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Analysis of Water Pollution in the Kapuas River Due to Illegal Gold Mining (IGM) Activities

Yuris Sutanto[1,*)], Elvi Darina Safitri[1)], Andi Ihwan[2)], Hasanuddin[1)], Kukuh Prasetya[2)]
[1)] Physics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura, Pontianak, Indonesia
[2)] Geophysics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura, Pontianak, Indonesia

Correspondence Email: yuris@physics.untan.ac.id

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ABSTRACT

Illegal gold mining (IGM) activities, utilizing mercury (Hg) in their processing, have the potential to pollute and impair river functions. Therefore, a study was conducted to analyze the water quality status of the Kapuas River due to IGM activities in Sekadau Regency based on physical and chemical parameters. Water quality status was determined by comparing observations at the research site with quality standards using the Pollution Index (PI) method. In this scientific paper, the physical parameters tested are turbidity, conductivity, total dissolved solids (TDS), total suspended solids (TSS), and water temperature. In contrast, the chemical parameters tested are pH, dissolved oxygen (DO), Iron (Fe), Hg, lead (Pb), and manganese (Mn). Based on the research results, the parameters that meet the quality standards are TDS, TSS, pH, Hg, Pb, and Mn. Parameters not meeting the quality standards are turbidity, conductivity, water temperature, DO, and Fe. The PI value obtained was (5.25 ± 0.008). Based on the PI value, the water quality status was classified as moderately polluted. The TSS parameter exhibits a radial pattern from the pollution source, indicating that the measured TSS values decrease with increasing distance from IGM activity.

KEYWORDS: Illegal Gold Mining; Mercury; Water Quality; Kapuas River; Amalgamation

INTRODUCTION

Kapuas River is the longest river in Indonesia. It stretches 1,086 km in West Kalimantan Province (Ministry of Public Works, 2012). The Kapuas flows through eight regencies: Pontianak City, Mempawah, Kubu Raya, Landak, Sanggau, Sekadau, Sintang, and Kapuas Hulu. The Kapuas River water is often used for sanitary hygiene.

Illegal gold mining (IGM) activities in the area have the potential to pollute the river water. The local community executed the IGM activities without permission from the government (Dutu, 2016). Mining activities can damage the environment by changing the natural landscape (Razi & Titah, 2024). IGM activities have a negative impact because they hurt the environment, disrupting ecosystem balance (Susanti et al., 2018). IGM activities use mercury (Hg) to separate gold grains from rocks. Mercury is a heavy metal pollutant that is cumulatively toxic. Mercury-containing waste pollutes the river because it is improperly handled (Pant et al., 2024; Rodríguez et al., 2012). Mercury pollution from IGM activities has become a global environmental and health issue (Latuconsina et al., 2024). IGM activities are located upstream and right in the residential areas, as shown in Figure 1.

IGM activities absorbed the soil and discharged it back into the river. IGM activities

dig the soil material underwater to obtain gold minerals. The suction machine and pump are placed on driftwood on the riverbank. The soil suction process causes the turbidity of the river to increase. Turbidity affects sunlight's ability to penetrate the bottom of the water. When turbidity levels are high, sunlight cannot penetrate the bottom of the water. Photosynthesis activity decreases, resulting in a decrease in water activity. Thus, the turbidity level affects organisms' growth in the water (Zhang et al., 2017). Low turbidity indicates good water conditions and does not harm the ecosystem (Austin et al., 2017; Nieman & Gray, 2019). Sediment accumulates in the riverbed, reducing the river's capacity to accommodate water. When rainfall is high, a flood occurs because the river overflows. The soil suction process was conducted to obtain rocks containing gold. Subsequently, these rocks are crushed to obtain smaller sizes.

IGM activity results are processed by amalgamation, which binds gold metal using mercury. The crushed rocks are placed into cylindrical troughs or containers filled with water and mercury (Barakati et al., 2023). After some time, gold separates from the rocks because mercury has a high attraction or affinity for gold metal. Mercury is utilized in the gold ore processing process because it effectively binds gold from the crushed rocks (Soe et al., 2022). Naturally, gold and mercury form an amalgam of Au_2Hg_3 Amalgam is a solid solution compound of mercury and several metals such as gold, silver, copper, tin, and zinc. A solid may form upon contact between mercury and gold metal. Mercury-containing waste discharged into the river causes the river to be contaminated with mercury.

Mercury can combine with other organic and inorganic elements. High levels of mercury can damage the brain, kidneys, and developing fetus. Pollution of waters by mercury can damage ecosystems and the health of humans who consume aquatic products because mercury can accumulate in the tissues of aquatic biota (Rodrigues et al., 2019).

