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Operational Risk Simulation Model and Financial System for Wastewater Treatment Plants (WWTP) in Industrial Parks

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ABSTRACT
Industrial Wastewater Treatment Plants (WWTPs) are essential infrastructures for managing industrial waste, maintaining environmental quality, and protecting public health. However, high concentrations of organic and chemical contaminants increase energy demand, particularly for pumping and treatment processes, contributing to indirect greenhouse gas emissions. This study aims to develop a simulation model to assess operational and financial risks in industrial WWTPs. The framework focuses on the linear relationship between technical and financial variables under uncertain conditions, analyzed using Monte Carlo simulations. Variability in wastewater discharge and quality from multiple industrial tenants introduces technical risks that affect process efficiency, operational costs, and compliance with environmental standards. Key input variables, such as discharge volume, BOD/COD concentrations, and energy and chemical prices, are modeled as probability distributions. The simulation generates probabilistic outputs of operational costs and potential penalties. This approach enables systematic analysis of uncertainty and supports more effective, data-driven decision-making in WWTP management.

Keywords: Risk Simulation Model, Financial System, Wastewater Treatment, Industrial Park.

I. Introduction

The development of Wastewater Treatment Plants (WWTPs) in industrial areas related through number of complex challenges dominated by heterogeneous composition of industrial waste, need for advanced treatment technologies and consistency of increasingly stringent environmental standards. Increasing compliance demands and capital investments further reinforce the need for comprehensive risk assessments and number of mitigation stages to ensure project feasibility and regulatory compliance. The WWTPs function as vital infrastructure in treating domestic and industrial wastewater before being discharged into environment, however, WWTPs are revised as one of most energy-intensive components of urban systems and are an important source of greenhouse gas (GHG) emissions (Wang et al., 2016). Several recent studies have focused on importance of sustainable operational strategies through optimization of treatment parameters, including hydraulic retention time and solids retention time, both of which impact process

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performance and energy efficiency (Adebayo et al., 2021). The diverse environmental challenges of WWTPs, namely high energy demand and GHG emissions, highlight the need for an integrated risk assessment framework which simultaneously addresses treatment performance and ecological sustainability. Normative emissions are categorized into direct emissions from biological processes and linear indirect emissions from electricity consumption, chemical use and sludge handling (Parravicini et al., 2016). Empirical data indicates that indirect emissions, particularly those arising from energy use, dominate the overall carbon footprint of WWTPs (Kyung et al., 2015). Despite their interdependence, these systems are often evaluated separately, resulting in inefficiency, fragmented integration and lack of regulatory progress (Djukic et al., 2016). However, WWTP operations also has significant risks from both operational and financial perspectives. The operational risks covered equipment failure, changes in wastewater quality and other operational disruptions. Apart from these conditions, financial risks which arise include high operational costs, unpredictable maintenance costs and other significant economic impacts. Based on background description, main phenomenen of this research is formulated to focus on how to develop simulation model strategy which could predict operational and financial risks in WWTP industrial system and types of technical and financial parameters which have most significant influence on efficiency and sustainability of WWTP system and strategies for compiling risk mitigation based on simulation results for more efficient and measurable decision making.

The simulation model implemented in this study is able to assist WWTP managers in predicting significant impact of operational and financial risks and developing effective mitigation strategies. It is expected that WWTP operations could be optimized and linear risks of wastewater treatment could be minimized. Developing operational and financial risk simulation models for industrial area WWTPs could also aid in better and more effective decision-making. The using simulation models, WWTP managers could predict significant impacts on number of operational and financial scenarios and develop most effective strategies for managing risk. This research focuses on development of simulation model for operational and financial risks in industrial area wastewater treatment plants (WWTPs) to support WWTP managers in predicting and managing linear operational risks. The simulation model is supported by systematic and comprehensive approach and would be validated by implementing historical data obtained in field. This research is limited to wastewater treatment systems or WWTPs located in industrial areas with processing capacity of between 500 and 10,000 m^3 per day. This research focuses on analysis of operational and financial risks faced during implementation of WWTP system management, particularly those caused by uncertainty of input parameters, including fluctuations in daily wastewater discharge, variations in BOD and COD concentrations, treatment process efficiency (biological and chemical), energy and chemical costs and risk of penalties due to non-compliance with quality standards. This research does not cover aspects of physical design of buildings, internal piping systems, or sludge handling, however, emphasizes managerial aspects and data-based risk analysis. This research is targeted to be able to identify and analyze the causes of uncertainty in WWTP system, analyze the significant impact of uncertainty on technical performance and financial feasibility of WWTP system, prepare basis for WWTP planning for capacity of 3000 m3up to 5000 m3per day which is more responsive to operational and environmental changes and develops mitigation strategies. Based on overall systematic simulation results, this research is expected to have significant impact on development of simulation-based risk management approach in industrial wastewater treatment systems and to increase the effectiveness and efficiency of decision-making in sustainable WWTP management.

