

Quality Improvement of Wastewater Treatment in the Sewage Treatment Plant Using Six Sigma Methodology

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ARTICLE INFO

Article history:

Received: December 06, 2025

Revised: March 23, 2026

Accepted: August 06, 2026

JEL Classification:

Q53, M11, Q56, O13

DOI:

10.14414/jebav.v29i1.5486

Keywords:

Six Sigma, Wastewater Treatment, Quality, Continuous Improvement, Cost of Poor Quality

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ABSTRACT

Indonesia has facing global challenges related to water issues, such as clean water scarcity, unequal access to services, and suboptimal infrastructure development. Collaborative efforts by institutions, community, and the government are needed to increase awareness and knowledge of wastewater treatment to produce water quality that meets quality standards. PT BCD, a wastewater treatment service provider, prioritizes water quality to meet customer satisfaction. This study aims to analyze continuous improvement efforts for management in resolving water treatment quality issues to achieve maximum production efficiency and profit. This study is quantitative and qualitative using the Six Sigma method using the DMAI (Define, Measure, Analyze, and Improve) framework for the period of August and September 2025. The analysis results show that the sigma value of water quality in August and September 2025 is 2.88 and 2.78 of the expected 6 sigma (zero defect) value. The sigma value affects revenue due to defect costs or Cost of Poor Quality by >40%. Fishbone diagram analysis identified eight categories of critical factors causing defects: machine, method, human, communication, material, regulatory/legal, technological, and environmental factors. Improvement proposals were generated through an impact-effort matrix analysis to determine the most prioritized actions based on impact and ease of implementation.

ABSTRAK

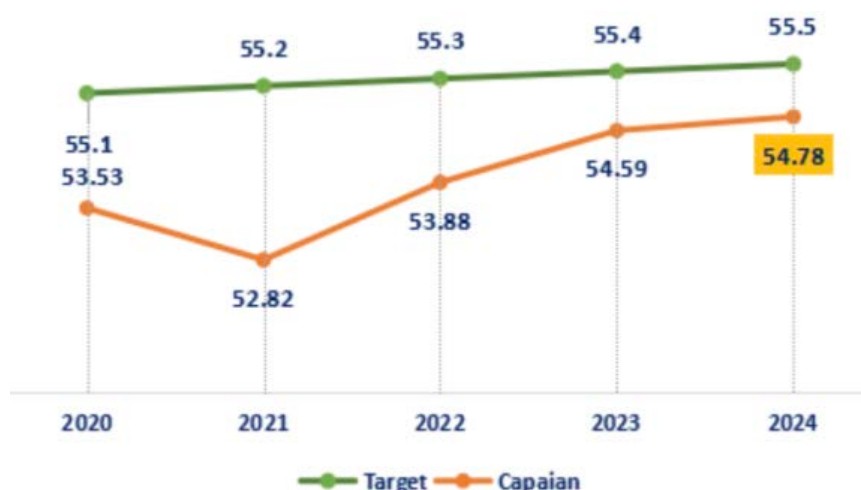
Indonesia mengalami tantangan global terkait persoalan air, seperti kelangkaan air bersih, akses layanan yang tidak merata serta pembangunan infrastruktur yang belum optimal. Upaya kolaboratif oleh institusi, masyarakat dan pemerintah diperlukan dalam meningkatkan kesadaran dan pengetahuan terhadap pengolahan air limbah agar menghasilkan kualitas air berdasarkan ketentuan baku mutu. PT BCD adalah perusahaan penyedia jasa layanan pengolahan air limbah menjadikan hasil kualitas air sebagai prioritas pelayanan untuk memenuhi kepuasan pelanggan. Penelitian ini bertujuan untuk menganalisis upaya secara continuous improvement bagi manajemen dalam penyelesaian masalah kualitas pengolahan air sehingga dapat mencapai efisiensi produksi dan profit yang maksimal. Penelitian ini bersifat kuantitatif dan kualitatif dengan metode Six Sigma yang menggunakan kerangka kerja DMAI (Define, Measure, Analyze dan Improve) pada periode Agustus dan September 2025. Hasil analisis menunjukkan bahwa nilai sigma kualitas air pada bulan Agustus dan September 2025 adalah 2,88 dan 2,78 dari nilai 6 sigma (zero defect) yang diharapkan. Nilai sigma mempengaruhi pendapatan akibat biaya defect atau Cost of Poor Quality sebesar >40%. Analisis diagram fishbone mengidentifikasi 8 kategori faktor kritis penyebab defect yaitu faktor mesin, metode, manusia, komunikasi, material, regulasi/legal, teknologi, dan lingkungan. Usulan perbaikan dilakukan melalui analisis impact-effort matrix untuk dapat menentukan tindakan yang paling prioritas berdasarkan dampak dan kemudahan implementasi.

1. INTRODUCTION

Water resources play an important role in living organisms. Water resources can realize prosperity by fulfilling basic human needs, helping to realize health and livelihood creation and economic development, strengthening food and energy security, and maintaining environmental integrity (UNESCO & Ministry of PUPR RI, 2024). In realizing this prosperity, everyone has a role in developing, maintaining, and managing water resources. Based on Law of the Republic of Indonesia Number 17 of 2019 concerning Water Resources, the regulation of water resources aims to ensure the sustainability of water availability of water resources in

order to provide equitable benefits to the community and ensure the preservation of water functions and water sources to support sustainable development. Ensuring the availability and management of quality clean water and sustainable and equitable access to sanitation is a global and national commitment for Indonesia as a short-term effort to achieve Sustainable Development Goal (SDG) 6 by 2030 (Ministry of National Development Planning/Bappenas, 2020). According to UNESCO and the Indonesian Ministry of Public Works and Housing (PUPR), clean water use will only increase by less than 1% per year in 2024 due to a 70% increase in clean water use from the agricultural sector, a 20% increase in the industrial sector, and a 10% increase in the household sector. By 2024, 2.1 billion people will lack access to safely managed drinking water, and 3.4 billion will lack access to safely managed sanitation (WHO & UNICEF, 2025). While meeting the 2030 SDG 6 targets, no targets for universal access to clean drinking water and adequate sanitation have been met (WHO & UNICEF, 2025; UNESCO & the Indonesian Ministry of Public Works and Housing, 2024).

Indonesia has demonstrated progress toward SDG 6, which addresses "Clean Water and Adequate Sanitation," aiming to achieve its 2030 target (UNESCO & the Indonesian Ministry of Public Works and Housing, 2024). However, Indonesia faces increasing global challenges with water issues, such as the scarcity of clean water availability, scarcity of access to water services due to water supply issues during climate change, uneven distribution across regions, and suboptimal national infrastructure development (Herlambang, 2025). Based on the National Water Quality Index in 2024, water quality was at 54.78%, below the national target of 55.5%. Based on Figure 1. Figure 1 shows the National Water Quality Index and explains that from 2020 to 2024, national water quality in Indonesia has not reached the set target. Based on the distribution of provinces in Indonesia, as shown in Figure 2, of the 38 provinces in Indonesia, 24 provinces (63%) do not reach the national target, and 14 provinces (37%) reach the national target.