Based on a previous study conducted by Abigani, et al. (2023), in 2022, the water quality of Kahayan River is lightly polluted. Kayahan River is located in Middle Borneo. People who lived near the river used the water of river for hygiene sanitation. In addition, other studies related to illegal mining activities (PETI) have shown that the mercury concentration in the Kuantan River has exceeded the water quality standard due to illegal gold mining activities (Yulis, 2018). Other studies conducted around the research location were limited to measuring raw water quality. The parameters measured were pH, temperature, turbidity, and color. The results showed that the measured turbidity reached 34.9, exceeding the established water quality standard (Atikah et al., 2023).

Based on the studies that have been presented, previous research still has many limitations regarding locations close to this study area, the statistical methods used, and the variation of data, thus encouraging the author to conduct this research by analyzing the pollution of the Kapuas River water because of the IGM activities. This study analyzed the water quality of the Kapuas River for sanitary hygiene. Physical parameters analyze water quality: total dissolved solids (TDS), total suspended solids (TSS), turbidity, water temperature, and conductivity, and chemical parameters: dissolved oxygen (DO), power of hydrogen (pH), and concentration of heavy metals such as iron (Fe), mercury (Hg), lead (Pb), and manganese (Mn)

RESEARCH METHOD

The study occurred in the Kapuas River, which flows through the Sekadau district, in February 2024. The map of the research location is shown in Figure 1. Sampling and measurements occurred at four observation points, with each activity conducted at a single location and repeated three times, incorporating time variations for each repetition. Measurements at the upstream control point were not conducted. Data was collected at the first point at 12:00 PM, at the second point at 1:07 PM, at the third point at

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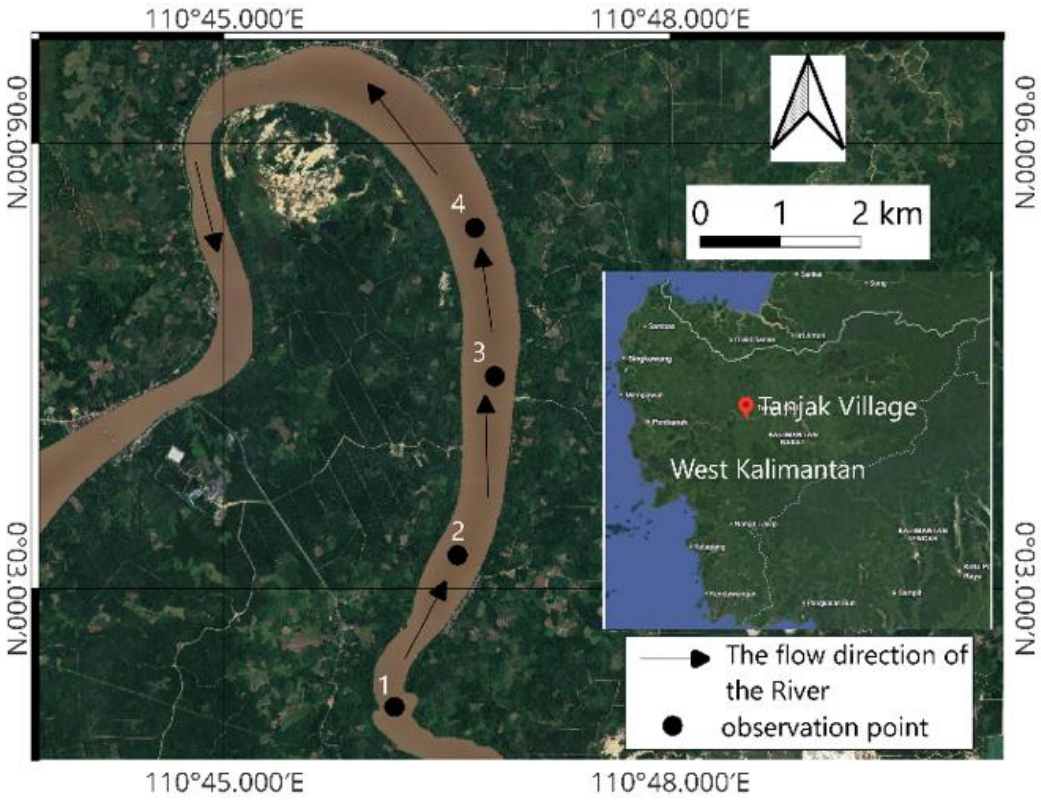

Figure 1. The map of the research location

2:00 PM, and at the fourth point at 3:00 PM. The first point is 200 m after the location of the operating IGM activities. The second, third, and fourth points are located downstream of the first point at distances of 2, 4, and 6 km, respectively, making the total length of the river observed 6 km. Data acquisition was conducted in the rainy season. Based on data obtained from the Copernicus Climate Change Service, the rainfall at 12:00 PM was 0.9 mm/h. Tools and materials used in this research are 12 pieces of 500 mL glass bottles, distilled water, an environmental thermometer, a TDS meter, a turbidity meter, vial bottles, and a water quality meter.