II. Literature Review and Hypothesis Development

WWTP management in Indonesia is required to comply with Government Regulation No. 22 of 2021 concerning wastewater quality standards, which regulates permissible concentration limits of BOD, COD, TSS, pH and heavy metal pollutant parameters in industrial effluents. Non-compliance with quality standards could have significant impacts on administrative, criminal and financial sanctions. Therefore, risk management system needs to accommodate regulatory provisions as part of operational feasibility evaluation. The use of monitoring technology and automatic control systems is crucial to maintaining WWTP performance within

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the established compliance limits. Wastewater Treatment Plant (WWTP) management in Indonesia is required to comply with Government Regulation No. 22 of 2021 concerning wastewater quality standards and this regulation regulates permissible concentration limits of BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solid), pH and heavy metal pollutant parameters in industrial effluents. Government Regulation No. 22 of 2021 concerning The Implementation of Environmental Protection and Management establishes wastewater quality standards that should complied with by industry. These wastewater quality standards are measure of limits or levels of living creatures, substances, energy, or components that should met and/or pollutant elements which are tolerable in water. Non-compliance with wastewater quality standards has significant impact on administrative sanctions, criminal penalties and financial fines. Therefore, risk management system needs to accommodate regulatory provisions as part of operational feasibility evaluation. It's concluded that effective and efficient WWTP management is fundamental to ensuring that wastewater quality meets quality standards stipulated in Government Regulation No. 22 of 2021 concerning The Implementation of Environmental Protection and Management, Attachment VI of Government Regulation No. 22 of 2021 concerning National Water Quality Standards (Surface Water) and avoids unwanted sanctions.

Research related to Waste Water Treatment Plants (WWTPs) has progressed progressively, however, several gaps remain. This research has also discussed economic evaluation of WWTP projects, however, the approach is still deterministic and tends to ignore the uncertainty of input parameters and operational fluctuations. Despite these conditions, discussions related to risk analysis in WWTPs are still normatively limited to qualitative risk identification without implementing data-based modeling or simulations. The use of monitoring technology and automatic control systems is crucial to maintaining WWTP performance within established compliance limits. This technology could assist in real-time monitoring of wastewater quality and implementation of necessary adjustments to ensure wastewater quality meets established quality standards. Wastewater Treatment Plants (WWTPs) are an integral part of community infrastructure that plays significant role in improving the quality of life through treatment of municipal and industrial wastewater and discharge of treated wastewater to receiving water bodies (Ehsan Aghdama et al., 2023). The WWTP performance is significantly influenced by several parameters, including variations in inlet load and shock load (Ansari et al., 2020). Obtaining influent characteristics is considered fundamental for designing WWTPs and adjusting operational parameters such as the amount of aeration consumed and electrical energy in WWTP (Wang et al., 2022). Moreover, WWTP systems in industrial areas are expected to have high flexibility, efficiency and reliability in addressing variations in pollutant loads. It is concluded that WWTPs are categorized into several stages: initial treatment or screening and grit removal. This stage is process of liquid waste being processed to remove large solid objects and small particles which could interfere with subsequent treatment processes, primary treatment or sedimentation, which is stage where liquid waste is settled to remove solid particles which could settle to bottom of tank. Secondary treatment, or aerobic or anaerobic biological processes, describes the use of microorganisms to decompose organic matter in wastewater.

Aerobic biological processes use oxygen to decompose organic matter, while anaerobic biological processes do not. Tertiary treatment, which includes filtration, disinfection and adsorption, describes the further treatment of wastewater to remove any remaining pollutants. Government Regulation No. 22 of 2021 stipulates water classes and is based on its intended use, namely class one that the water used could be used as raw water for drinking water and/or other uses that require the same water quality as the use. Class two is explained as water which could be used for water recreation infrastructure/facilities, freshwater fish farming, animal husbandry, water for irrigating crops, and/or other uses that require the same water quality as the use. Class three is water which could be used for freshwater fish farming, animal husbandry, water for irrigating crops, and/or other uses that require the same water quality as the use. Class four is water which could be used for irrigating crops and/or other uses that require the same water quality as the use. This study uses number of basic assumptions in building the simulation model, including the main input variables, namely discharge, BOD/COD and energy prices, which follow certain probability distributions, such as normal, triangular, or lognormal.

