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Evaluation of Settling Pond Management at PT Borneo Indobara to Maintain the Total Suspended Solid (TSS) Outflow Within Standard Threshold

Dede Wijayanto, Gatot Yudoko, Pipin Rio Sianturi
Institut Teknologi Bandung, Indonesia
Emails: dede_wijayanto@sbm-itb.ac.id, gatot@sbm-itb.ac.id, pipin.sianturi@borneo-indobara.com

ABSTARCT

Effective wastewater management in coal mining is critical for minimizing environmental impact and ensuring regulatory compliance. This study evaluates the performance of *Settling Pond SP 02 GH* at PT Borneo Indobara (*PT BIB*), a major coal producer in South Kalimantan, Indonesia. Despite existing controls, TSS outflow from *SP 02 GH* has periodically exceeded this threshold, resulting in environmental complaints, operational costs, and reputational risks. The primary research objectives are to identify the root causes of excessive TSS discharge and to develop data-driven, economically viable solutions. A Lean Six Sigma *DMAIC* (*Define, Measure, Analyze, Improve, Control*) framework was employed. Data collection involved semi-structured interviews, field observations, water sampling, and the use of historical TSS and rainfall records. Analytical methods included descriptive statistics, linear regression, and root cause analysis using *Fishbone Diagrams*. The analysis revealed a strong correlation ($R^2 = 0.9997$) between TSS levels at the inlet and TSS pump discharge, identifying the pump system as the dominant contributor to excessive TSS. In contrast, rainfall intensity showed no significant effect ($R^2 = 0.027$). Key interventions include the establishment of a maximum TSS pump limit of 25,000 mg/L, installation of real-time TSS sensors at both pump and outlet points, and the development of *standard operating procedures (SOP)* for monitoring and maintenance of the settling pond. Economic feasibility was assessed using a *Benefit-Cost Ratio (BCR)* analysis, indicating a highly favorable outcome: projected annual benefits of IDR 51.94 billion versus implementation costs of IDR 1.6 billion, resulting in a BCR of 32.57.

Keywords: Total Suspended Solid (TSS), Coal Mining, Wastewater Treatment, Real Time Monitoring.

INTRODUCTION

The coal mining industry plays a significant role in Indonesia's economy, contributing substantially to the national GDP through its production and export activities (Brodny & Tutak, 2022; Chu et al., 2021; Le & Dong, 2021; Mbedzi et al., 2018; Sutomo et al., 2020). PT Borneo Indobara (PT BIB) is one of the key players in this sector, with ambitious production targets. In 2024, the company aims to achieve coal production of 46.8 million tons, with plans to increase this to 54 million tons the following year. To achieve this target, efficient operational strategies and effective environmental management are crucial.

One of the main challenges faced by PT BIB is ensuring that its mining operations do not negatively impact on the surrounding environment, particularly the quality of water discharged from the settling ponds. The company's environmental policies, guided by national regulations and the Ministry of Energy and Mineral Resources, focus on minimizing the environmental impact of its mining activities. However, Total Suspended Solids (TSS) from the settling ponds have exceeded the regulation threshold, causing several environmental issues, particularly from surrounding palm oil companies and pollution concerns in the river flows around the mining area (Figure 1).

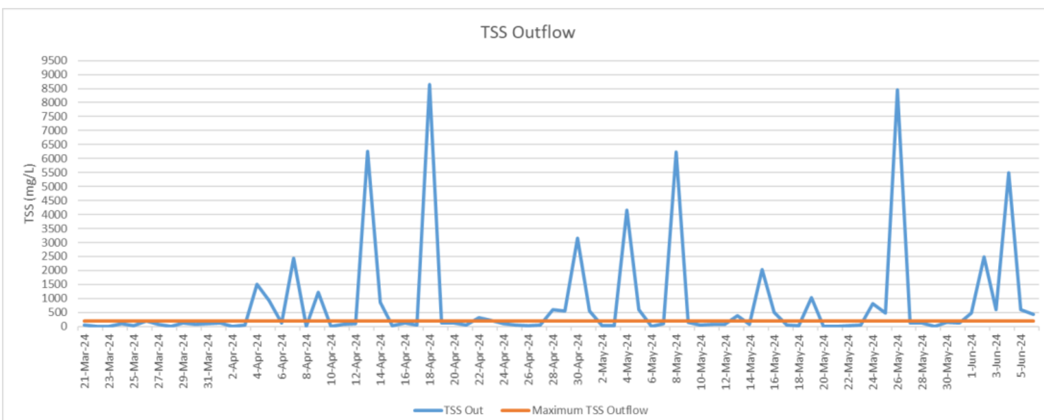


Figure 1. Spike Outflow Total Suspended Solid at SP 02 GH

The aim of this study is to evaluate the management of TSS at PT BIB's settling ponds, specifically at the SP 02 GH pond, where the TSS levels discharged to the surrounding communities and palm oil plantations sometimes exceed the specified limits. Using the DMAIC (Define, Measure, Analyze, Improve, Control) framework, this research aims to identify the root causes of these deviations and propose measures to maintain TSS outflow in compliance with regulations, as outlined in the Minister of Environment Decree No. 113 of 2003. The study will focus on evaluating operational practices at the pond, including the TSS Outlet Pump limits, maintenance schedules, water flow management, and the integration of technological improvements for real-time monitoring.

Accurate TSS management is crucial not only for regulatory compliance but also to ensure that water quality does not interfere with local business operations and communities. By addressing the challenges in TSS management, PT BIB aims to improve operational efficiency, reduce environmental risks, and enhance its reputation as a responsible corporate entity. The findings of this study will provide valuable insights for improving TSS management, which can be applied to other mining operations in the region to support sustainable mining practices.