Sampling uses the grab sampling method, which takes water samples directly at the location points. Water samples were taken repeatedly three times at four observation points. Some parameters were tested in the laboratory, while others were measured directly during water sampling. Parameters tested in the Borneo Enviro laboratory Indonesia are TSS, Fe, Mn, Pb, and Hg, whereas other parameters were measured directly during sampling. A turbidity meter was used to measure turbidity, and a TDS & EC meter was used to measure TDS with a minimum resolution of 1 ppm. Water quality meter was used to measure conductivity, DO, and pH with a minimum resolution of 0.1 μS, 0.1 dan 0.1 mg/L. The environmental thermometer was used to measure air temperature. The parameters tested, along with their quality standard, are presented in Table 1.

Table 1. Physical and chemical parameters with its quality standard (*Minister of Health Regulation No. 2 of 2023 About the Implementing Regulations of Government Regulation Number 66 of 2014 on Environmental Health*, 2023; Minister of Health Republic of Indonesia, 2021)

Parameters	Quality standard
Turbidity	≤ 3 NTU
Total Dissolved Solid	≤ 300 mg/L
Conductivity	42-500 µS/cm
Total Suspended Solid	≤ 40 mg/L
Water temperature	Air temperature ± 3 °C
pH	6.5-8.5
Iron (Fe)	≤ 0.2 mg/L
Manganese (Mn)	≤ 0.1 mg/L
Lead (Pb)	≤ 0.01 mg/L
Mercury (Hg)	≤ 0.001 mg/L
Dissolved Oxygen (DO)	≥ 4 mg/L

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The pollution index (PI) determines water quality status and shows the pollution level against water quality standards. The determination of pollution level using the PI method is done by comparing the concentration of water quality parameters with the quality standard. Based on Keputusan Menteri Negara Lingkungan Hidup (KEPMENLH) No. 115 Tahun 2003, the calculation of water quality using the PI method. Refers to the PI value, water quality category based on KEPMENLH No. 115 of 2003, classified in Table 2.

Table 2. Water quality category based on PI values

PI value	Category
$0 \leq PI \leq 1$	Meets quality standards
$1.0 < PI \leq 5.0$	Lightly polluted
$5.0 < PI \leq 10$	Moderately polluted
$IP > 10$	Heavily polluted

RESULTS AND DISCUSSION

Physical Parameters

The physical parameters that meet the quality standards are TDS and TSS, while the physical parameters that do not meet the quality standards are turbidity, conductivity, and water temperature. Figure 2 - Figure 6 display bar charts showing the concentration of each parameter along with its quality standard. The turbidity levels at each point exceeded the maximum allowable limit. The maximum turbidity for hygiene and sanitation is 3 NTU, as indicated by the red line in Figure 2. The highest turbidity value is at observation point 3, with a value of 55 NTU. High turbidity indicates many suspended substances in the water, including clay, mud, organic matter, and suspended particles.

Water with a high turbidity level inhibits light from entering the river, disrupting photosynthetic activities within the river. One of the factors contributing to high turbidity is soil erosion carried by rainwater into rivers. IGM activities also increase turbidity levels, as the sediment resulting from soil suction is diffused into the river. Additionally, the meandering river carries sediment through both suspended and bed loads, which creates specific features in sediment deposition that increase turbidity (Yuskar et al., 2018). Previous research was conducted in 2023 in Kedukul Village, approximately ± 1.5 km from observation point 4. The measured turbidity was 34.9 NTU (Atikah et al., 2023). This indicates an increase in turbidity in 2024.