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III. Research Method

This research was conducted through several stages, including data collection related to WWTP operations, such as data on wastewater discharge, wastewater quality, and operational costs. The development of the simulation model involved constructing a Monte Carlo simulation model to analyze operational and financial risks in the WWTP system. The analysis of simulation results was carried out to identify potential risks and develop effective mitigation strategies. The mitigation strategy was developed based on data driven and adaptive approaches to reduce operational risks in WWTP management. This research is expected to contribute to the development of a more effective and efficient WWTP system and to reduce potential risks and their associated impacts. The primary data in this study were obtained through direct observation of WWTP operations in an industrial area. This observation was conducted to understand the wastewater treatment process, identify potential risks, and collect data that were not available from secondary sources. These primary data were supported by secondary data sources. Historical data on wastewater discharge and wastewater quality, including BOD, COD, and TSS, were used to analyze patterns and variability in the quantity and quality of wastewater entering the WWTP. Data on energy prices, chemicals, and WWTP operational costs were used to calculate operational expenditures and identify potential cost related risks. Environmental quality standards and government regulations were also collected to understand the regulatory framework applicable to WWTP operations in industrial areas and to identify potential risks related to non compliance with these standards and regulations. The research variables consist of input variables and output variables. Input variables are variables used as inputs in the simulation model. The input variables in this study include wastewater discharge measured in cubic meters per day, which represents the volume of wastewater entering the WWTP each day. The concentration of BOD, COD, and TSS measured in milligrams per liter represents the level of organic matter and suspended solids in the wastewater. The price of electricity and chemicals measured in rupiah per unit represents the costs incurred for electricity and chemical inputs used in the wastewater treatment process. Labor and maintenance costs measured in rupiah per month represent the costs required to pay workers and maintain the WWTP facilities.

The output variables are variables generated from the simulation model. Total operational costs measured in rupiah per month represent the total costs required to operate the WWTP each month. The risk of non compliance expressed as probability represents the likelihood that the WWTP will fail to meet established environmental quality standards. Potential environmental penalties or fines measured in rupiah represent the possible financial sanctions imposed if the WWTP fails to comply with environmental regulations. This study employs several data collection techniques to obtain accurate and relevant information. Field surveys and WWTP system documentation were conducted to understand the system directly and collect data on the wastewater treatment process and the equipment used in the system. Documentation of the WWTP system was also used to obtain information related to the design and operation of the facility. In addition, operational and financial reports from the WWTP for at least the previous twelve months were collected to obtain information on operational performance and cost structures. These data were used to analyze operational and financial risks associated with the WWTP system. Expert interviews were also conducted to validate the probability distribution assumptions used in the simulation model. The experts interviewed included individuals with knowledge and experience in WWTP operations and risk analysis.

This study applies several data analysis techniques to evaluate operational and financial risks in WWTP operations. The first step involves identifying the key variables that influence operational risks and operational costs. These variables are then used as input parameters in the simulation model. The next step is determining the probability distributions of the input variables by analyzing historical data patterns using statistical tools. The probability distributions considered in this study include normal, lognormal, and triangular distributions. Monte Carlo simulations were implemented using Oracle Crystal Ball software by running 10,000 simulation iterations to generate distributions of cost and risk outcomes. These simulation results were used to analyze potential risks and cost variability. Sensitivity analysis was also conducted to identify the variables that have the most significant influence on the simulation outputs. The interpretation

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and validation of results were performed by analyzing the simulation outputs, including the mean value, standard deviation, percentile values, and worst case scenarios. Validation was carried out using data triangulation with interview results and realization reports related to actual operational costs to ensure the accuracy of simulation results and detailed formula for the WWTP project feasibility indicators mentioned is as follows:

a. Net Present Value (NPV)

$$NPV = \sum \left(\frac{Income}{(1+r)^t} \right) - Beginning\ Investment$$

Description:

NPV : Net Present Value
Cash Inflow : Expected cash flow in period t
r : Discount rate
t : Time period
Initial Investment : Initial investment cost of the project

b. Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discount rate that makes the Net Present Value equal to zero. In other words, IRR is the discount rate at which the present value of future cash inflows equals the initial investment. The IRR cannot be calculated directly using a simple formula; therefore, it is generally determined using an iterative method or by applying the IRR function in financial calculators or spreadsheet software.