The management of Total Suspended Solids (TSS) in coal mining wastewater has been extensively studied due to its environmental and regulatory implications (G. Adjovu et al., 2023; G. E. Adjovu, Stephen, & Ahmad, 2023; G. E. Adjovu, Stephen, James, et al., 2023; Aladejare & Akeju, 2020; Pizarroso et al., 2022). Previous research by Carlsson (1998) emphasized the importance of sedimentation theory in wastewater treatment, highlighting how improper settling pond design can lead to inefficient TSS removal. Similarly, Simons (1982) provided a manual for sedimentation control, underscoring the role of physical and chemical treatments in mitigating TSS levels. However, these studies often focus on theoretical frameworks or generalized solutions, leaving gaps in context-specific applications, particularly for large-scale mining operations like PT Borneo Indobara (PT BIB) in Indonesia. This gap is critical, as regional factors such as rainfall patterns and operational practices can significantly influence TSS dynamics.

A notable research gap lies in the integration of real-time monitoring and Lean Six Sigma methodologies for TSS management in settling ponds. While Pyzdek (2003) and Thomsett (2005) demonstrated the efficacy of Six Sigma in industrial process improvements, its application to environmental management in mining remains underexplored. Additionally, studies like that of Husaini (2018) on chemical treatments for TSS reduction lack empirical data on cost-benefit analyses, which are crucial for justifying large-scale implementations. The absence of standardized procedures for TSS pump limits, as observed in PT BIB's operations, further exacerbates the problem, leading to inconsistent compliance with regulatory thresholds.

The urgency of this research stems from PT BIB's recurring TSS exceedances, which have triggered environmental complaints from local communities and palm oil plantations. Regulatory breaches, such as those violating Indonesia's Minister of Environment Decree No. 113 of 2003, not only incur fines but also damage corporate reputation and stakeholder trust. Moreover, unmanaged TSS discharges disrupt agricultural activities and aquatic ecosystems, amplifying socio-environmental conflicts. Addressing these issues is imperative to align PT BIB's operations with sustainable development goals and national environmental policies, while ensuring uninterrupted production targets of 54 million tons annually.

This study introduces novelty by combining Lean Six Sigma's DMAIC framework with real-time sensor technology to address TSS management holistically. Unlike prior works that focus solely on technical or regulatory aspects, this research proposes data-driven interventions, including TSS pump limits (25,000 mg/L) and sensor-based monitoring, validated by a robust Benefit-Cost Ratio (BCR) of 32.57. The integration of Fishbone root cause analysis and regression modeling ($R^2 = 0.9997$ for pump-inlet TSS correlation) further distinguishes this study, offering a replicable model for similar mining operations.

The purpose of this research is to evaluate and optimize TSS management at PT BIB's SP 02 GH settling pond, ensuring compliance with environmental standards while minimizing operational costs. By implementing SOPs, real-time sensors, and staff training, the study aims to reduce TSS-related risks and enhance stakeholder relations. The benefits extend beyond PT BIB, providing a scalable framework for the mining sector to achieve environmental compliance, operational efficiency, and sustainable resource management. This aligns with global trends in responsible mining and circular economy principles, offering both economic and ecological value.

RESEARCH METHOD

This research used a mixed-methods approach, combining both quantitative and qualitative data to thoroughly investigate the causes of high Total Suspended Solids (TSS) levels in the *SP 02 GH* settling pond at PT Borneo Indobara. The *DMAIC* framework from the Lean Six Sigma methodology was utilized to identify and resolve inefficiencies in the TSS management process. Each phase of *DMAIC* aimed to improve the quality of water management practices in compliance with environmental regulations.

In the *Define* phase, the research identified the problem of high TSS levels in the outflow from the *SP 02 GH* settling pond. The main objective was to understand the root causes of TSS deviations and set clear goals for improvement. Stakeholders, including management and environmental officers, were involved in defining the specific issues affecting TSS management.

During the *Measure* phase, data collection included both qualitative and quantitative methods. Qualitative methods involved interviews, field observations, and *Focused Group Discussions (FGD)* with key stakeholders such as environmental officers, maintenance crews, and operations managers to identify procedural gaps, potential sources of human error, and operational inefficiencies. Quantitative methods involved collecting historical data on TSS levels, rainfall patterns, and operational activities. Measurements included water sampling from both the inflow and outflow points of the pond, TSS pump data, and rainfall data to evaluate their correlation with TSS levels.

In the *Analyze* phase, descriptive statistics and regression analysis were used to assess the relationship between TSS levels and various factors such as rainfall and TSS pump activities. Descriptive statistics summarized the data to identify trends and variations in TSS levels, while linear regression examined the correlation between TSS measurements from various sources to identify factors influencing TSS levels in the settling pond.

Based on the analysis, the *Improve* phase focused on implementing improvements to reduce TSS exceedances. This included process optimization such as managing the TSS outlet pump limits, improved maintenance scheduling, and the implementation of more effective water treatment technologies and real-time monitoring. Recommendations were tested to assess their feasibility and effectiveness.

To ensure that the improvements made were sustained, the *Control* phase involved developing *Standard Operating Procedures (SOPs)* for monitoring, maintenance, real-time monitoring, and periodic reviews. The goal was to prevent future TSS deviations and ensure long-term compliance with environmental standards.