Source : Direktorat Pengendalian Pencemaran Air, 2024

Figure 1. National Water Quality Index 2020 - 2024

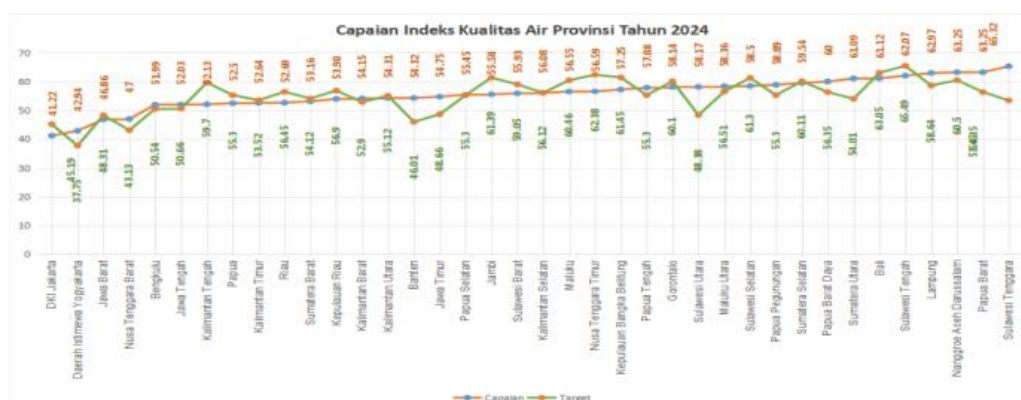


Figure 2. Achievement of the Water Quality Index of Provinces in Indonesia in 2024

The scarcity of clean water in Indonesia can be caused by water pollution originating from household, industrial, and agricultural waste (Wulandari & Ratni, 2024). This water pollution is a crucial problem in Indonesia. The problem of water pollution is not only an environmental issue but also a problem of human awareness in maintaining the environment and water quality, managing and monitoring it in accordance with applicable regulations (Ramadi et al., 2024). Collaborative efforts are needed by institutions, communities, and the government to ensure the continuity of life of living creatures and the sustainability of ecosystems, control the use of natural resources wisely, realize sustainable development, and anticipate global environmental issues (Akbar & Dwiyanto, 2024; Republik Indonesia, 2009). Companies often discharge hazardous industrial and domestic waste into water sources without effective treatment and testing, and the use of fertilizers and pesticides on agricultural land can cause water pollution. To improve water resource management, companies need to increase awareness and knowledge regarding wastewater treatment, specifically wastewater treatment plant (WWTP) management (Allu et al., 2023). Based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia (Permen LHK RI) Number P.68/Menlhk-Setjen/2016 concerning Domestic Wastewater Quality Standards, every business and/or activity that produces domestic wastewater is required to treat the resulting domestic wastewater. Every business is required to monitor compliance with wastewater quality standards (Kemen LHK RI, 2016).

Companies that produce domestic wastewater but are unable to process it must outsource their processing to another party whose business and/or activities involve the processing of domestic wastewater (Kemen LHK RI, 2016). Government Regulation of the Republic of Indonesia Number 2 of 2021 also stipulates that wastewater processors must possess an environmental permit, technical approval, and an operational feasibility letter (SLO). This will help companies strengthen their commitment to complying with applicable laws, protecting the environment from water pollution, and supporting SDG 6. PT BCD is a trusted partner in providing integrated, efficient, and environmentally friendly wastewater treatment solutions (PT BCD, 2025).

Based on the company profile, PT BCD is a private company that provides services related to the investment, construction, and maintenance of water treatment plants (WTP) and sewage treatment plants (STP) to its customers in Indonesia. The company provides services supported by waste management and handling technology for water sources in accordance with applicable standards and ensures water quality according to customer requirements (PT BCD, 2025). This company serves various industries, such as food and beverages, hospitals, hotels, mining, urban areas, and offshore (PT BCD, 2025). Based on preliminary interviews with the management, PT BCD requires a management strategy to continuously improve the quality of services and wastewater treatment processes in accordance with applicable regulations and to win the market. Product quality is a major factor that influences consumer trust and company image (Eric & Nainggolan, 2023). Efforts to improve quality control can use the Six Sigma method (Tuasamu et al., 2023). This can improve work process effectiveness and operational cost efficiency, thereby increasing customer satisfaction using the Six Sigma approach (Akbar & Dwiyanto, 2024).

Six Sigma is a business process improvement approach implemented by organizations to identify and eliminate the causes of defects and errors, reduce production cycle times and costs, increase productivity, meet customer expectations, and achieve higher asset utilization and return on investment (ROI) in manufacturing and service operations (Blocher et al., 2022). Six Sigma is a management approach aimed at encouraging continuous improvement in quality and strategy execution. Numerous studies have addressed the Six Sigma methodology. Several previous studies have discussed the Six Sigma methodology with various research subjects, including Mulyani et al. (2025), who conducted a study on the Six Sigma method to improve quality in a printing company, specifically in the security products sector. The study found that one parameter, the average total coliform content for a year, did not meet wastewater quality standards, at 6,448 MPN/100 ml. This was due to the malfunctioning disinfectant unit at the STP, resulting in a 1.5 sigma value, which categorizes the process as uncompetitive (Mulyani et al., 2025). Research conducted by Ulfah et al. (2024) used the Six Sigma method to improve water quality at a bottled water production company. The study found that waste was caused by excessive processing, with defects predominating, and unnecessary inventory and transportation in managing 220 mL bottled water, resulting in a 4.5 sigma value (Ulfah et al., 2024).

Wulandari & Ratni (2024) used the six sigma method to analyze the water quality of the Wonokromo River, Jl. Nginden Intan – Jl. Wonorejo. The study results stated that the average sigma value in the Wonokromo River was 2.625 with a range of 2.471–5 on the quality standard parameter indicator caused by a decrease in water quality due to domestic activities, industry, and lack of river water management. Zafira

& Iriani (2025) used the six sigma method to analyze the water quality of the Bondoyudo Baru River in Lumajang. The study results stated that several parameters did not meet water quality standards, such as COD, DO, total coliform, and fecal coliform, which produced a sigma value of 3.295 caused by domestic activities, industry, and lack of river revitalization (Zafira & Iriani, 2025).

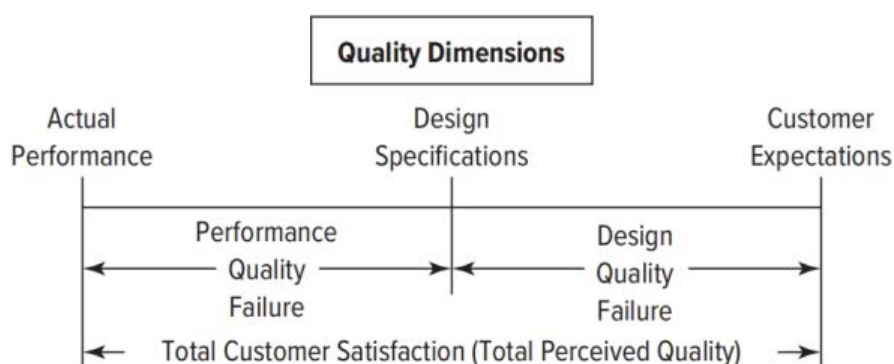
Based on the explanation of previous research related to the six-sigma methodology, it shows that six-sigma is one of the best ways to find solutions and managerial urgency to support continuous quality improvement. However, this research on service companies, such as commercial wastewater management services, is still limited. This encourages researchers to offer novel research to measure sigma level, analyze the root cause of defects, and make improvements with the main priority scale for PT BCD, not only addressing the company's production and operational quality issues, particularly Quality Control (QC) performance, but also increasing customer satisfaction and fostering long-term competitive advantage by using the six-sigma method. Additional tools used include adding voice of customer indicators such as customer feedback and complaints to define the underlying problems occurring within the company, conducting Cost of Poor Quality (COPQ) conversions in analyzing measurements to determine the estimated costs caused by defects, using questionnaires to identify the root causes of problems faced by lower operational management, and using impact-matrix effort tools to determine the main priority scale in using the six-sigma method.

2. LITERATURE REVIEW

2.1 Quality Management

Based on the ISO 9001:2015 International Standard, a quality management system is a strategic decision for a company to improve overall performance and provide a strong foundation for sustainable development initiatives. The principles of quality management are customer focus, leadership, people engagement, process approach, improvement, evidence-based decision-making, and relationship management.

According to Blocher et al. (2022), quality is the overall level of customer satisfaction with a product or service offered by a company. Quality has two main components: features and performance. Features relate to the design of a product or service according to customer expectations, such as its characteristics, attributes, and functionality. Performance is the difference between a product's design specifications and its actual performance. Results that do not meet these expectations will affect the total cost of quality. Figure 3 illustrates that failures in performance and design quality significantly impact the overall customer satisfaction with the product.



