon River exceeded the applicable quality standards. Low brightness indicates a high concentration of suspended particles and sediment in the water, originating from solid waste or soil erosion around the riverbanks. Rain can affect water brightness because during rainfall, the volume of water in the river increases, causing a stronger current that stirs up sediments deposited on the riverbed and decreases the water brightness at the sampling site[17], [18]. The higher the concentration of particles or dissolved organic matter, the higher the turbidity of the water[19]. Waste entering the water body at the sampling location originated from residential areas, livestock farms, markets, shops, and manufacturing industries[20].

The natural water temperature in tropical regions ranges between 25 and 32°C. Table 3 shows that the results of temperature measurements in the Babon River, Semarang, are still within the normal range (Dev 3) for the natural temperature of rivers in tropical areas. An increase in temperature can accelerate the decomposition of organic matter by microbial activity but has a negative impact on the solubility of oxygen in water[21]. Temperature has a negative relationship with dissolved oxygen in water; therefore, higher temperatures reduce DO levels in the water, which could potentially affect the condition or survival of aquatic biota if there is an excessive decrease in the dissolved oxygen[22]. Several factors occurring in rivers can affect water temperature, such as the entry of waste with high or low temperatures, rainfall, which can influence fluctuations in river temperature, season or cloud cover, interaction of water with air, the river's geographical position, and wind speed[23].

The biological oxygen demand (BOD) reflects the amount of oxygen required by microorganisms to decompose organic matter in water. The tested BOD values showed results exceeding the applicable threshold for BOD, which is 3 mg/L. Organic waste generally consists of materials that decompose or break down easily through microbial activity; when discharged into water bodies, it can lead to increased BOD [24]. Organic waste is easily oxidized, thereby increasing the oxygen demand for decomposition, which, in turn, results in high BOD values[25]. BOD fluctuated at each sampling point, indicating an increase in organic waste from activities such as residential and industrial discharge entering the river body[26] (Harianja et al., 2018).

Chemical oxygen demand (COD) indicates the amount of oxygen required to chemically oxidize organic and inorganic substances. The COD value in Table 3 exceeds the applicable quality standard of 25 mg/L. This condition occurs due to the discharge of industrial waste in the surrounding area; industrial waste generally contains organic compounds that are easily oxidized, thereby increasing the oxygen demand in the oxidation process, resulting in a high COD value and indicating that the waters of the Babon River contain a large amount of pollutants[27]. This condition shows that the river has become a disposal site for various types of waste, ranging from household waste such as detergents, food scraps, and other organic waste to industrial waste[28]. Proper treatment or filtration is strongly recommended to ensure that the water is safe for use in rivers classified as category 2.

Pollution Index (PI)

The measurement results obtained in this study were then analyzed using the Pollution Index (IP) calculation, which is one of the methods for determining water quality status by comparing the established quality standards outlined in Regulation of the Decree of the Minister of Environment Number 115 of 2003 concerning Guidelines for Determining Water Quality Status. The results of the pollution index calculation are shown in Table 4 and 5.

Table 4. Pollution Index (1st Sampling).

1 st Sampling											
Variable	St1	St 2	St 3	\bar{x}	Class II Quality Standard	Pollution Index					
						St 1		St2		St3	
						Ci/Li j 1 st	Ci/L ij 2 nd	Ci/L ij 1 st	Ci/L ij 2 nd	Ci/L ij 1 st	Ci/L ij 2 nd
DO (mg/L)	5,5	5,7	4,9	5,37	4	0.64	0.64	0.60	0.60	0.79	0.79

pH	9,1	9,1	8,9	9,03	6-9	0,81	0,81	0,81	0,81	0,79	0,79
Temperature (°C)	26	26,6	27	26,53	Dev 3	0,33	0,33	0,53	0,53	0,67	0,67
BOD (mg/L)	7,5	9,2	9,3	8,67	3	2,5	2,99	3,07	3,43	3,1	3,46
COD (mg/L)	70,95	82	75,16	76,04	25	2,84	3,27	3,28	3,58	3,01	3,39
(Ci/Lij) M						3.58					
(Ci/Lij) R						1.74					
IPj						2,81 (slightly polluted)					

Table 5. Pollution Index (2nd Sampling).