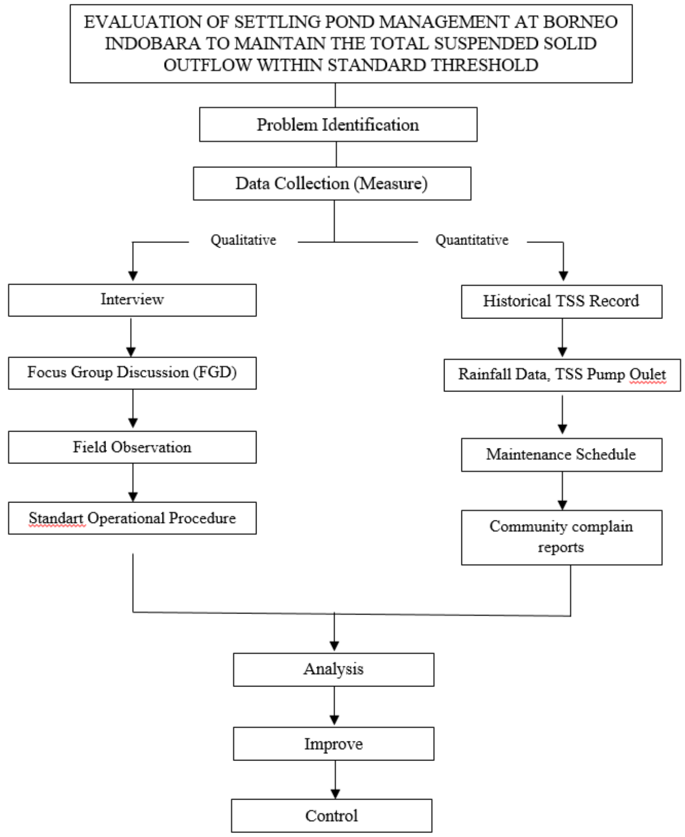


Figure 2. Research Design

RESULT AND DISCUSSION

Define

This research begins with a significant issue: high levels of Total Suspended Solids (TSS) in the outflow from the SP 02 GH settling pond at PT Borneo Indobara. The TSS levels exceeding environmental standards create challenges in meeting established water quality regulations. This impacts the company's reputation and triggers complaints from external parties, particularly from palm oil companies located near the operational area, as well as complaints from local communities regarding environmental pollution in the river area. These complaints focus on sedimentation occurring in the drainage channels, which disrupts the palm oil harvesting process. In addition to environmental impacts, PT Borneo Indobara also faces high operational costs due to emergency measures for cleaning sediment along the drainage channels near the palm oil plantation area, which disrupts the company's operational activities. This project aims to manage the inflow into the settling pond to meet the prescribed TSS threshold set by regulations, avoid operational disruptions, and improve relationships with stakeholders.

Customer needs are identified through the Voice of the Customer (VOC) approach. Key stakeholders, such as local communities, management, and palm oil companies, require water quality that meets environmental standards. The management team needs efficient TSS management to prevent external complaints and fines, while the environmental team ensures that water management complies with the set regulations.

The scope of activities includes monitoring and improving TSS management processes, ensuring the settling pond operates effectively, and maintaining water quality standards. A SIPOC analysis is created to map the TSS management process, identifying suppliers, inputs, processes, outputs, and customers involved.

Table 1. SIPOC of Water Management in Settling Pond

Supplier	Input	Process	Output	Customer
Government	Water and environmental quality regulations	Monitoring and enforcement of water quality standards	Compliance with water quality standards	PT Borneo Indobara
Management	Water quality and TSS monitoring reports	Evaluation and planning for process improvements.	Policies and strategies for improving TSS management	All Stakeholders, including Government and Communities
Operation Team	The pump from the sump can run efficiently	Coal Loading & OB Removal are not disrupted	Coal & OB Production can be achieved	Management
Environment Team	Water quality data (TSS), settling pond condition	Water processing and quality monitoring	Processed water that meets water quality standards.	Palm Oil Companies, Local Communities

Based on the SIPOC results above, it is stated that the Government sets the water quality regulations that PT Borneo Indobara must adhere to. The Operations Team ensures that the pump operates efficiently and without interruptions to avoid disruptions in coal loading and overburden (OB) removal. The Environmental Team collects TSS data and monitors the settling pond conditions, ensuring that the processed water meets the required quality standards. The Management Team receives water quality and TSS reports, and develops policies to improve TSS management that benefit all stakeholders.

Measure

The Measure phase in this research is a crucial initial step to understand the current state of the TSS management process at the SP 02 GH settling pond and to establish a baseline that will serve as the foundation for evaluating improvements. The primary goal at this stage is to collect data and establish performance metrics that are relevant to the project's main objective, which is to reduce the Total Suspended Solids (TSS) levels in the outflow from the settling pond to meet the established water quality standards. The key performance indicator (KPI) for this phase is to ensure that the TSS levels in the outflow do not exceed the regulatory threshold of 200 mg/L. Data will be collected on current TSS levels, water quality, and the condition of the settling pond to understand the existing performance and identify areas for improvement. This baseline will help determine the effectiveness of future interventions aimed at reducing TSS levels and improving water quality management at the site. By setting these performance measures, the project aims to enhance water management at the settling pond, ensure compliance with environmental standards, and reduce operational disruptions caused by complaints from the surrounding community. This will provide a solid foundation for making more informed decisions regarding water quality management and maintaining positive relationships with local communities and stakeholders.

The measurement baseline for the TSS management project at the SP 02 GH settling pond is determined based on the TSS levels in the outflow water from the settling pond between March 2024 and June 2024 (Figure IV.2). This baseline reflects the TSS levels in the water before any improvements are implemented, which often exceed the allowable limit of 200 mg/L. Establishing this baseline is crucial as it provides a clear and measurable starting point for evaluating the project's progress.