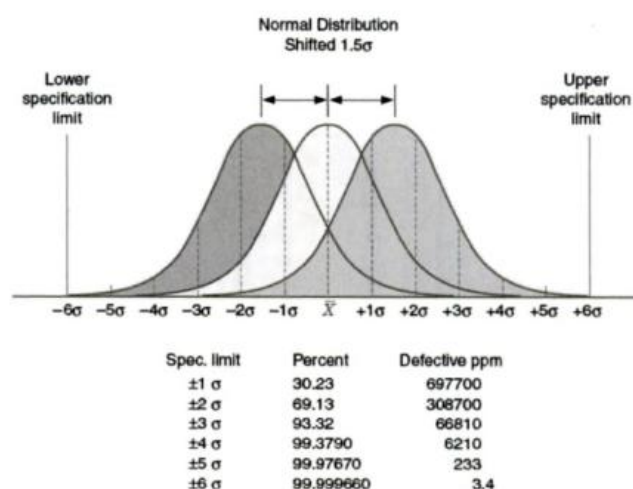
Source : Blocher et al. (2022)

Figure 3. *Dimensions of Quality*

2.2 Six Sigma

According to Thompson et al. (2022), Six Sigma is a management approach that aims to encourage continuous improvement in terms of quality and strategy execution. This approach requires the use of advanced statistical methods to identify and eliminate the causes of non-standard defects or errors and unnecessary variability in carrying out an activity or business process. According to Gaspersz (2007), a six sigma process with a normal distribution allows the mean value of the process to shift 1.5 sigma from the quality target desired by the customer. The six-sigma quality level is when the performance of an activity or business process is valued at no more than 3.4 defects per million units produced or equivalent to an accuracy level of 99.9997%,

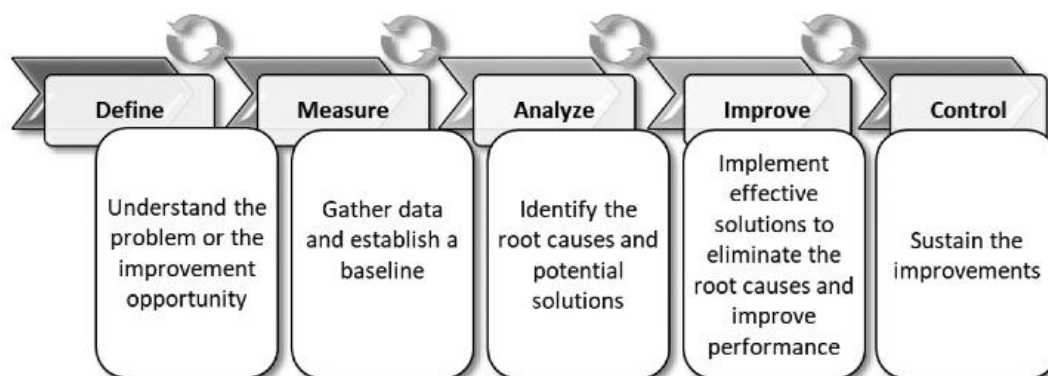
as shown in Figure 4. The shift in the yield to 99.9997% in a normal distribution by 1.5 sigma represents a significant improvement toward six sigma, resulting in very high quality, achieving almost zero defects, and excellent customer satisfaction.



Source: Gaspersz, 2007

Figure 4. Six Sigma Motorola Concept

Several processes are required to develop Six Sigma quality improvement techniques, including define, measure, analyze, improve, and control (DMAIC). There are three basic principles of Six Sigma statistical thinking: (1) all workers are a process; (2) all processes have variability; and (3) all processes produce data that explain variability (Thompson et al., 2022). DMAIC (define, measure, analyze, improve, and control) is a data-driven improvement methodology focused on enhancing and optimizing processes, systems, and products (Al-Rifai, 2024). The DMAIC model is an iterative framework for building, refining, and improving business process flows, as shown in Figure 5 (Al-Rifai, 2024).



Source: Al-Rifai, 2024

Figure 5. DMAIC Framework

a. Define Phase

The Define Phase is a critical initial stage because it establishes the foundation for the entire project, such as defining the problem and its impact on the organization, identifying stakeholders, establishing goals, objectives, and the project's scope. This stage is crucial for ensuring that the team has a clear and aligned understanding of the problem, goals, and scope (Al-Rifai, 2024).

b. Measure Phase

The Measure Phase is the second stage in problem-solving or business process improvement, focusing on data collection and establishing a baseline for the process or problem. This phase identifies the measurement metrics to gauge project success, determines how to collect data, and improves understanding (Al-Rifai, 2024).

c. Analyze Phase

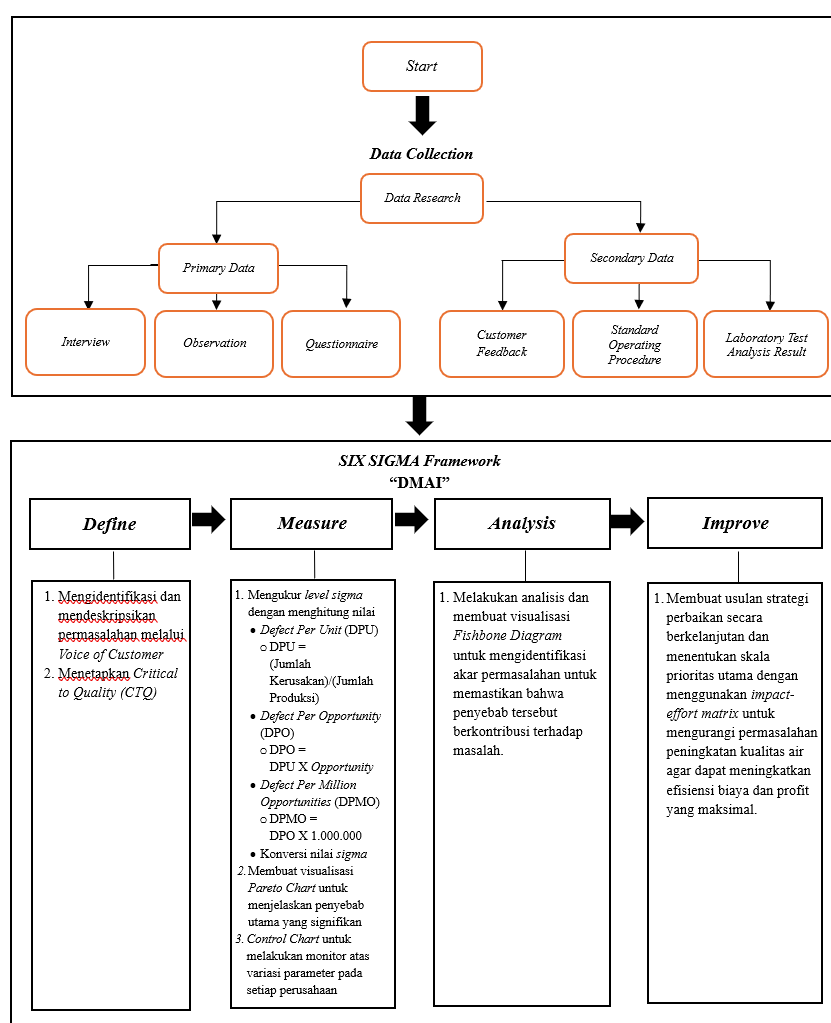
The Analyze Phase focuses on identifying the root causes of established problems and developing potential solutions based on data analysis. One method for identifying root causes is the fishbone diagram. The identified potential causes are then verified to ensure that they contribute to the problem (Al-Rifai, 2024).

d. Improve Phase

The Improve Phase focuses on identifying and implementing solutions to the problem at hand using the data and insights gathered in the previous phase. This phase generates improvement ideas, determines key priorities, and tests them to determine the most effective way to address the root causes. This phase is crucial because it requires decision-making regarding the appropriate actions to address problems and achieve tangible improvements (Al-Rifai, 2024).

e. Control Phase

The Control Phase is the final stage of the DMAIC process, focusing on monitoring and controlling the solution implemented in the improve phase to ensure its sustainability and consistent implementation over time. This includes developing procedures, updating training materials, conducting training, and communicating with the stakeholders. This phase also involves collecting data on key metrics to assess the success of the solution. Corrective actions are required if issues arise. Once the new process is documented and consistently followed, it is handed over to stakeholders responsible for long-term management and monitoring (Al-Rifai, 2024).



Source: data processed by the author
Figure 6. Conceptual Framework

2.3 Conceptual Framework

To compete with competitors and increase their competitive advantage by providing superior service, companies must prioritize improving the quality of their wastewater treatment processes. This will impact operational efficiency and increase profits. Companies must continuously monitor their water treatment processes and implement a quality control system to prevent parameter defects, thereby enhancing customer needs and complying with applicable regulations. The concept of implementing a Six Sigma strategy using the DMAIC methodology is highly relevant for PT BCD, as it can help the company develop and improve its business processes early on, leading to its future growth as a major corporation. This research aligns with several previous studies that use the Six Sigma approach as a tool for analyzing and continuously improving the effectiveness and efficiency of business processes within the company.