$$NPV = \sum \left(\frac{Cash\ Inflow}{(1+IRR)^t} \right) - Initial\ Investment = 0$$

Information:

Payback Period : the time required to recover the initial investment
Initial Investment : the initial investment cost of the project
Annual Cash Inflow : the expected cash inflow per year

c. Sensitivity Analysis

Sensitivity analysis is conducted by varying selected variables and observing their impact on financial outputs. The formula for sensitivity analysis cannot be expressed in a single general form, as it depends on the specific variables being tested and the financial indicators being measured. This research flowchart outlines several stages, beginning with problem identification and ending with the development of mitigation strategies. The first stage focuses on identifying operational and financial risks associated with WWTP operations. The second stage involves data collection, including historical data on wastewater discharge, wastewater quality, and operational costs. The next stage is variable modeling, where key variables influencing risks are identified and represented as probability distributions. This is followed by the Monte Carlo simulation stage using Oracle Crystal Ball to generate distributions of cost and risk outputs. The results are then analyzed to identify potential risks, costs, and key influencing variables. The final stage involves developing mitigation strategies based on the analysis. The flowchart, presented in Figures 1 and 2, ensures a systematic and structured research process.

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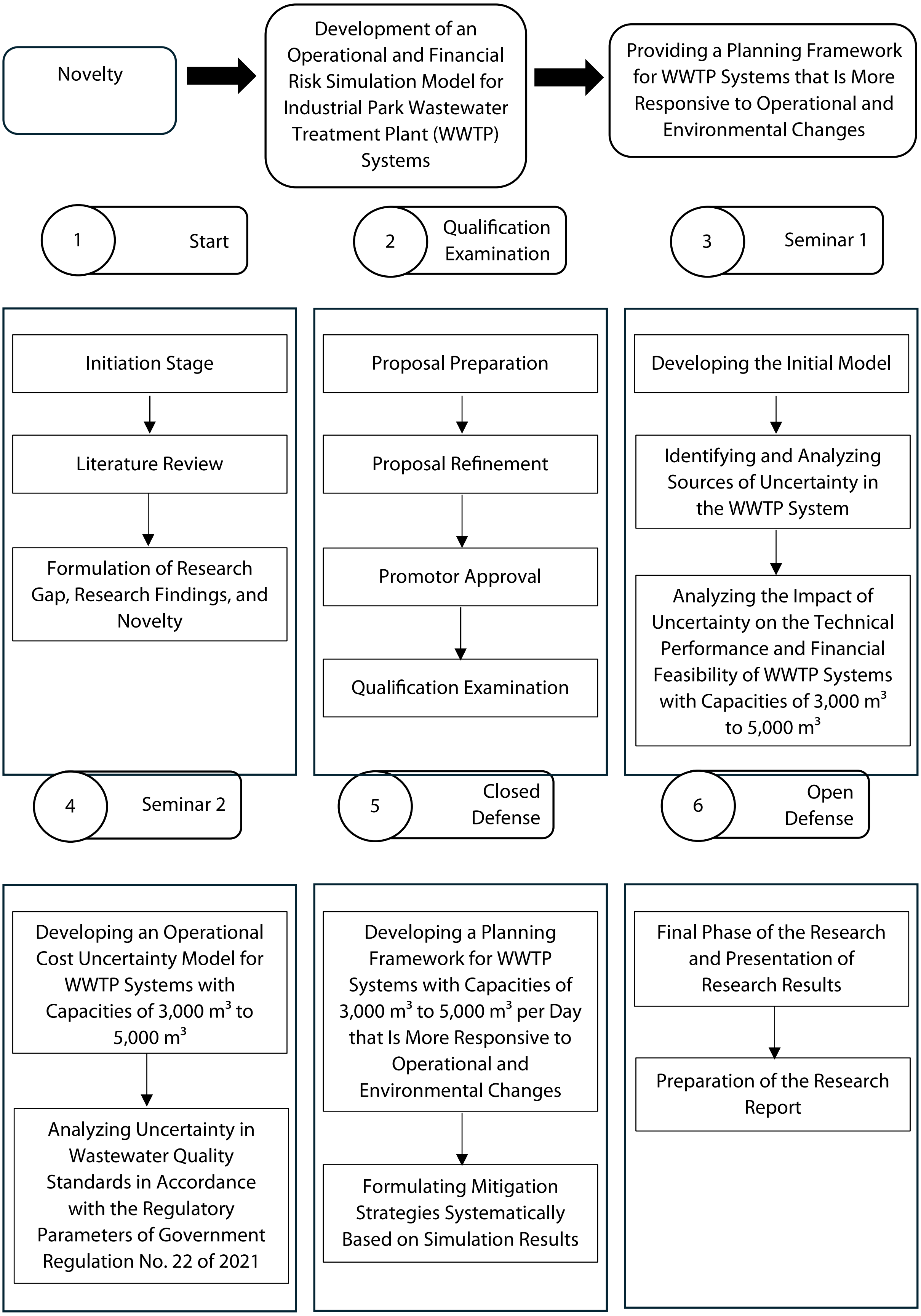