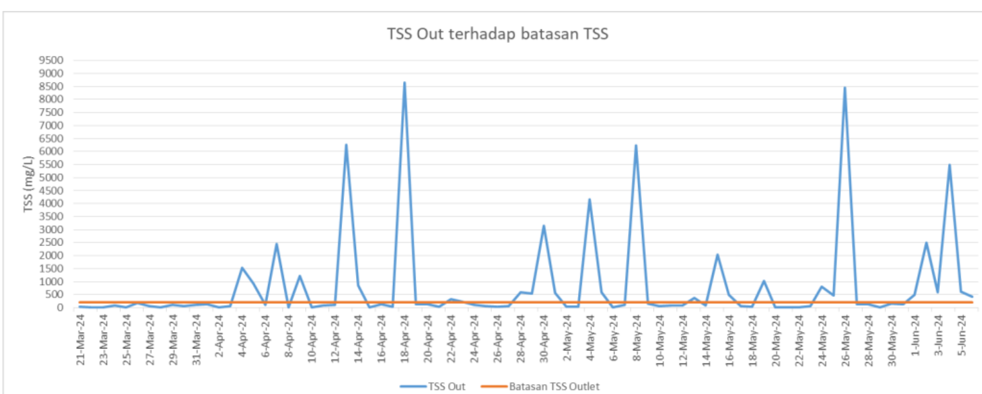


Figure 3. TSS Levels and Measurement Baseline from March 2024 - June 2024

In this project, the primary performance metric used is the TSS levels in the outflow water from the settling pond, with a maximum target of 200 mg/L, in accordance with regulatory standards. This metric was chosen because it directly impacts environmental compliance and the quality of water discharged from the settling pond, which is essential for maintaining positive relationships with surrounding communities and stakeholders. This metric will serve as the primary reference to determine if the improvement process successfully achieves the project objectives.

TSS statistical data collected from the SP 02 GH settling pond between March 2024 and June 2024 was gathered and analyzed. This analysis includes key statistical measures such as mean, median, standard deviation, kurtosis, skewness, range, minimum, and maximum values. These statistics help identify trends and variability in TSS levels, which will help understand conditions that may contribute to high TSS levels in the settling pond.

Table 2. Descriptive Statistic of TSS Inlet SP 02 GH

	TSS Inlet SP 02 GH
Mean	31.766.51 mg/L
Median	6.300 mg/L
Standard Deviation	44.221 mg/L
Kurtosis	2,04
Skewness	1,55
Range	209.900 mg/L
Minimum	23 mg/L
Maximum	209.900 mg/L
Count	102

After the TSS data is collected and analyzed, regression tests are conducted to examine the influence of rainfall and pumping TSS. The data collected from March 2024 to June 2024 shows a positive linear relationship between the two variables, indicating that higher rainfall tends to correspond with higher TSS levels. However, this correlation is very weak, as indicated by the low R^2 value, which suggests that rainfall is not the primary factor influencing the high TSS levels at the inlet.

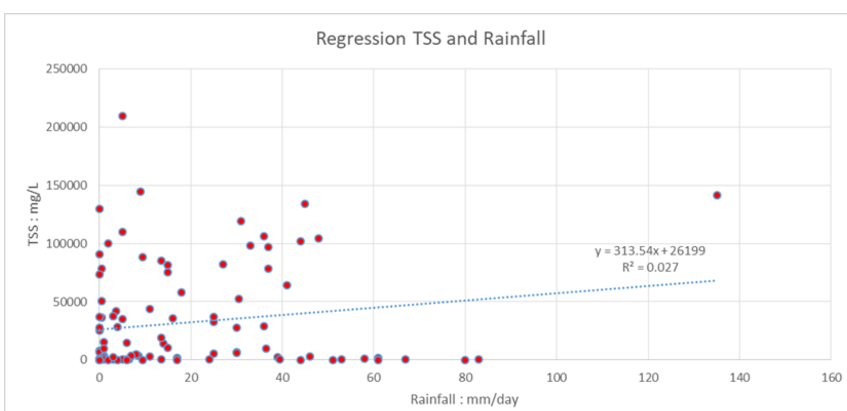


Figure 4. Correlation Rainfall against TSS Inlet SP 02 GH

The regression equation is y = 313.54x + 26199, where "x" represents the amount of rainfall in mm/day, and "y" represents the TSS level in mg/L. The R^2 value of 0.027 indicates that only about 2.7% of the variation in TSS levels can be explained by the variation in rainfall, meaning that this linear regression model does not show a meaningful relationship between rainfall and TSS.

A second regression analysis is conducted to explore the relationship between the TSS levels at the pump and the TSS levels at the inlet of the SP 02 GH settling pond. The results show a very strong positive linear relationship, with a high R^2 value of 0.9997, indicating that changes in TSS pump levels are almost entirely correlated with TSS levels at the inlet.

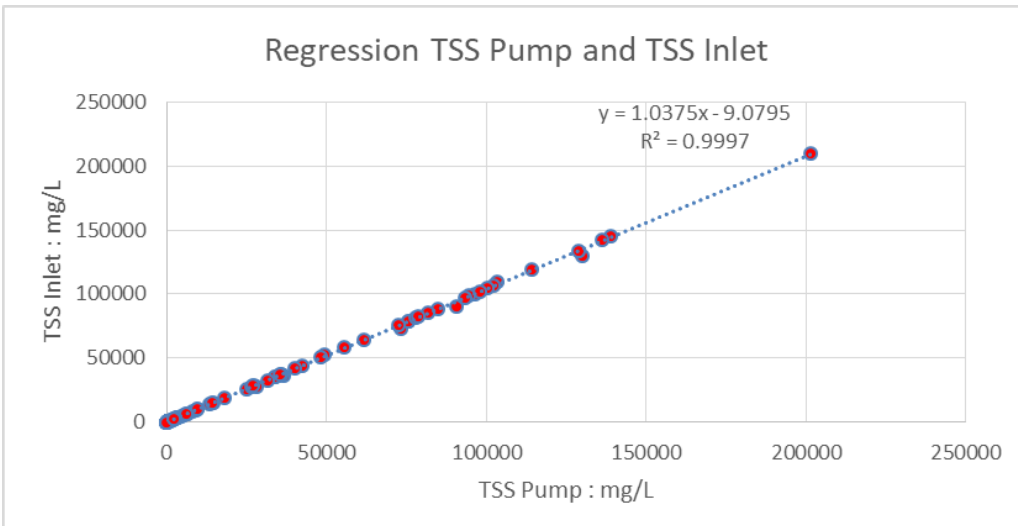


Figure 5. Correlation TSS outlet pump against TSS Inlet SP 02 GH

The regression equation is y = 1.0375x - 9.0795. This strong correlation shows that high TSS levels entering the settling pond are largely influenced by high TSS levels in the uncontrolled pump water. This suggests that stricter management and monitoring of the TSS pump are needed to mitigate the negative impact on the water quality entering the settling pond.