2 nd Sampling											
Variable	St 1	St 2	St 3	x̄	Class II Quality Standard	Pollution Index					
						St 1		St 2		St 3	
						Ci/Lij j _{1st}	Ci/Lij j _{2nd}	Ci/Lij j _{1st}	Ci/Lij j _{2nd}	Ci/Lij j _{1st}	Ci/Lij j _{2nd}
DO (mg/L)	4,4	3,9	3,4	3,9	4	0.84	0.84	0.71	0.71	0.89	0.89
pH	9,1	9,2	9,2	9,17	6-9	0,81	0,81	0,82	0,82	0,82	0,82
Suhu (°C)	28	28,9	30	28,97	Dev 3	1	1	1,3	1,57	1,67	2,11
BOD (mg/L)	3,3	4	4	3,77	3	1,1	1,21	1,33	1,62	1,33	1,62
COD (mg/L)	220	280	310	270	25	8,8	5,72	11,2	6,25	12,4	6,47
(Ci/Lij) _M						6.47					
(Ci/Lij) _R						2.16					
IPj						4,82 (slightly polluted)					

Tables 4 and 5 present the Pollution Index (IP) values obtained from two consecutive measurements, yielding results of 2.81 and 4.82, respectively ($1 \leq IP \leq 5$). These values indicate that, based on the IP calculations, the Babon River in Semarang was classified as slightly polluted.

The findings reveal a deterioration in the water quality of the Babon River relative to its natural state. However, the pollution level remains low and has not yet escalated to moderate or severe categories. Despite this, the exceedance of the IP value beyond 1 signifies that one or more water quality parameters have already breached the established standards. This situation reflects environmental pressure resulting from anthropogenic activities in the river basin area[29].

The difference in IP values between the first replication (2.81) and the second replication (4.82) reflects variation in water quality conditions during the observation period. The IP value in the second replication approaches the upper limit of the lightly polluted category, indicating an increase in pollutant load compared to the first replication. Such fluctuations may be influenced by various factors, such as changes in river discharge, rainfall, community domestic activities, industrial waste disposal, agricultural runoff, or other activities occurring around the Babon River basin[30].

The Babon River is one of the rivers that passes through urban and industrial areas in the city of Semarang, making it prone to receiving pollutant inputs from multiple sources. Domestic waste containing organic materials, detergents, as well as industrial waste containing specific chemical compounds, can increase the concentrations of pollutant parameters in the waters. In addition, surface runoff during rainfall can also carry sediments, nutrients, or other pollutants into the river body, thereby affecting the IP value[31].

The lightly polluted status found in this study shows that the Babon River still has assimilative capacity to mitigate the impacts of pollution through dilution, sedimentation, or natural decomposition processes. However, if the input of pollutants continues to increase without adequate management efforts, this condition could develop into moderate or even heavy pollution in the future[32]. Therefore, continuous efforts to control pollution sources are needed, both through improved management of domestic and industrial waste, in order to maintain the water quality of the Babon River and support its ecological functions.

The results of this study are consistent with various research on urban rivers in Indonesia which shows that residential, industrial, and land-use activities in river basin areas are the main factors contributing to increased values of the Pollution Index[33]. Therefore, regular water quality monitoring needs to be carried out as the basis for evaluating the effectiveness of environmental management and for the policy-making process in water pollution control.

CONCLUSION

Based on the results of the conducted research, it can be concluded that in the Babon River, Semarang, the concentration of the heavy metal Pb contained in the sediment is still below the applicable quality standard, namely 47.82 mg/kg according to the United States Environmental Protection Agency (USEPA). Analysis of water quality shows that most variables are below the threshold of the class II river water quality standard; however, there is a decline in water quality caused by BOD and COD levels. The Pollution Index (IP) for the Babon River, based on the results obtained from this study, indicates that the Babon River

falls into the lightly polluted status category. Continuous water quality monitoring and sustainable waste management are necessary to prevent increased heavy metal contamination and maintain the sustainability of aquatic ecosystems.

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