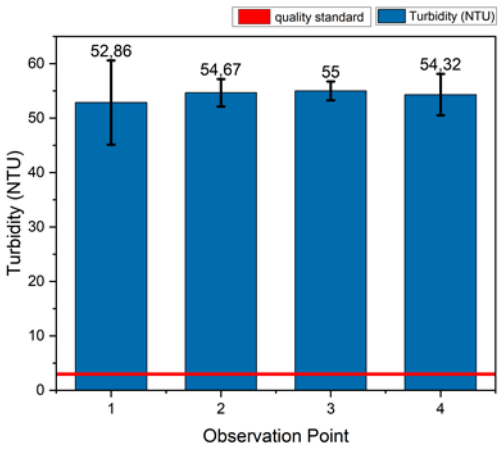

Figure 2. Bar chart showing the average turbidity values

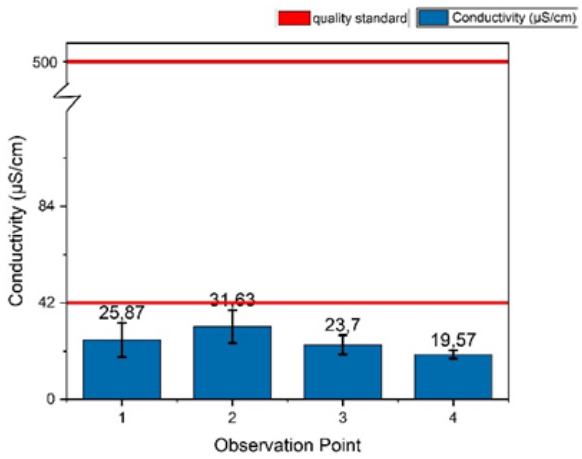

Figure 3. Bar chart showing the average conductivity values

Figure 3 shows the average conductivity values. The average conductivity values at all points are relatively low. Electrical conductivity measures a solution's ability to conduct an electric current. The electric current in the solution is conducted by the ions contained within it. The electrical conductivity value only indicates the solution's total ion concentration (Taylor et al., 2018). The conductivity of water correlates with TDS. An increase in TDS can lead to changes in salinity, ion composition alterations, and individual ions' toxicity (Rebello et al., 2020). TDS and conductivity exhibit a positive correlation,

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meaning that the conductivity value will also increase as the TDS value increases. The highest average conductivity value is at point 2, with a value of 31.63 µS/cm. The lowest average conductivity value is at point 4, with a value of 19.57 µS/cm.

Figure 4 shows the average TDS values. The average TDS measurements at all points meet the quality standard. The maximum permissible TDS level for hygiene and sanitation is 300 mg/L. The sources of TDS pollution are household waste, industrial waste, detergent waste, and chemical substances (Manasa & Mehta, 2020; Tadesse et al., 2018). The low TDS values are due to the high discharge of the Kapuas River. The highest average TDS value is at points 2 and 4, with a value of 7 mg/L. The lowest average TDS value is at point 1, with a value of 5.67 mg/L.