In this case, maintenance of the settling pond is essential to prevent excessive sedimentation and ensure that the water treatment system operates optimally. Based on the results of the Focus Group Discussion (FGD) with the Operations, Environmental, and Mine Planning teams, it was agreed that the full sedimentation time in the settling pond should be at least twice the time required for sludge pumping (maintenance) from the settling pond to the disposal area. The sludge pumping time for maintenance is 2 months, ensuring the settling pond can still be used for chemical treatment. This activity is one of the requirements to ensure the water management system operates more effectively (Table 3). This concept can be illustrated as shown in Figure 6.

Table 3. Minimum Maintenance Time

Clustering	Settling Pond	Passive Capacity	CA Area	Number of Pump	Settling Volume	Maintenance Duration (month)	Remarks
		(m^3)	(Ha)	(line)	(m^3/month)	Slurry Pump	
GH	SP 02 GH	278.308	66	7	**48.548**	2.0	60% from capacity SP 02 GH
		Total			**48.548**		-

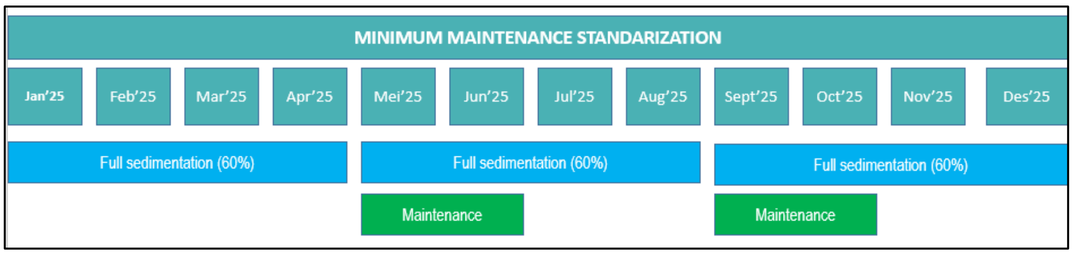


Figure 6. Maintenance Management Concept

Water management in the SP 02 GH settling pond is a complex process and requires careful monitoring and regulation of TSS levels. High TSS levels entering the SP 02 GH settling pond are primarily caused by two main factors: TSS from rainfall catchment and TSS produced through the pumping process. Data analysis reveals that while rainfall has a limited impact on TSS levels (2.7%), the pumping process has a significant effect on TSS levels, with a very high correlation of 99.97%.

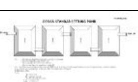
One of the major contributors to high TSS levels in the SP 02 GH settling pond is the pumping process. There are 7 pumps operating for dewatering mining pit that enter the ditch which then enter into the settling pond. Each of these pumps carries a large amount of water that contains substantial TSS. The pumping process plays a major role in transporting solid particles from higher areas into the settling pond, leading to an increase in TSS levels entering the pond. This process presents a major challenge in TSS management because the pumped water not only contains clean water but also dissolved materials such as mud, sand, and other substances that elevate TSS levels. Therefore, this pumping system must be carefully managed to prevent significant degradation in water quality, which could severely impact water management across the entire area.

Based on water balance calculations, catchment area, minimum maintenance time, rainfall, and pumping calculations, it is shown that the SP 02 GH settling pond's capacity is sufficient to handle the volume of water entering the SP 02 GH area (Table 4 and Table 5). Water balance analysis indicates that, although the volume of water entering is quite large, with the current pumping system, the settling pond can still accommodate large volumes of water and efficiently carry out the sedimentation process. However, with the high TSS levels, the challenge is to ensure that the settling pond does not exceed its capacity and can maintain effective water treatment processes.

Table 4. Capacity SP 02 GH

Settling Pond 02 GH				
Compartment	Top area	Bottom area	Capacity (m³)	
	(m²)	(m²)	Active	(m²)
1	10.193	5.714	11.930	27.837
2	11.105	6.389	13.121	30.615
3	9.528	5.229	11.068	25.825
4	10.348	5.841	12.142	28.331
5	16.346	10.343	20.017	46.706
6	12.777	7.510	15.215	35.502
Volume Total	278.308		83.492	194.815

Table 5. Capacity Requirment SP 02 GH

Perhitungan Desain dan Dimensi Sediment Trap						
No	Deskripsi			Simbol	Lokasi SP 02 GH	Unit
1	Perhitungan Debit dengan Metode Rasional					
	1.1	Limpasan (Run-off)				
		a.	Catchment area	A	66	Ha
		b.	Intensitas hujan rencana	I	126.00	mm/hari
		c.	Curah Hujan max bulanan	I (bulanan)	600	mm/bulan
		d.	Koefisien limpasan	C	0.75	
		e.	Durasi hujan		4	jam
		f.	Rain Intensity	I mononobe	28.49	mm/jam
		g.	Debit run-off	Q1	**3.92**	m³/s
	1.2	Pompa				
		a.	Kapasitas pompa	Q1	650	m³/jam
		b.	Jumlah pompa	unit	7	Line
		c.	Working hour pump	EWH	18.36	jam/ hari
		d.	Debit pompa per detik	Q1	**1.26**	m³/s
		e.	Debit pompa per hari	Q2	71.007	m³/day
	Total Debit yang masuk			Q total	**5.18**	m³/s
2	Perhitungan Minimal Kapasitas Pasif & Aktif					
	2.1	Kapasitas Pasif				
		a.	Persentase Sedimentasi	k	0.02	
		b.	Air mengalir	k	0.96	
		c.	Umur maintenance	n	4.00	bulan
		d.	Debit Air Hujan	Q	2.427.219	m³/bulan
		e.	Volume air menuju sungai	V	2.330.130	m³/bulan
		f.	Volume yg mengendap	V	48.544	m³/bulan
		g.	Minimal Kapasitas pasif	Dimension	242.722	m³