This research uses the Define-Measure-Analyze-Improve (DMAI) phase. This research design utilized both quantitative and qualitative methods, with data triangulation conducted between the two studies. In the quantitative research, the analysis examined the failure rate, which determined the problems faced by PT BCD. This quantitative research was supported by qualitative research to validate the results and reduce potential bias by gaining a more comprehensive understanding through data collection, observation, and interviews. Figure 6. shows the conceptual framework used to conduct this research as a whole.

3. RESEARCH METHOD

This research is qualitative, descriptive, and quantitative, employing a case study approach at PT BCD. Qualitative methods are research procedures designed to understand phenomena in depth and in context, and to gain insight into the experiences and perspectives of research subjects (Nartin et al., 2024). Quantitative methods employ a systematic approach using numerical data to analyze phenomena (Kusumatuti et al., 2024). The problem addressed in this research concerns the quality of PT BCD's domestic wastewater treatment process for customers (companies producing waste), resulting in water quality or defects that do not meet quality standards. The observational data collection period was for domestic wastewater treatment in August 2025 and September 2025. This study employed the DMAI-based approach, which was limited to the improvement stage, while the control stage was not conducted. This study did not use the full DMAIC methods.

This study consisted of two stages: the first stage involved observation, interviews, and data collection. Data collection was conducted through preliminary interviews to obtain a general overview of the company's business processes. After data collection, the next step was data processing using the Six Sigma approach. The Define (D) step involves defining the main problem being faced. This begins with creating a SIPOC diagram (Supplier, Input, Process, Output, Customer) to provide a detailed overview of the water treatment process and understand the relationships between the various stakeholders involved in meeting customer needs. Next, data analysis was conducted on customer feedback to identify the root causes of the quality of PT BCD's performance, services provided to the company, and complaints. After describing the critical issues, Critical To Quality (CTQ) criteria were determined and analyzed based on laboratory test results on samples provided by PT BCD for the periods of August 2025 and September 2025.

Table 1. COPQ Terminology Based On *Sigma Level*

<i>Level Sigma</i>	<i>Defect (%)</i>	<i>Defect (DPMO)</i>	<i>COPQ vs. Sales Revenue</i>
1-Sigma	69,15%	691.462	Uncountable
2-Sigma	30,85%	308.538	Uncountable
3-Sigma	6,68%	66.807	25-40% from sales
4-Sigma	0,62%	6.210	15-25% from sales
5-Sigma	0,0233%	233	5-15% from sales
6-Sigma	0,000034%	3,4	<1% from sales

Source : Gaspersz, 2007

The Measure (M) step involves measuring the water quality level against quality standard parameters using Defects Per Million Opportunities (DPMO) and converting it to sigma values and the Cost of Poor Quality (COPQ). The sigma level is directly related to COPQ because the size of the defect produced

using the sigma level requires costs to repair the defect, resulting in increased product quality. The relationship between COPQ and the sigma level is shown in Table 1. The next stage is the Pareto diagram and control chart. The Pareto chart is a data visualization tool used to identify the most significant root causes so that they can be prioritized for continuous improvement. The control chart is a data visualization tool in the form of a graph for quality control in monitoring the stability of a change process.

The analyze step (A) is to identify the root cause of the problem or factors that cause defects using a fishbone diagram, and the improve step (I) is to develop alternative solutions for continuous improvement using an impact-factor matrix analysis to explain the priority scale for efforts that can be made by PT BCD by considering the impact and ease of implementation so that it can improve efforts to improve the level of performance or quality of water treatment processes. This is expected to increase profits and control costs in wastewater treatment.

4. RESULT AND DISCUSSION

4.1 Result

4.1.1 Define Phase

An overview of business process mapping can be seen in the SIPOC diagram shown in Figure 7. For the operational department to improve the quality of wastewater treatment and meet the clean water needs of customers, there were complaints during implementation; the largest was on water quality at 31%, as shown in Figure 8.

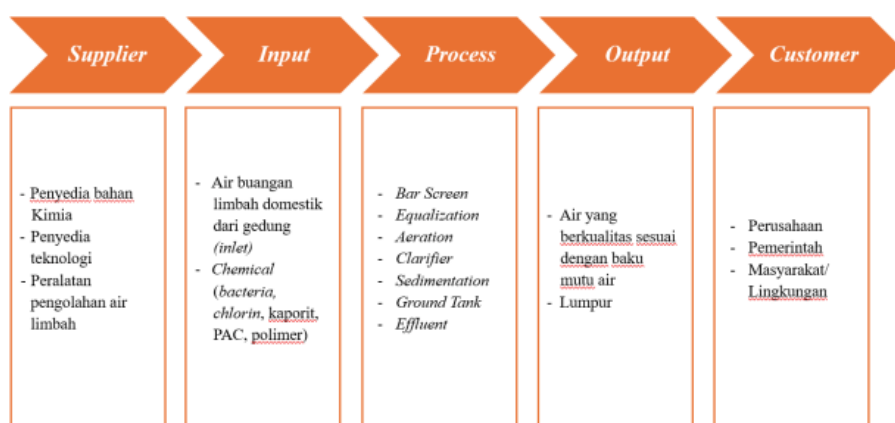


Figure 7. SIPOC Diagram

No	Klasifikasi Keluhan	Jumlah Keluhan	%
1	Keluhan Mengenai Administrasi	3	19%
2	Keluhan Mengenai Kebersihan	3	19%
3	Keluhan Mengenai Respon & Koordinasi	2	13%
4	Keluhan Mengenai Fasilitas & Peralatan	3	19%
5	Keluhan Mengenai Kualitas Air	5	31%
Total Keluhan		16	100%

Source : Customer feedback

Figure 8. Customer Complaints

To determine the characteristics of water quality according to standards, the CTQ used in this study is a separate wastewater treatment parameter based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.68/Menlhk-Setjen/2016, which can be seen in Figure 9.

No	Parameter	Satuan	Baku Mutu
1	pH (in lab)	-	6 - 9
2	BOD	mg/L	30
3	COD	mg/L	100
4	TSS	mg/L	30
5	Minyak dan Lemak	mg/L	5
6	Amonia	mg/L	10
7	Total Coliform	Jumlah/100ml	3.000

Source : Kementerian LHK RI, 2016

Figure 9. Critical to Quality

Based on laboratory test results from August to September 2025, 26 samples from companies were selected for this study. The sample selection process was based on complete results, parameters, and research period. This study compared water quality data with seven wastewater quality standard parameters. The final water quality data from 26 companies' wastewater treatment plants (WWTPs) served by PT BCD, in the form of laboratory test results from August and September 2025, are shown in Figure 10.

4.1.2 Measure Phase

DPMO and Sigma Level

Table 2 shows the results of the DPMO and Six Sigma Level calculations for August 2025, and Table 3 shows the results of the DPMO and Six Sigma Level calculations for September 2025.

Pareto Chart

A Pareto Chart aims to visualize the factors that are the main causes of problems or failures. Figure 11 shows data on wastewater quality standards for the period August 2025 and September 2025, presented in a Pareto chart.

Control Chart

Figure 12 shows the results of the calculation of CL, UCL, and LCL for each parameter for the periods of August and September 2025.