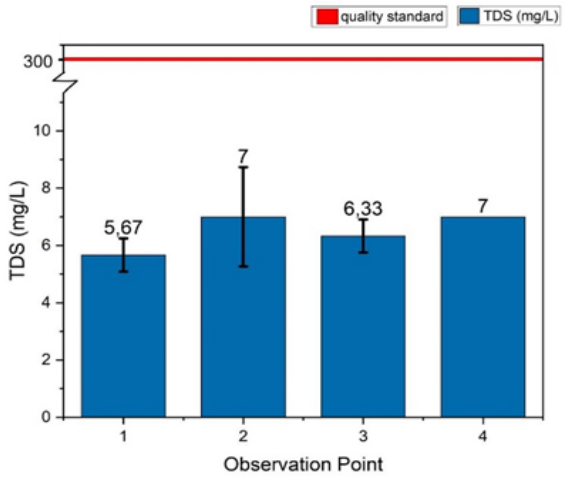

Figure 4. Bar chart showing the average TDS values

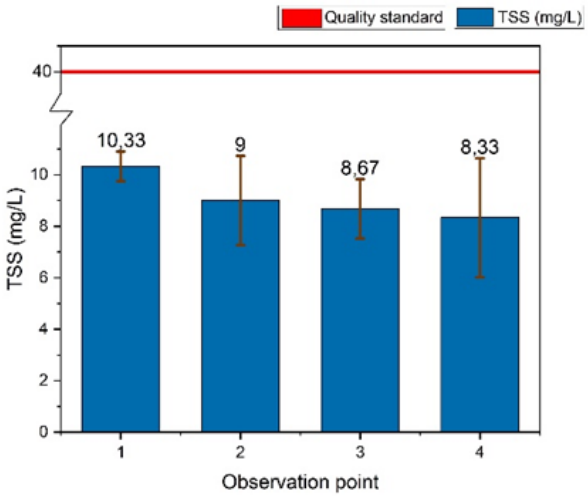

Figure 5. Bar chart showing the average TSS values

Figure 5 shows the average TSS values. The measured TSS meets the quality standard. The maximum allowable TSS concentration is 40 mg/L. TSS consists of silt, fine sand, and microscopic organisms, primarily caused by soil erosion or land runoff entering water bodies (Hansen et al., 2021; Sugiarti et al., 2023). IGM activity results in the dispersion of silt into rivers, particularly during the soil suction process to extract mineral rocks. The closer the observation point is to the pollution source, the higher the TSS concentration. Consequently, observation point 1 has the highest TSS value, with a value of 10.33 mg/L. Conversely, observation point 4 is the farthest from the IGM activity, at a distance of 6 kilometers. Consequently, observation point 4 has the lowest TSS value, with a value of 8.33 mg/L. In the measurement of TSS, a spatial pattern is observed, showing differences in the average TSS results between sampling points. The closer the point is to the IGM site, the higher the average TSS values.

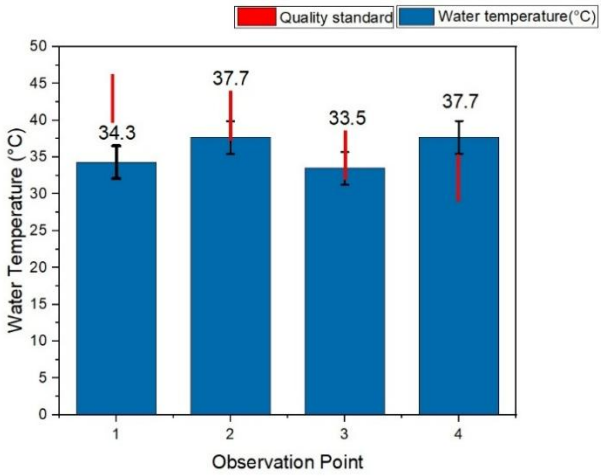

Figure 6. Bar chart showing the average water temperature values

Figure 6 shows the average water temperature values. Temperature is a physical parameter that significantly affects aquatic organisms, including their distribution, composition, abundance, and mortality (Abram et al., 2016). The water quality standard for temperature is ± 3°C of the air temperature. The water temperature at observation points 2 and 3 meets the quality standard, whereas observation points 1 and 4 do not. The water temperature does not meet the standard

quality as it is not within the ± 3°C range of the air temperature. Sampling was conducted during the day when the weather was hot. Consequently, the surrounding air temperature of the river was high.

Chemical Parameters

Chemical parameters meeting the quality standards are pH, Hg, Pb, and Mn, whereas DO and Fe are the chemical parameters not meeting the quality standards. The concentrations of these six chemical parameters are shown in Figures 7 to 12.

Figure 7 shows the average pH values. The average pH value of the water at each observation point meets the quality standards, which range from 6.5 to 8.5. The measured pH remains safe, as it falls within the quality standard range. pH is a chemical parameter that indicates a solution's acidity or alkalinity level (Islam et al., 2017). pH can influence a chemical compound's toxicity, aquatic organisms' metabolic processes, and biochemical processes in aquatic environments (Gao et al., 2019; Logeshwaran et al., 2018). The overall average pH value across all observation points is 7.05 ± 0.32, which is categorized as neutral.

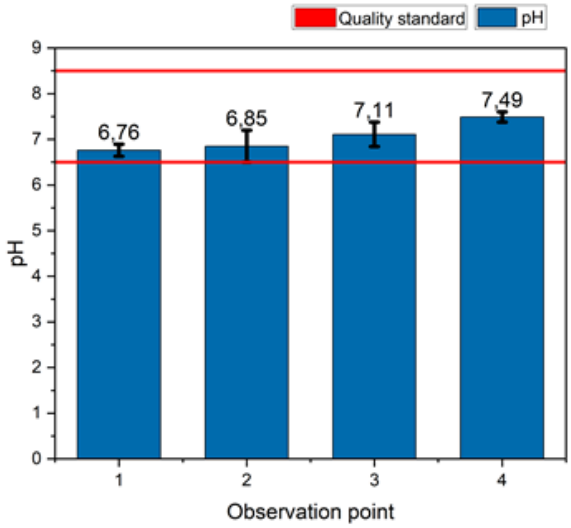

Figure 7. Bar chart showing the average pH values

Figure 8 shows the average DO values. DO is regarded as an essential water quality parameter that affects the physical and biological processes in a waterbody, and it plays a crucial role in evaluating the suitability of aquatic resources for the survival of both fauna and flora (Ujjania et al., 2018). The primary source of oxygen in a body of water comes from the diffusion process of free air and the photosynthesis of organisms living in the water. DO levels of a water body are influenced by turbidity. As the turbidity of a river increases, the intensity of light penetrating the water decreases, thereby affecting the photosynthetic activity. DO levels are also affected by water temperature. Higher water temperatures result in decreased oxygen solubility in water. Low DO levels in aquatic environments may also be caused by high Fe concentrations. High Fe shows in Figure 9. Iron oxidation processes can consume dissolved oxygen, thereby affecting the availability of DO in the water.