Analysis

The analysis phase in this study aims to understand the significant variation in Total Suspended Solids (TSS) entering the SP 02 GH settling pond, based on data collected during the Measurement Phase. To investigate the causes of these fluctuations, descriptive statistical analysis, regression analysis, and Ishikawa diagram analysis were conducted.

The descriptive analysis shows that the main challenge is managing episodic spikes in TSS levels, which may be caused by various external factors (such as heavy rainfall or pumping activities). Mitigation measures that can be implemented include tightening the monitoring of the pumping process, controlling the quality of incoming water, and ensuring that the TSS levels entering the settling pond do not exceed manageable limits.

Based on the results of the descriptive analysis, regression analysis was conducted to determine the percentage of the significant relationship between TSS variation and rainfall, as well as TSS Pump outlet. From this data, it was found that the influence of the TSS Pump outlet significantly affects the TSS levels, as expressed by an R^2 value of 0.9997. This indicates that 99.97% of the variation in TSS inlets can be explained by the variation in TSS Pump. Based on these results, it can be concluded that the high TSS levels at SP 02 GH are greatly influenced by the high, uncontrolled TSS levels from the TSS Pump. This suggests that stricter management and monitoring of the TSS Pump are needed to reduce the negative impact on the water quality entering the settling pond.

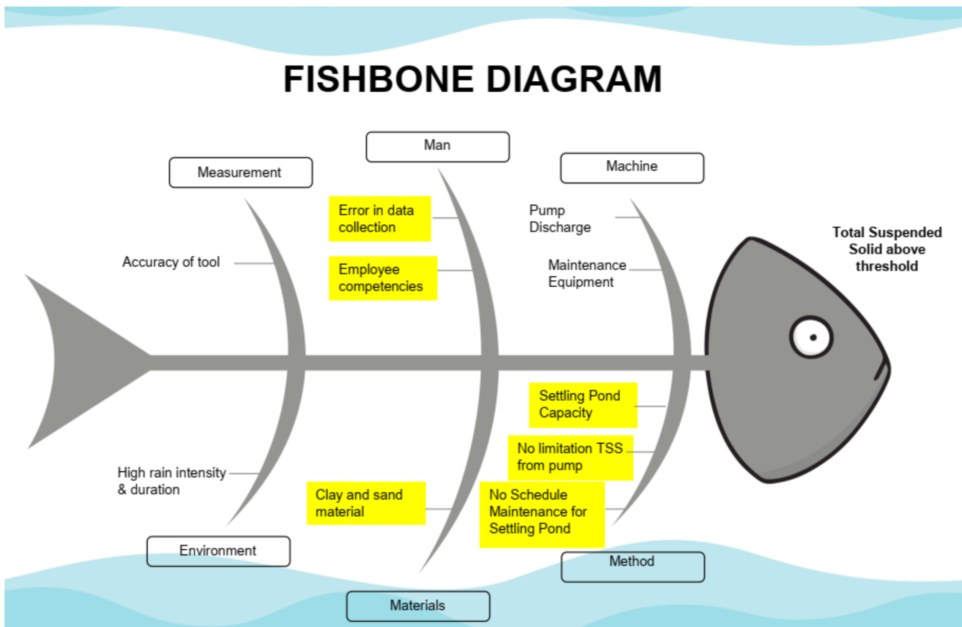


Figure 6. Root Cause Analysis (Ishikawa)

The Fishbone diagram (Figure 6) identifies potential causes of the high variability in TSS levels entering the settling pond. The Fishbone diagram helps to identify root cause of a problem by categorizing potential causes into major groups such as methods, machines, materials, manpower, measurement, and environment (6M).

In the human category, there are several significant operational errors, such as Errors in manual sampling are a major concern, with inconsistent sampling times and varying conditions leading to discrepancies in TSS data. Human errors, such as improper sampling techniques or failure to account for environmental factors, can affect the accuracy of TSS measurements. there are environmental disruptions, such as Extreme weather conditions such as heavy rainfall or local flooding may interfere with the sampling process, potentially causing inaccurate data collection and measurement errors. While significant, this does not appear to be the primary cause of TSS fluctuations in the pond.

In category of methods, key issues Lack of Standard Operating Procedures (SOPs): The absence of clear SOPs for managing the maximum TSS levels entering the settling pond results in significant fluctuations in TSS concentrations. Without standard guidelines, the treatment process becomes unpredictable and difficult to manage. This causes operational inefficiencies and potential environmental harm due to fluctuating TSS levels. There are Inconsistent Methodology such as the methods used to calculate TSS levels, including the absence of clear standards for TSS entering the pond, contribute to unstable results. This can lead to an increased use of chemicals for water treatment and inefficient sedimentation processes because fluctuating TSS levels are difficult to manage without clear procedural guidelines.

In terms of materials, Composition of Incoming Water: The presence of materials such as clay and sand in the incoming water can affect TSS levels and complicate the sedimentation process. Clay, for example, tends to bind with other suspended solids, preventing proper separation in the pond. This complicates the treatment process and exacerbates the already high TSS concentrations.