Source: Laboratory Test Results by PT BCD
Figure 10. Laboratory Test Results

Table 2. DPMO and Sigma Level Period August 2025

IPAL Perusahaan	Parameter						
	Ph (in lab)	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Minyak dan Lemak (mg/L)	Amonia (mg/L)	Total Coliform (MPN/100ml)
1	7,20	3,00	10,00	5,00	5,00	2,80	-
2	7,20	1,65	16,70	1,00	0,54	0,16	-
3	7,10	3,22	15,60	4,00	0,54	0,67	200,00
4	6,80	6,00	13,00	5,00	5,00	0,10	-
5	7,76	26,00	63,23	7,84	5,00	0,14	2.600,00
6	6,90	7,00	13,00	5,00	5,00	9,50	-
7	7,20	28,00	54,00	5,00	5,00	4,50	-
8	7,70	4,79	12,90	3,00	0,59	16,42	-
9	6,90	9,00	17,00	5,00	5,00	2,00	-
10	7,10	17,00	37,00	5,00	5,00	1,60	-
11	7,75	23,00	57,09	6,12	5,00	0,14	1.600,00
12	6,90	13,00	25,00	5,00	5,00	1,40	-
13	8,00	2,00	10,00	2,00	1,60	7,00	1,80
14	7,72	28,00	66,10	5,16	5,00	0,15	2.400,00
15	7,20	1,41	4,00	1,00	0,54	0,24	400,00
16	7,90	2,57	10,20	4,00	0,54	17,16	-
17	7,20	5,00	15,00	12,00	0,30	0,29	2.722,00
18	7,70	12,00	28,00	7,00	0,40	0,17	1.900,00
19	7,80	10,00	24,00	5,00	0,30	0,16	1.820,00
20	7,80	6,00	18,00	2,00	0,30	0,13	1.822,00
21	7,70	2,00	11,00	9,00	0,30	0,12	1.988,00
22	7,70	19,00	57,00	13,00	0,40	0,15	1.180,00
23	6,90	8,00	20,00	12,00	0,30	0,15	1.668,00
24	7,00	16,00	31,00	5,00	5,00	3,40	-
25	7,20	9,00	19,00	5,00	5,00	2,20	-
26	7,20	25,00	49,00	5,00	5,00	3,36	-
Total	-	-	-	-	13	2	-
DPU	-	-	-	-	0,5000	0,0769	-
DPO	-	-	-	-	0,0714	0,0110	-
DPMO	-	-	-	-	71.429	10.989	-
Tingkat Sigma	6,00	6,00	6,00	6,00	2,96	3,79	6,00

No	Parameter	DPMO
1	Ph	-
2	BOD	-
3	COD	-
4	TSS	-
5	Minyak dan Lemak	71.429
6	Amonia	10.989
7	Total Coliform	-
Total DPMO		82.418
Tingkat Sigma		2,88

Source: PT BCD

Table 3. DPMO and Sigma Level Period September 2025

IPAL Perusahaan	Parameter						
	Ph (in lab)	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Minyak dan Lemak (mg/L)	Amonia (mg/L)	Total Coliform (MPN/100ml)
1	7,00	10,00	20,00	5,00	5,00	0,10	-
2	7,30	3,55	12,80	2,00	0,82	3,67	-
3	7,30	2,02	20,10	2,00	0,76	3,52	-
4	7,20	1,39	4,60	2,00	0,88	3,61	-
5	7,63	32,00	73,28	11,40	5,00	0,09	1.900,00
6	6,80	17,00	34,00	5,00	5,00	0,10	-
7	7,90	2,71	14,00	1,00	0,54	0,40	-
8	7,00	11,00	22,00	5,00	5,00	0,28	-
9	6,70	3,13	17,70	4,00	0,54	18,43	-
10	6,90	2,09	20,00	5,00	0,57	18,68	-
11	7,19	54,00	113,59	10,96	5,00	0,07	1.400,00
12	6,40	10,65	55,00	19,00	0,54	8,75	-
13	8,20	1,12	4,00	3,00	0,54	0,03	-
14	7,38	35,00	78,90	11,84	5,00	0,07	2.900,00
15	6,70	7,00	13,00	5,00	5,00	0,10	-
16	6,90	13,00	25,00	5,00	5,00	0,28	-
17	7,02	4,36	75,30	23,00	1,50	0,16	2.100,00
18	10,50	5,00	14,00	10,00	0,20	0,20	1.892,00
19	7,90	4,00	13,00	6,00	0,20	0,30	1.906,00
20	7,70	5,00	16,00	4,00	0,20	0,10	1.549,00
21	7,60	5,00	14,00	6,00	0,20	0,20	1.904,00
22	7,58	9,16	63,34	22,00	1,30	0,50	2.100,00
23	6,70	5,00	14,00	9,00	0,20	0,30	1.967,00
24	6,50	23,00	48,00	5,00	5,00	9,00	-
25	6,90	14,00	27,00	5,00	5,00	0,70	-
26	6,90	18,00	37,00	5,00	5,00	0,56	-
Total	1	3	1	-	11	2	-
DPU	0,0385	0,1154	0,0385	-	0,4231	0,0769	-
DPO	0,0055	0,0165	0,0055	-	0,0604	0,0110	-
DPMO	5.495	16.484	5.495	-	60.440	10.989	-
Tingkat Sigma	4,04	3,63	4,04	6,00	3,05	3,79	6,00

No	Parameter	DPMO
1	<i>Ph</i>	5.495
2	<i>BOD</i>	16.484
3	<i>COD</i>	5.495
4	<i>TSS</i>	-
5	<i>Minyak dan Lemak</i>	60.440
6	<i>Amonia</i>	10.989
7	<i>Total Coliform</i>	-
Total DPMO		98.901
Tingkat Sigma		2,78

Source: Data Processing 2025

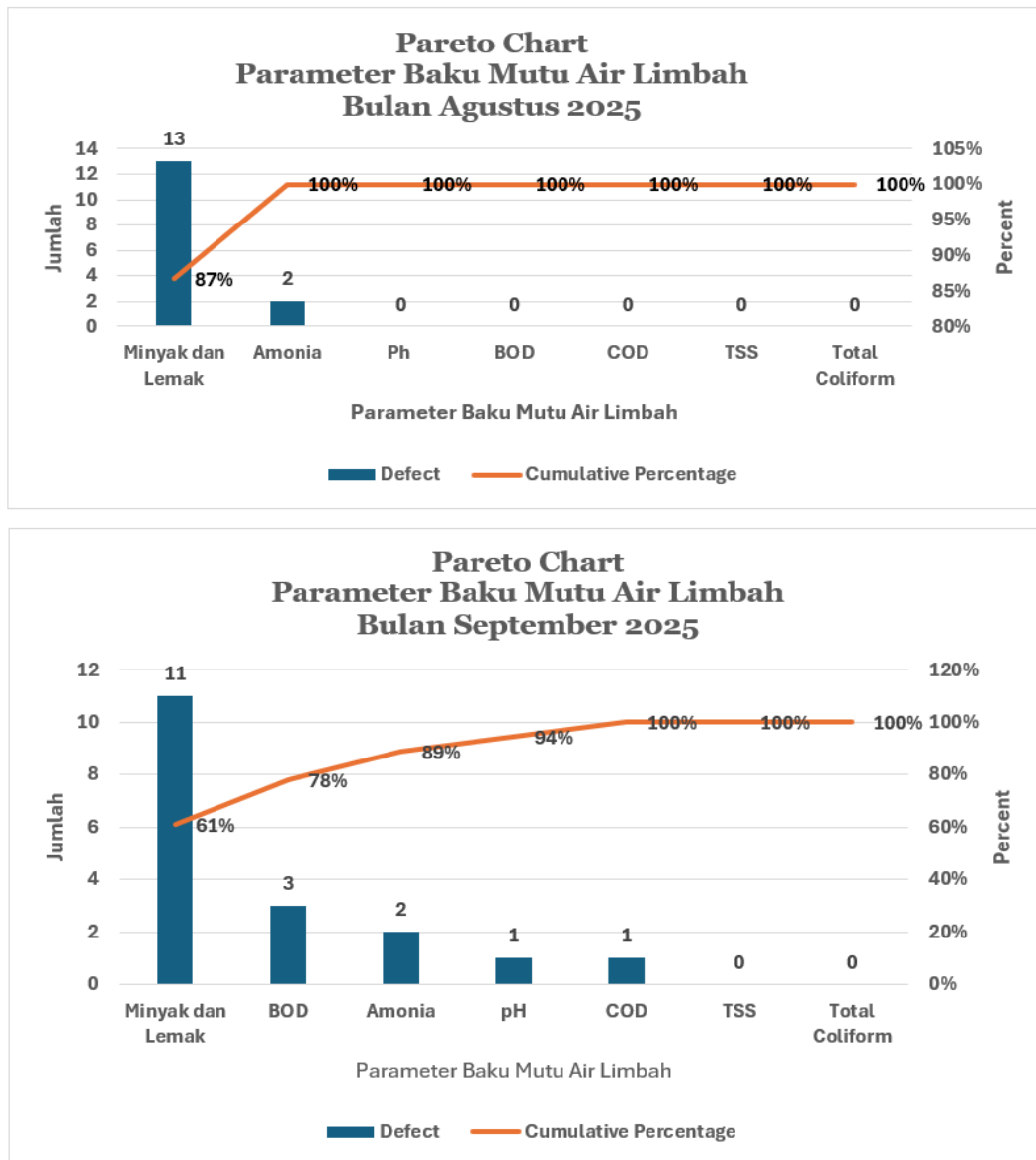


Figure 11. Pareto Chart Parameter Baku Mutu Air Limbah
Source: PT BCD

Cost of Poor Quality

Cost of Poor Quality (COPQ) is the cost wasted due to defects. This wasted cost in the wastewater treatment process represents the cost of defects that cannot generate revenue because the performance levels do not meet the requirements stipulated in the cooperation agreement.