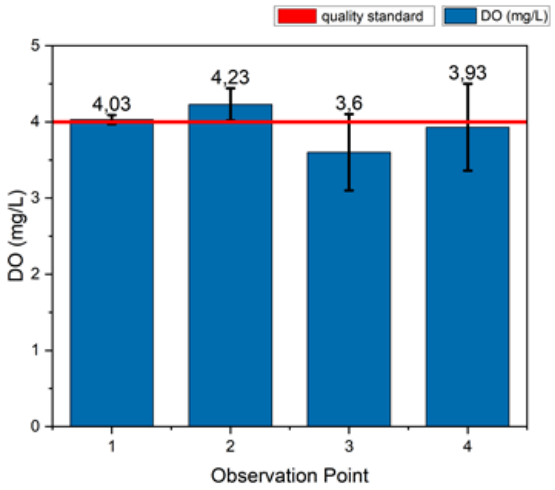

Figure 8. Bar chart showing the average DO values

The minimum DO level stated in the Minister of Health Regulation No. 2 of 2023 is ≥ 4 mg/L, as indicated by the red line in Figure 9. The average DO values at points 1 and 2 meet the standard, while points 3 and 4 do not. The highest average DO value is at point 2, with a value of 4.23 mg/L. The lowest average DO value is at point 3, with a value of 3.6 mg/L.

Figure 9 shows the results of Fe measurements in the Kapuas River exceeding the maximum permissible limit for hygiene and sanitation, which is 0.2 mg/L. The average Fe values across all points are of the same order. This slight difference indicates that Fe has been evenly distributed in the river. Fe pollution sources come from soil, industrial

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waste, and residential waste (Long et al., 2021; Wu et al., 2022). IGM is one of the sources of Fe pollution because it discharges soil into rivers. Apart from soil, Fe also originates from human activities on land, such as household waste containing iron, water reservoirs containing iron, industrial waste deposits, and corrosion from iron containing water pipes carried by river currents (Liu et al., 2018).

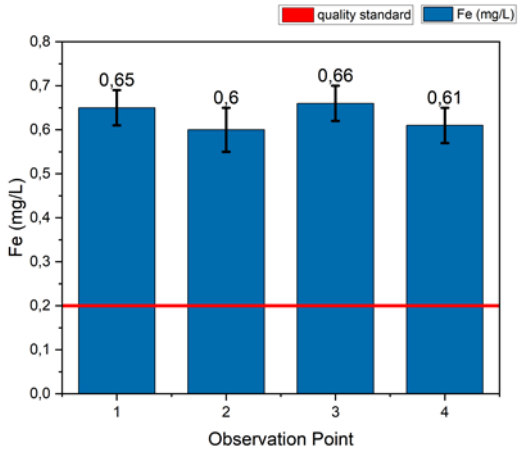

Figure 9. Bar chart showing the average Fe values

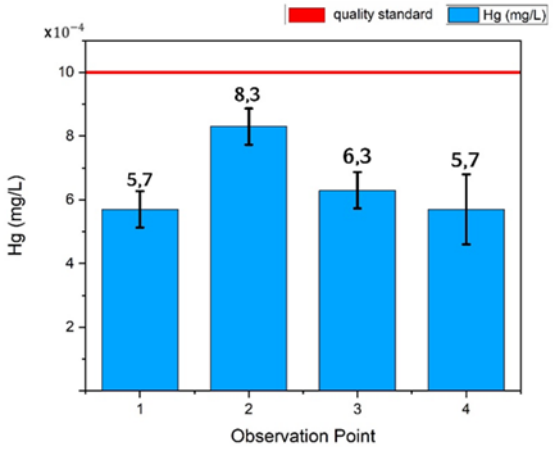

Figure 10. Bar chart showing the average Hg values

The maximum allowable concentration of Hg in the areas of oil, gas, geothermal, and mineral resources mining, according to Minister of Health Regulation No. 2 of 2023, is 0.001 mg/L. Based on Figure 10, the concentration of Hg at all points meets the standard. IGM activities, gold ore processing activities, and climate or weather conditions influence the concentration of Hg in water. An increase in IGM activities correlates with an increase in gold ore processing activities. Hg levels in water will be elevated if gold ore processing activities are carried out near rivers. Water waste containing Hg used in the amalgamation process causes Hg to concentrate and settle in river sediments due to its high density (M. Liu et al., 2021).