Figure 1. Research Flowchart

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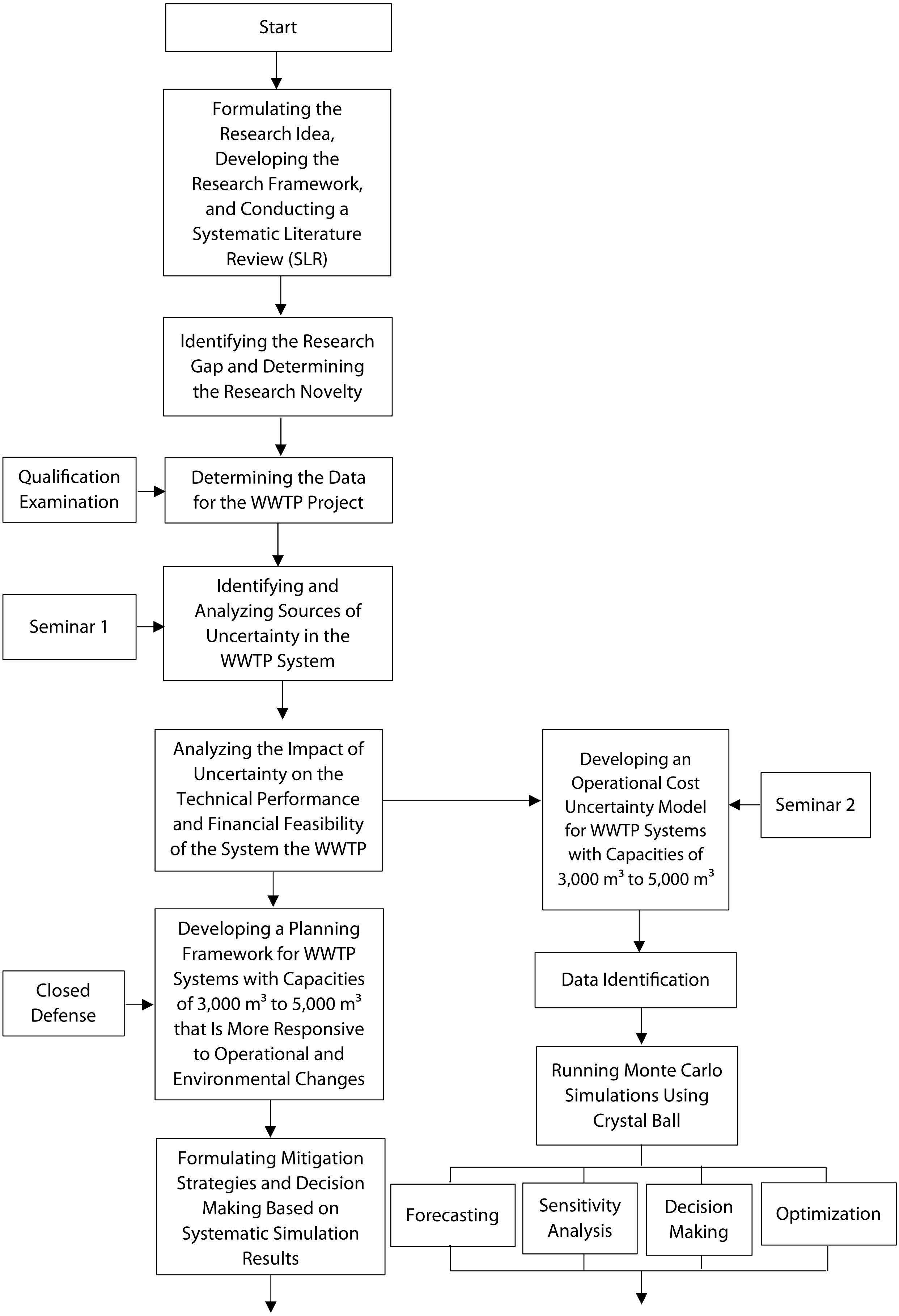