Based on the sigma calculations in Tables 2 and 3, for August 2025, the sigma value is 2.88, which could impact the company's total revenue if defect-related costs exceed 40% of total sales or are incalculable. Similarly, in September 2025, the sigma value is 2.78, which could affect the company's total revenue if defect-related costs exceed 40% of the total sales or are incalculable.



Figure 12. Control Chart

4.1.3 Analyze Phase

In this analysis stage, the root causes of critical factors that lead to the main defects in wastewater treatment quality were analyzed. The method used in this analysis process was a fishbone diagram (Figure 13). The results of the identification of potential root causes originating from human factors (man), machine (machine), material (material), communication (communication), operational methods and systems (method), technology (technology), regulation (regulation), and environment (environment) are shown in the following diagram:

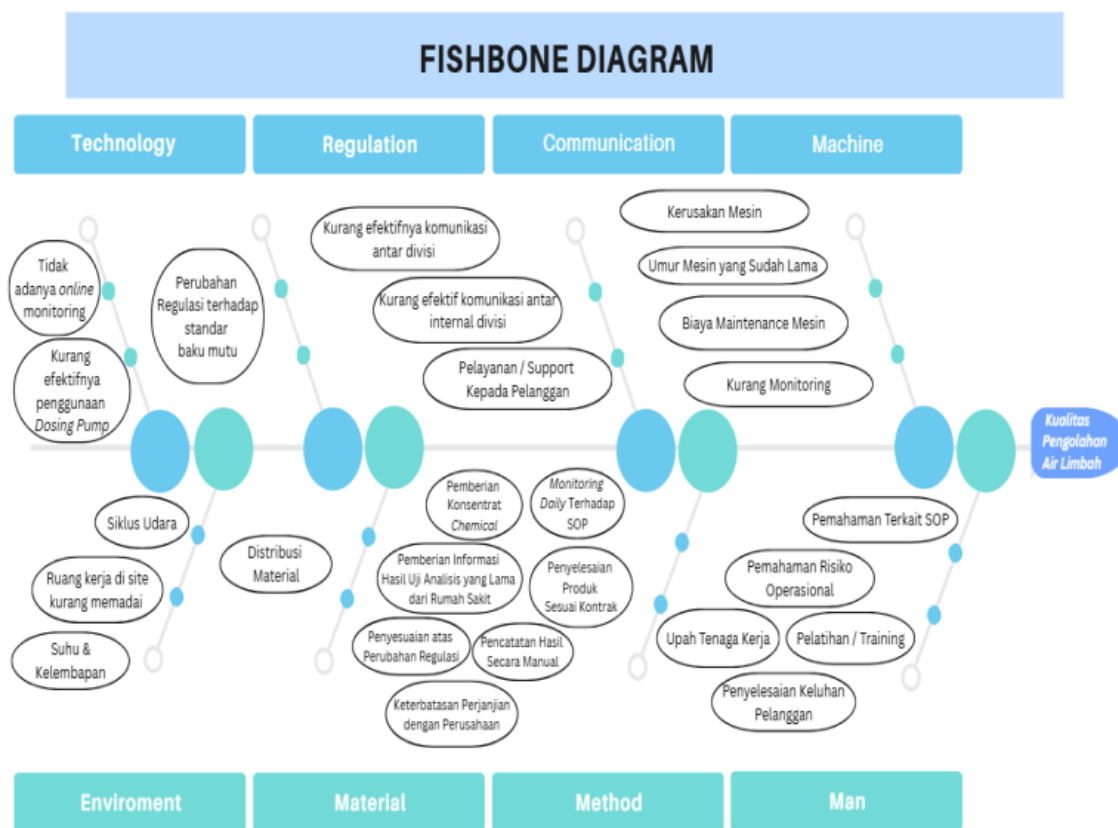


Figure 13. Fishbone Diagram

4.1.4 Improve Phase

After identifying the root causes of each factor, a proposed improvement for each root cause is developed, and an impact-effort matrix analysis is conducted to select the solution that will provide the highest impact and ease of implementation for the current year. The results of the development of the proposed continuous improvement are visualized in the impact-effort matrix graph shown in Figure 14. An explanation and classification of the priority scale order can be seen in Table 4.

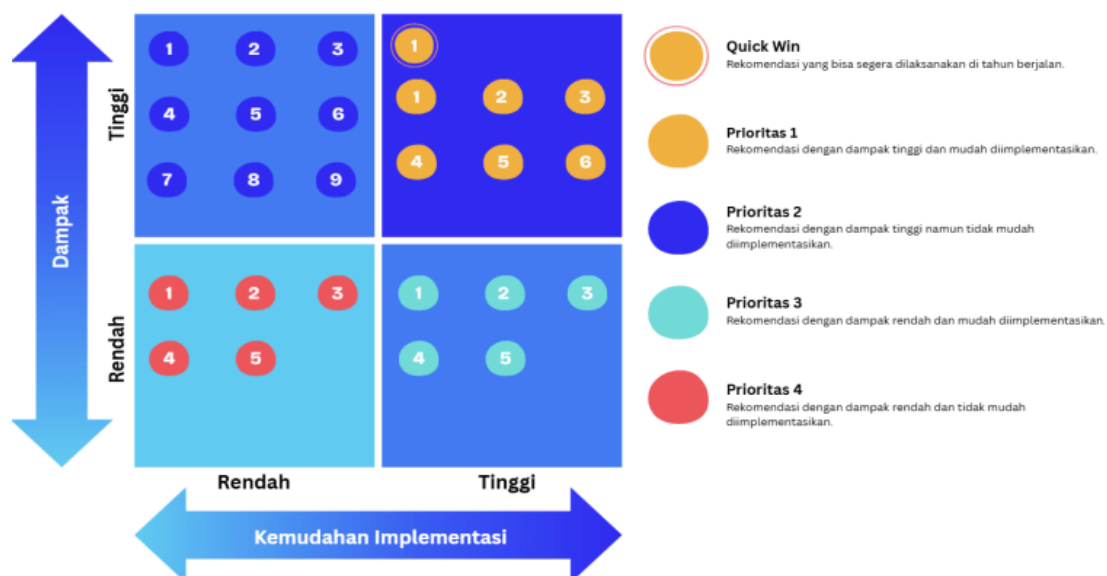


Figure 14. Impact-Effort Matrix

Table 4. Explanation of the Priority Scale Based on *Impact-Effort Matrix*

No	Impact	Ease of Implementation	Priority Scale	Factor	Root Cause	Improvement
1	High	High	Quick Win - 1	Regulation	Regulatory Changes to Quality Standards	Implementing parameter provisions in accordance with the applicable quality standards.
2	High	High	Priority 1 - 1	Machine	Lack of Monitoring	Creating a daily checklist and installing simple sensors to monitor machine performance indicators.
3	High	High	Priority 1 - 2	Method	Chemical Concentrate Usage	Improving communication processes and developing SOPs related to chemical dosage based on water flow.
4	High	High	Priority 1 - 3	Method	Daily Monitoring of SOPs	Creating a daily checklist to ensure that all steps have been carried out.
5	High	High	Priority 1 - 4	Man	Understanding SOP	Training on SOP understanding, briefings, and refresher sessions
6	High	High	Priority 1 - 5	Communication	Customer Service/Support	Creating SOPs and establishing Service Level Agreements (SLAs) for complaint responses and support.
7	High	High	Priority 1 - 6	Technology	Ineffective Dosing Pump Usage	Weekly monitoring and calibration of the dosing pump.
8	High	Low	Priority 2 - 1	Machine	Machine Damage	Maintaining a digital maintenance log for proper documentation
9	High	Low	Priority 2 - 2	Machine	Old Machine Age	Gradually replacing machines
10	High	Low	Priority 2 - 3	Method	Limitations in Customer Agreements	Communicate with customers regarding current conditions and recommend changes or addendums to the cooperation agreements.
11	High	Low	Priority 2 - 4	Method	Product Completion According to Contract	Reviewing Organizational KPIs and Integrating Operational Team KPIs for Water Quality
12	High	Low	Priority 2 - 5	Method	Manual Recording of Results	Documenting and recording data online and in real time
13	High	Low	Priority 2 - 6	Method	Adjustment Regulations	Training for Operational Teams, Regularly communicating and updating applicable regulations, and conducting regulatory assessments for Operational Teams
14	High	Low	Priority 2 - 7	Man	Understanding Operational Risks	Risk identification training, briefings, and conducting effective communication and risk consultations
15	High	Low	Priority 2 - 8	Man	Training	Increasing the frequency of training, conducting competency surveys, and enhancing the sense of belonging