Climate or weather can influence the Hg concentration in water by affecting the discharge and currents of rivers. Hg concentrations are higher during the dry season than during the rainy season. During the dry season, river discharge and currents decrease, accumulating Hg content only around pollution sources. Conversely, river discharge and currents increase during the rainy season, resulting in higher mobility levels of Hg content being transported far from pollution sources. In addition, in flowing waters (*lotic systems*), mercury tends to be transported along with sediment materials due to water currents and flow turbulence, whereas in lentic systems such as lakes or reservoirs, mercury is more likely to accumulate in bottom sediments because of the lower flow velocity and longer water residence time (Portela et al., 2020). Therefore, measurements conducted only in surface water may not fully represent the potential mercury contamination at the study site. Sampling was conducted during the rainy season, resulting in increased discharge and currents. Therefore, Hg concentration in the Kapuas River is low. The highest average Hg concentration is at point 2, at 8.3×10^{-4} mg/L. The lowest average Hg concentration is at points 1 and 4, at 5.7×10^{-4} mg/L.

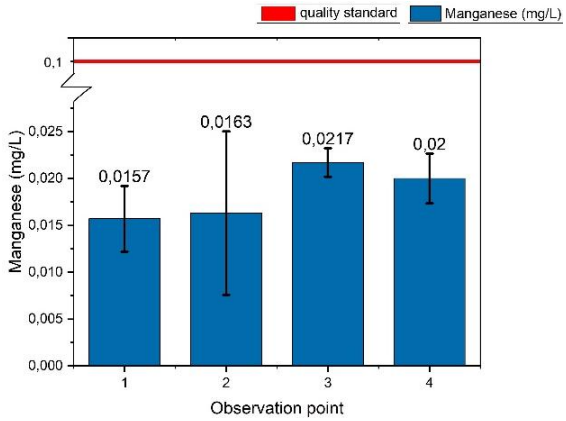

Figure 11. Bar chart showing the average Mn values

Figure 11 shows the average Mn values. The average Mn concentration at all

observation points meets the quality standard. The maximum allowable Mn concentration is 0.1 mg/L. The highest Mn concentration is 0.0217 mg/L, measured at observation point 3. The lowest Mn concentration is 0.0157 mg/L, measured at observation point 1. The average Mn concentration across all observation points is $(1.8 \pm 0.3) \cdot 10^{-2}$ mg/L.

Figure 12 shows the average Pb values. The average Pb concentration at all observation points meets the quality standard. Not all water samples contain Pb, indicating that Pb is not uniformly distributed throughout the river. The maximum allowable Pb concentration is 0.01 mg/L. The highest Pb concentration is 0.0013 mg/L, measured at observation point 3. The lowest Pb concentration is 0.00033 mg/L, measured at observation point 2. The average Pb concentration across all observation points is $(9 \pm 4) \cdot 10^{-4}$ mg/L.

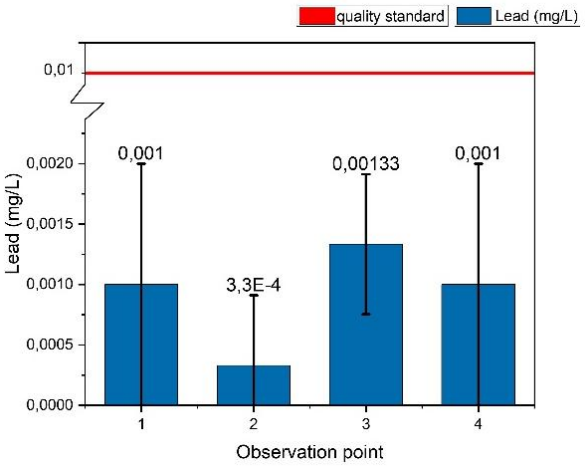

Figure 12. Bar chart showing the average Pb values

Analysis Water Quality

Analysis water quality using pollution index (PI) method for observation point 1 is presented in Table 3. The PI value at observation point 1 is 5.24. Based on the water quality categories in Table 3, the water quality status at observation point 1 is moderately polluted. The PI value at observation point 2 is 5.25. Using the same formula to identified PI value in observation 1. the water quality status at observation point 2 is moderately polluted. The PI value at observation point 3 is 5.26. The water quality status at observation point 3 is moderately polluted. The PI value at observation point 4 is 5.25. The water quality status at observation point 4 is moderately polluted.