For the machinery category, Sludge pump performance: The pumping of sludge for maintenance of the settling pond serves as a reference for determining the minimum maintenance limits. This should be incorporated as a constraint in the design process to meet the required limits. According to the FGD results, to avoid interference with the effectiveness of the settling pond, the minimum maintenance frequency should be twice the duration of the pumping time required for settling pond maintenance. There are Outdated Equipment such as the effectiveness of pumping equipment for maintaining the settling pond must be ensured and meet specifications, including a minimum Physical Availability of 90% and Utilization Availability above 85%, to prevent delays in maintenance and avoid disrupting the effectiveness of the settling pond.

Finally, in the environmental category, External Environmental Conditions: Rainfall and weather conditions do influence TSS levels, although regression analysis shows a weak correlation between rainfall and TSS variation. Despite this, factors such as heavy rainfall, flooding, or seasonal weather patterns can cause temporary spikes in TSS levels, requiring more responsive management during such events. There are Local Environmental Impact such as Potential contamination from surrounding activities (e.g., mining, construction) or pollution from external sources can introduce additional TSS into the water, further complicating the treatment process.

Improve

The Improve stage focuses on the development and implementation of improvement solutions to address the root causes of the issues identified during the Define, Measure, and

Analyze phases. Based on the results of the previous analysis, the improvements are directed toward addressing the high fluctuations in Total Suspended Solids (TSS) levels, particularly the uncontrolled TSS pump outputs and the lack of real-time monitoring. The goal of this stage is to stabilize the TSS levels by entering the SP 02 GH settling pond and ensure more efficient and reliable water treatment, ultimately improving water quality and reducing environmental risks. Standardization of Recording and Reporting Procedures.

1. Standardization of TSS Pump Limits

   The first improvement step is the development of a Standard Operating Procedure (SOP) for regulating the maximum TSS levels that can enter the settling pond. Currently, there are no clear limits on the TSS entering the pond, which has led to highly fluctuating and difficult-to-manage TSS concentrations. These fluctuations result in suboptimal sedimentation processes and increased maintenance frequency. The new SOP will define the maximum permissible TSS levels based on technical parameters, including the pond's capacity to treat water, settle solids, and meet water quality standards.

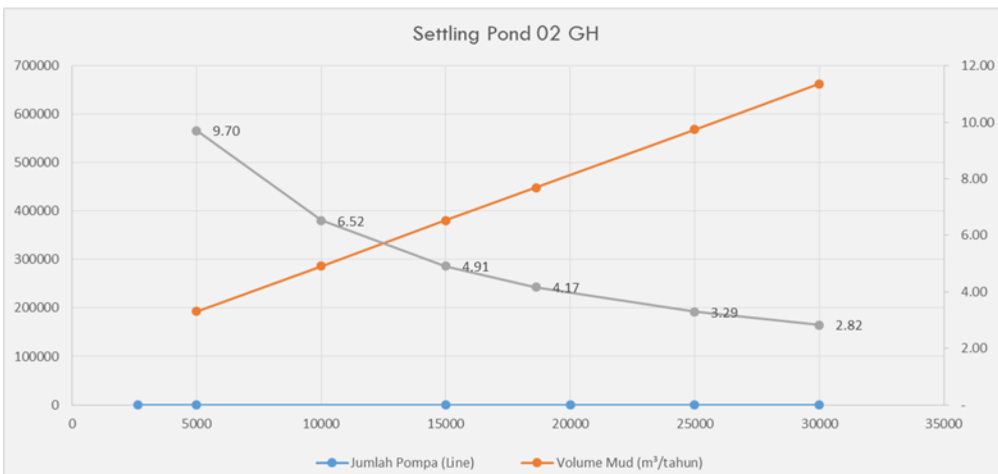


Figure 7. TSS Limit Pump against Maintenance time

2. Installation of Real-Time TSS Sensors

   Another significant improvement involves the installation of real-time TSS sensors at both the inlet and outlet of the SP 02 GH settling pond. Currently, there is no continuous monitoring system for TSS levels, making it difficult to respond to fluctuations in water quality. The installation of sensors at both points will allow for real-time tracking of TSS concentrations, enabling immediate corrective actions when needed.

   At the pump inlet, the sensors will monitor incoming water and automatically shut off the pump if TSS levels exceed the set threshold. This will prevent further contamination and protect surrounding ecosystems from high TSS concentrations. At the outlet, sensors will ensure that the water leaving the pond meets environmental quality standards. If TSS levels exceed the allowable limits, the system will trigger alarms or automatic corrective actions to bring the levels back into compliance. By providing continuous, accurate data, these sensors will optimize the sedimentation process, improve the settling pond's performance, and minimize the risk of environmental contamination.

3. Benefit to Cost Ratio Analysis for TSS Management Improvements

   To ensure that the proposed improvements are financially viable, a Benefit-Cost Ratio (BCR) analysis was conducted. The Benefit-Cost Ratio (BCR) is the ratio of the present value of benefits to the presents value of costs. A BCR greater than one indicates that the benefits of a project exceed its costs, making it economically justifiable (Boardman et al, 2018). The BCR method is one of the tools that can measure profit or loss and assess whether a project should be implemented. The BCR method evaluates the comparison between the value of benefits and the value of the costs and losses that will be incurred.

   a. Overview of Benefits:
      - Reduction in water management costs: By stabilizing TSS levels and improving sedimentation efficiency, there will be savings of Rp 11,547,003,976 per year.
      - Reduction in maintenance costs: Improved sedimentation will reduce the need for frequent pond maintenance, saving Rp 6,873,216,652 annually.
      - Improved compliance with water quality standards: Avoiding fines and maintaining good relations with the community results in savings of Rp 698,565,584 annually.
      - Protection from operational shutdowns: Preventing TSS contamination in local rivers and agricultural areas helps avoid shutdowns and claims, with an estimated benefit of Rp 31,824,000,000 per year.