16	High	Low	Priority 2 - 9	Technology	Lack of Online Monitoring	Creating innovations to enable online system monitoring and developing sensors and alerts for wastewater quality standards. These results can be documented in a real-time dashboard.
17	Low	High	Priority 3 - 1	Method	Providing Information on Delayed Analytical Test Results from Hospitals	Coordinating SLAs with the laboratory, sending soft copies in advance, and using alternative certified laboratories if SLAs are not match.
18	Low	High	Priority 3 - 2	Man	Customer Complaint Resolution	Communication and service training, creation of a complaint handling tracking system, and conducting weekly reviews.
19	Low	High	Priority 3 - 3	Communication	Ineffective Communication Between Internal Divisions	Conducting weekly coordination meetings and creating an online dashboard for water quality reports for real-time monitoring are also recommended.
20	Low	High	Priority 3 - 4	Communication	Ineffective Communication Between Divisions	Conducting weekly coordination meetings to share problems and solve them.
21	Low	High	Priority 3 - 5	Material	Material Distribution	Improving communication and follow-up with procurement for non-urgent material requests so that they can be prepared by the procurement team.
22	Low	Low	Priority 4 - 1	Machine	Machine Maintenance Costs	Prepare a budget for preventive repairs and maintenance costs.
23	Low	Low	Priority 4 - 2	Man	Labor Wages	Evaluate the wage structure based on workload and operational risk, and provide additional incentives for operations if quality targets are met.
24	Low	Low	Priority 4 - 3	Environment	Air Cycle	The building owner should be contacted to add additional ventilation for air circulation.
25	Low	Low	Priority 4 - 4	Environment	Inadequate On-Site Workspace	Communicate with the building owner to improve the infrastructure of a comfortable workspace.
26	Low	Low	Priority 4 - 5	Environment	Temperature & Humidity	Communicate with the building owner to add additional ventilation to reduce humidity, schedule weekly checks, and issue alerts if the temperature and humidity do not comply with the applicable regulations.

4.2 Discussion

4.2.1 Define Phase

Based on the results of laboratory analyses of seven parameters in the sewage treatment plant process, see Figure 10. In September 2025, five parameters did not meet the quality standard requirements: oil and fat, BOD, ammonia, pH, and COD. In September 2025, the number of parameters that did not meet the quality standard requirements increased to five: oil and fat, BOD, ammonia, pH, and COD. The results of the laboratory analysis tests for two months showed that five parameters, including oil and fat, BOD, ammonia, pH, and COD, did not meet the wastewater quality standard requirements. These results underscore the water quality problem that PT BCD has not effectively addressed.

This result is not in line with Mulyani's research, which states that one parameter that did not meet the requirements for several months was total coliform, and Zafira and Iriani's research, which states that

several parameters did not meet the quality standards, such as COD, DO, total coliform, and fecal coliform. This is because of differences in research objects.

4.2.2 Measure Phase

Wastewater treatment process performance was measured by calculating the defects per unit (DPU), defects per opportunity (DPO), and defects per million opportunities (DPMO) for each parameter, and then calculating the aggregate DPMO for the entire observation period. The DPMO was then converted to a sigma value using the DPMO-to-sigma conversion table based on Motorola's 6-Sigma Process (Normal Distribution Shifted 1.5-sigma). Based on these results, it can be seen that in August 2025, there were 71,429 defects in the oil and grease parameter per million test opportunities, which, when converted, equals 2.96 sigma. The ammonia parameter had 10,989 defects per million test opportunities, a sigma value of 3.79 sigma. Overall, the wastewater quality in August 2025 had 82,418 defects per million test opportunities, a sigma value of 2.88 sigma.

In September 2025, the pH parameter had 5,495 defects per million test opportunities and a sigma value of 4.04. The BOD parameter had 16,484 defects per million test opportunities and a sigma value of 3.63. The COD parameter had 5,495 defects per million test opportunities and a sigma value of 4.04. The oil and grease parameter had 60,440 defects per million test opportunities, with a sigma value of 3.05. The ammonia parameter had 10,989 defects per million test opportunities and a sigma value of 3.79. Overall, the wastewater quality in September 2025 had 98,901 defects per million tested, with a sigma value of 2.78.

The wastewater treatment process performance was measured by calculating the Defect Per Unit (DPU), Defect Per Opportunity (DPO), and Defect Per Million Opportunities (DPMO) for each parameter, and by calculating the total aggregate DPMO over the observation period. Subsequently, the DPMO was converted to a sigma value using Motorola's 6-Sigma Process (Normal Distribution Shifted 1.5-sigma). Table 2 presents the results of the calculation of the DPMO value and Six Sigma Level for the period of August 2025, and Table 3 presents the results of the calculation of the DPMO value and Six Sigma Level for the period of September 2025.

This method of measurement is in line with previous research, such as Mulyani's, Ulfah's, Wulandari and Ratni's, and Zafira and Iriani's.

Pareto Chart

The graph shows that the oil and fat parameters experienced the largest deviations from the applicable quality standards compared to the other parameters. This parameter is the focus of quality control for reducing the defect rate. Other parameters, such as BOD and ammonia, require further quality control.

Control Chart

After identifying the defect, the next step was to determine whether the defect in the parameter was still within the control limits, which can be determined by calculating the central line (CL), upper control limit (UCL), and lower control limit (LCL), which are visualized on the control chart. The CL is the control limit that is the basis for calculating the deviation of the observation results in each parameter. The UCL is the upper control limit that shows the highest deviation from the control limit. The LCL is the lower control limit that shows the lowest deviation from the control limit. In the parameters of pH, BOD, and ammonia, there was one Company WWTP in each parameter that was above the UCL, which indicates that wastewater treatment has not been effectively carried out at the companies served by PT BCD.

4.2.3 Analyze Phase

The following is a description of the variations in indications based on the eight categories in this fishbone diagram:

1. Man

The operational team has a maximum of 2-3 years of work experience. This is sufficient to understand the work environment. However, the site operational team lacks a thorough understanding of SOPs and operational risks. This is related to the limited frequency of training, which is only conducted once a year for the operational team, especially in quality management. Furthermore, there is a lack of technical support to address customer complaints, such as follow-up, speed of complaint resolution, and professional complaint handling. Furthermore, labor wages do not directly impact water quality but significantly influence the performance of the site operational team in terms of work motivation and work schedules.

2. *Method*

Wastewater quality parameters that do not meet wastewater quality standards are significantly affected by the administration of chemical concentrates. Five parameters that do not meet these standards are oil and grease, BOD, ammonia, pH, and COD. Oil and grease occur due to ineffective treatment during the inlet process of wastewater from customers for processing through bar screens and equalization. BOD and COD are influenced by blower conditions, oxygen supply to bacteria during the aeration process, and room conditions affecting the room temperature and air circulation. Ammonia occurs due to insufficient bacterial concentration during the aeration process, which prevents the bacteria from optimally breaking down toxic ammonia into harmless compounds. The pH is also affected by insufficient chemical concentrate administration. If the pH is too acidic, insufficient NaOH is used to increase the pH. However, if the pH is too alkaline, there is insufficient use of citric acid to lower the pH. The administration of chemical concentrates is also problematic because of contractual limitations within customers. Regulatory changes also pose water quality issues owing to the increase in domestic wastewater quality standards, which significantly impact operational activities related to chemical administration. This was due to the lack of daily monitoring of SOPs by the operational team.