Table 3. The interpretation of the PI for observation point 1

Parameters	C_i	L_{ij}	C_i/L_{ij}	C_i/L_{ij} ***new***
Turbidity (NTU)	52.8	3	17.62	7.230
TDS (mg/L)	5.67	300	0.019	0.019
Conductivity (µS/cm)	25.9	42-500	1.071	1.148
TSS (mg/L)	10.3	40	0.258	0.258
Water temperature (°C)	34.3	41.27-47.27	3.32	3.6
pH	6.76	6.5-8.5	0.74	0.74
Fe (mg/L)	0.65	0.2	3.27	3.57
Mn (mg/L)	0.016	0.1	0.157	0.157
Pb (mg/L)	0.001	0.01	0.1	0.1
Hg (mg/L)	0.0006	0.001	0.57	0.57
DO (mg/L)	4.03	4	0.247	0.247
Maximum				7.230
Average				1.604
PI				5.237

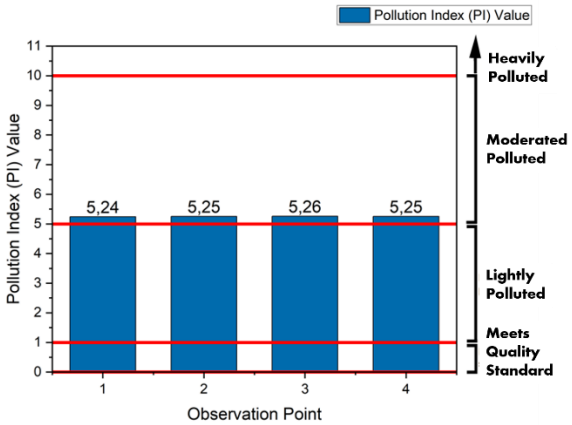

Figure 13. PI values at all observation point

Turbidity becomes the parameter with the highest C_i/L_{ij} value among other parameters due to the high difference between the turbidity measurement value and its standard limit. One thing to determining parameters for the PI value is the *Ci/Lij* maximum. Therefore, turbidity is the primary factor contributing to the high PI value. The Parameters with the highest difference between the measurement result and the standard limit after turbidity are water temperature and Fe concentration. Even though water temperature and Fe are not the

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C_i/L_{ij} maximum, they still significantly impact the average C_i/L_{ij} value. Parameters with a small C_i/L_{ij} value meet quality standards. This small C_i/L_{ij} value influences the low average C_i/L_{ij} value.

According to the water quality category based on the PI values in Table 3, the water quality status of the Kapuas River is moderately polluted, with average PI values at each observation point of 5.25 ± 0.008. The small standard deviation indicates a small difference between the PI values at all observation points.

Several previous studies regarding Pollution Index (PI) values in several rivers showed that the PI value of the Kahayan River was categorized as lightly polluted in 2022 (Abigani, et. al, 2023), while the water quality status of the Cibanten River was also categorized as lightly polluted (Pangesti, 2020). Based on the studies mentioned above, it can be seen that the water quality status based on the PI calculation in the Kapuas River is more polluted compared to the Kahayan River and the Cibanten River. This condition may occur due to illegal gold mining activities (PETI) around the research area. It was observed that turbidity became the parameter contributing the greatest influence to the increase in the PI value at the research location.

The Pollution Index (PI) value of 5.25 indicates a moderately polluted condition, suggesting that the aquatic environment has experienced a significant decline in water quality. If this condition persists over a long period, it may negatively affect communities that still rely on the river for hygiene and sanitation purposes. Long-term exposure to polluted water may increase health risks and reduce the suitability of the water for daily use. In addition, continuous pollution may lead to decreased dissolved oxygen levels, sediment accumulation, degradation of aquatic habitats, and disruption of the river ecosystem balance.

CONCLUSION

Physical parameters meeting the quality standards are TDS and TSS. Physical parameters exceeding the quality standards are turbidity, conductivity, and water temperature. Chemical parameters meeting the quality standards are pH, Hg, Pb, and Mn, whereas DO and Fe are the chemical parameters not meeting the quality standards. The water quality status of the Kapuas River due to illegal gold mining activities based on PI values with the values of 5.25 ± 0.008 indicates moderate contamination . The TSS parameter exhibits a radial pattern from the pollution source, indicating that the measured TSS values decrease with increasing distance from IGM activity. This condition may be influenced by local hydrodynamic factors, including water current direction and velocity, sediment transport, and the resuspension of bottom sediments caused by water movement and mining activities. No radial pattern was observed in the other parameters. IGM has serious negative impacts on the environment and local communities, including water quality degradation, sedimentation, erosion, landslides, and health risks to local communities.

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