      Estimated total benefits are around Rp 51,942,786,212.

   b. Overview of Costs:
      - Installation of real-time TSS sensors at both the pump inlet and the outlet: **Rp** 1,200,000,000 per year.
      - Integration with existing monitoring systems, including software installation: **Rp** 200,000,000 per year.
      - Sensor maintenance and calibration: Rp 80,000,000 per year.
      - Training and personnel costs: Rp 115,000,000 per year.

      Estimated total costs are around Rp 1,595,000,000.

Calculating the Benefit Cost Ratio around 32.57. This means that for every Rp 1 spent on improvements, Rp 32.57 will give benefit for around Rp 32.57, which is demonstrating a highly favorable return on investment (Figure 8).

Figure 8. Cost Benefit Ratio

BENEFIT			
Description	Cost Before (per Year)	Cost After (per Year)	Deviation (per Year)
1. Water Management Cost	Rp 18,306,623,236	Rp 6,759,619,260	Rp 11,547,003,976
2. Sludge Removal Cost	Rp 13,668,549,599	Rp 6,795,332,947	Rp 6,873,216,652
3. Compensation Claim Cost	Rp 698,565,584		Rp 698,565,584
4. Potential Loss from Operasional Stoppage	Rp 32,824,000,000		Rp 32,824,000,000
Benefit			**Rp 51,942,786,212**
COST			
Description	Cost per Year		
1. Installation of TSS Pump Outlet Sensor	Rp 600,000,000		
2. Installation of TSS Outlet SP 02 GH Sensor	Rp 600,000,000		
3. Dashboard Monitoring	Rp 200,000,000		
4. Sensor Callibration	Rp 80,000,000		
5. Training and Personnel	Rp 115,000,000		
Cost	**Rp 1,595,000,000**		
BENEFIT-COST RATIO (BCR)			**32.57**

4. Monitoring and Auditing for Sustainability
   To ensure that these improvements are sustained and continue to provide long-term benefits, routine monitoring and audits will be implemented. Regular checks on the performance of the TSS sensors and the effectiveness of the new SOPs will be carried out. These audits will help ensure that the TSS levels remain within acceptable limits, and any deviations are quickly addressed.

Control

In the Control phase, control measures are implemented to maintain consistency and accuracy in TSS data recording and reporting, as well as to prevent the recurrence of significant TSS deviation issues. Proper control ensures that the improvements made are not temporary but become an integral part of the operational process.

1. Implementation of Process Control through Real-Time Monitoring and Procedures
   To keep the procedures that have been implemented consistently followed by all operators, a continuous monitoring system has been created. Procedures are used as a standard reference in every production recording and reporting activity, and operators are required to undergo regular refreshment training sessions. The dashboard-based real-time monitoring system allows production and management teams to monitor the recording data in real-time. Deviations from the record-keeping standards can be detected quickly and corrective action can be taken immediately.
2. Use of Dashboard to Monitor Measurement Performance
   Control Dashboard are used as statistical control tools to continuously monitor variations in TSS measurements. These charts help the team identify if the TSS levels from the pump outlet and the settling pond outlet exceed the established limits. With the charts displayed on the

dashboard, warnings will be triggered when TSS levels approach or exceed the 200 mg/L threshold. These alerts will notify responsible personnel to take immediate corrective actions. When an alert is triggered, the system will automatically take corrective actions such as shutting off the pump or adjusting chemical treatments. The system will also notify the supervisor for manual intervention if necessary. If TSS levels exceed acceptable limits, corrective actions will be promptly taken, and the incident will be analyzed to prevent similar occurrences in the future.

3. Training and Capacity Building for Supervisors
   Regular training sessions will be conducted to update staff on the latest monitoring technologies, sensor calibration techniques, and troubleshooting methods. This will help staff stay aligned with the best practices in TSS management. Training will also include scenario-based simulations where staff can practice how to respond when TSS levels exceed regulatory thresholds or when equipment failures occur. In this case, we will also monitor the Key Performance Indicators (KPIs) of the supervisors, such as TSS levels at the inlet and outlet, chemical usage, maintenance activities, and system uptime. These KPIs will be tracked over time to monitor the success
4. Documentation and Reporting Audits
   Accurate documentation and reporting are essential to ensure transparency, accountability, and compliance with regulatory standards. The following steps will be taken: The performance of the TSS management system will be documented in routine reports that include data on TSS levels, corrective actions taken, and overall system performance. All operational data, maintenance logs, and corrective actions will be documented and stored securely for future reference and audits. An annual report will be generated to summarize the results of the TSS management process, the effectiveness of the improvements made, and any ongoing challenges.

CONCLUSION

This chapter summarized the research findings on the root causes of sedimentation in the creek connected to the *SP 02 GH* settling pond, identifying uncontrolled fluctuations in TSS levels—primarily due to the absence of pump limitations and real-time TSS monitoring at both the pump and outlet—as the main issue impacting nearby communities and palm oil plantations. By applying the *DMAIC* methodology, the study proposed improvements such as installing real-time TSS sensors, developing *SOPs* to regulate TSS pump limits, conducting routine maintenance, enforcing strict supervision of pump operations, and providing staff training with interdepartmental collaboration. Implementing these strategies through systematic Lean Six Sigma management is expected to enhance operational efficiency, reduce environmental risks, and improve community relations. For future research, it is recommended to examine the long-term effectiveness, cost-efficiency, and sustainability of real-time TSS monitoring systems under various operational conditions, explore advanced sediment control technologies like automated filtration or bioengineering solutions, and investigate the broader socio-environmental impacts of sedimentation. Expanding the research to other industrial settling ponds could also help validate the proposed solutions and identify best practices across different contexts.

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