Another factor affecting water quality is the daily manual recording of test results using equipment, which can result in data that is not real-time, a high rate of recording errors due to human error, and inaccurate data. The recording of these test results is related to the results of monthly laboratory analysis. This can cause problems if the recorded results indicate compliance with water quality standards, but according to the laboratory analysis results do not meet water quality standards. This is further compounded by the long time taken by the laboratory to check the test parameters for the analysis process and send the results to the Company. Based on this, customers believe that the Company's performance has not optimally met product conformity with standards and contract requirements.

3. *Machine*

The quality of wastewater is significantly affected by the condition of the equipment. Aging machines often experience breakdowns, which increase repair and maintenance costs. Blowers are often damaged, as they significantly impact the oxygen supply to bacteria, disrupting the wastewater treatment process and resulting in unpleasant odors and cloudy, pollutant-laden water. This can be caused by inadequate monitoring of equipment and machinery.

4. *Material*

Wastewater quality can also be affected by delays in material distribution at each operational site. Interviews with the operations team revealed that each month, the operations team sends the end-of-month inventory to the procurement team and requests supplies for the following month.

5. *Communication*

Lack of communication between internal divisions leads to unresolved issues and between divisions, resulting in work overload. This impacts customer service and support, such as ineffective communication, minimal explanation of work performance, and a lack of interactivity in responding to complaints.

6. *Environment*

The cramped conditions of the STP room result in inadequate air circulation, weather factors that affect temperature and humidity, and an inadequate workspace, which make the operational team uncomfortable.

7. *Technology*

The ineffective use of dosing pumps for chemical administration and the lack of real-time online monitoring result in uncontrolled and poorly documented wastewater quality data.

8. *Regulation*

The change in regulations from the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.68/Menlhk-Setjen/2016 to the current regulation, namely Regulation of the Minister of Environment and Forestry No.11/2025, which was stipulated on September 4, 2025, and took effect on September 9, 2025, is an obligation for companies to comply with the provisions of the wastewater quality standard parameters that have been set to avoid increasing the water pollution load. Changes in the provisions of the wastewater quality standard parameters can be seen in Figure 2.2 in Chapter 2. In the September 2025 period, 26 samples of companies that were provided with services by PT BCD did not use the wastewater quality standard criteria in accordance with the applicable regulations, namely Regulation of the Minister of Environment and Forestry No.11/2025, which was stipulated on September 4, 2025, and took effect on September 9, 2025. However, they still used the wastewater quality standard parameters based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.68/Menlhk-Setjen/2016.

4.2.4 Improvement Phase

The impact-effort matrix graph is used to produce quick wins, which are recommendations that can be implemented immediately in the current year, namely, meeting regulatory issues by implementing parameter provisions in accordance with applicable quality standards. Changes to current regulations constitute an obligation or compliance for the Company to comply with these regulations. If the Company fails to comply, this will have a significant impact on the Company's sustainability and reputation. The Company will be subject to administrative sanctions, and there will be legal and environmental risks that will impact the Company's operations, cause disruptions, and increase the costs of corrective actions.

Based on the proposed continuous improvement, it is expected to reduce wasted costs in the wastewater treatment process by more than 40%, affecting total revenue due to defects that cannot generate income, based on the COPQ values of 2.88 and 2.78 in August 2025 and September 2025 2.88 and 2.78. This is because there are parameters that do not meet the wastewater quality standards of 15 and 18 parameters in August 2025 and September 2025 from the 26 Company WWTPs. To improve the performance of the wastewater treatment process, management can increase the sigma value to 3-sigma, which is the middle value of the sigma level. A 3-sigma value with a DPMO level of 66,807 (6.68%) can reduce costs due to defects by 25–40% of the total revenue, as shown in Table 3.4 in Chapter 3. The tolerable defect value is set at:

$$DPMO = \frac{\frac{\text{amount of defect (x)}}{\text{amount of production}}}{\frac{\text{Total number of parameters}}{\text{amount of defect (x)}}} \times 1.000.000$$

$$DPMO = \frac{\frac{26}{7}}{\frac{182}{12,15}} \times 1.000.000$$

$$66.807 = \frac{1.000.000(x)}{182}$$

$$1.000.000(x) = 12.158.874$$

$$(x) = 12,15$$

Based on the above calculation, the total tolerable defects to reduce costs due to defects by 25–40% of the total revenue are 12 wastewater quality parameters that cannot meet the required quality standards. The results of this calculation can be used as a target for quality improvement. If these are met, the sigma value can be increased again to a 4-sigma value, which can affect the reduction in COPQ from total sales.

This finding supports previous research, especially for environmental sector services. The six sigma concept supports organizations in defining environmental issues, identifying sources of process inefficiencies, reducing operational errors, improving the quality of management, and the consistency of service quality, which directly impacts environmental protection and stakeholder satisfaction. The concept of quality is not only related to reducing errors or increasing productivity but also includes the organization's responsibility towards environmental sustainability.

5. CONCLUSION, LIMITATIONS, AND SUGGESTIONS

Conclusion

Based on the results of the Six Sigma calculation, the DPMO (Defects Per Million Opportunities) and the Six Sigma value conversion in August 2025 were 82,418, with a sigma value of 2.88 out of the expected 6 sigma (zero defects). The 2.88 sigma value, when converted using the COPQ, could affect more than 40% of the

company's total revenue due to defect-related or unquantifiable costs. In September 2025, the DPMO increased to 98,901, with a sigma value of 2.78, compared with the expected 6 sigma (zero defects). The 2.78 sigma value, when converted using the COPQ, could affect more than 40% of the company's total revenue due to defect-related or unquantifiable costs.

The main cause of the defect in the quality of wastewater treatment is caused by eight critical factors, including human quality factors (man), machine quality factors (machine), material quality factors (material), communication quality factors (communication), operational method and system factors (method), technology quality factors (technology), and regulatory/legal factors (regulation). The root cause of each of these factors was analyzed and visualized using a fishbone diagram. Proposed improvements were made by providing suggestions and mitigation strategies based on the findings of the causes of the problems analyzed using a fishbone diagram and conducting an impact-effort matrix analysis to provide recommendations according to a priority scale that considers the impact and ease of implementation. If this is implemented, it is expected to provide savings in production costs and increase profits as well as improve the quality of wastewater treatment. This is also expected to increase customer satisfaction and long-term competitive advantage for the Company.

Limitation

There are several limitations in this study, as this study is only limited to the DMAI (Define-Measure-Analyze-Improve) stage. In the Control stage, it is not possible to see the results of the implementation of the suggestions given and to know the improvements made using the six sigma method.

Suggestions

Based on the above description, in relation to government regulations, PT BCD should provide services to companies to improve water quality and test laboratory analysis results based on the latest domestic wastewater quality standards and wastewater treatment technology standards in accordance with the new regulation, namely Regulation of the Minister of Environment/Environmental Control Agency of the Republic of Indonesia Number 11 of 2025. This is done to avoid applicable sanctions such as written warnings, government coercion, administrative fines, suspension of business permits, and revocation of business permits in accordance with Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 14 of 2024. In addition, companies need to transition from manual systems to real-time online systems based on Internet of Things (IoT) to improve monitoring, recording, and internal control functions to produce data accuracy and reliability as well as the effectiveness of wastewater treatment.

A company is a collection of resources and capabilities that are the main factors in forming strategies and achieving company performance. In addition to the six-sigma strategy to improve quality in performance, the company can improve company performance by using the resources-based view (RBV) strategy, which is based on the company's resources and capabilities to produce internally generated competencies to increase the company's competitive advantage. Factors that can be used in identifying the RBV strategy are transparency, transferability, and durability. By implementing this RBV strategy, it is expected that the company can produce the best operational systems or procedures, reduce long-term operational costs through capability-based efficiency, and minimize risks so that it can compete with competitors to increase competitive advantage.

For future researchers, it is recommended that they conduct research by integrating Six Sigma with ISO 9001:2015. ISO 9001:2015 is an international standard for quality management systems that aims to ensure that companies provide goods and services in accordance with established requirements. These requirements are specific to customers and markets. Six Sigma focuses on improving quality to produce a zero-defect-oriented target. This is in line with ISO 9001:2015, which can be integrated with Six Sigma. The integration of Six Sigma with ISO 9001:2015 is expected to produce a reliable management framework because it involves processes, techniques, and resource development. By integrating the two, continuous quality improvement can be achieved, thereby increasing customer satisfaction targets.

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