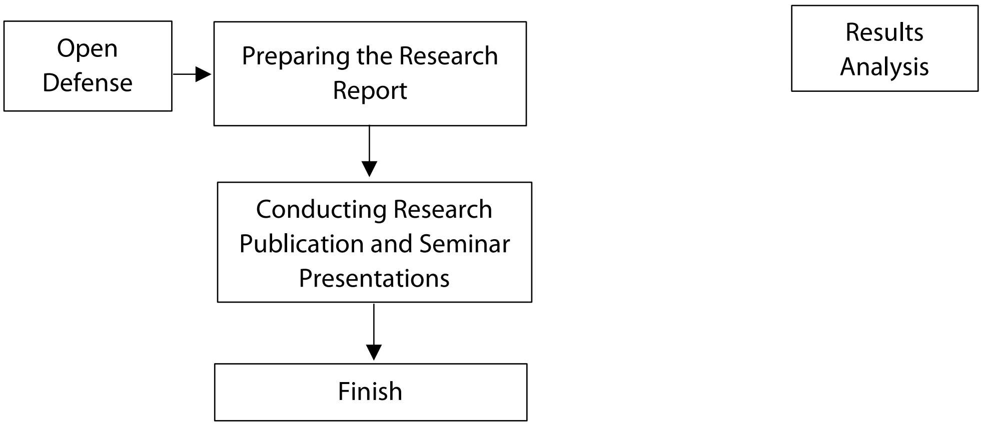

Figure 2. Research flow and stages

IV. Result and Discussion

Industrial estates are one of the sectors that contribute significantly to a country's economic growth. However, industrial activities also generate waste that has the potential to pollute the environment if it is not managed properly. Non compliance with wastewater quality standards can have significant consequences, including administrative sanctions, criminal penalties, and financial fines. The use of monitoring technology and automated control systems is essential for maintaining WWTP performance within established compliance limits. These technologies enable real time monitoring of wastewater quality and facilitate necessary operational adjustments. A wastewater treatment system, commonly referred to as a Wastewater Treatment Plant (WWTP), is an important infrastructure designed to treat liquid waste before it is discharged into receiving water bodies or reused. In industrial estates, wastewater typically has complex and diverse characteristics, including organic compounds, hazardous chemicals, heavy metals, and various physical and biological parameters. The effectiveness of the treatment process depends on several input parameters such as wastewater discharge, BOD and COD concentrations, pH, temperature, and other organic characteristics. Therefore, continuous monitoring and control of these parameters are essential to ensure that the WWTP operates effectively and efficiently. Studies related to Wastewater Treatment Plants have developed rapidly in recent years; however, several research gaps remain. Previous studies indicate that risk analysis in WWTP systems is often limited to qualitative risk identification without the application of data based modeling or simulation approaches. Some studies have implemented the Hazard and Operability Study method to identify potential risks in WWTP systems.

Environmental risks in WWTP operations may arise when the treatment system fails to process wastewater effectively, resulting in effluent quality that exceeds regulatory standards. The wastewater treatment system analyzed in this study is a centralized facility that serves an industrial area with diverse wastewater characteristics. The presence of various types of industries within the industrial area causes significant fluctuations in the quality and quantity of wastewater on both daily and seasonal bases. The WWTP is designed to treat wastewater with a planned capacity of approximately 3,000 to 5,000 cubic meters per day. The main treatment units consist of pre treatment units, equalization ponds, biological treatment processes, sedimentation units, and sludge treatment facilities. The treated effluent must comply with wastewater quality standards established by applicable regulations, particularly the parameters of BOD, COD, TSS, and pH. Operational practices show that the WWTP system does not operate under completely stable conditions. Changes in influent discharge, variations in pollutant loads, and operational disturbances such as power outages and equipment failures are important factors that affect both technical performance and operational costs. This section presents the results of data analysis, modeling, and simulation conducted to address the research objectives. It also discusses the implications of these findings for the management and planning of

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WWTP systems in industrial areas. The analytical context includes a description of the WWTP system, including process flow, design capacity, and major treatment units. It also includes the characteristics of the industrial area, existing operational conditions, wastewater quality standards used as references for BOD, COD, TSS, and pH, as well as an analysis of wastewater characteristics and operational variability.

4.1. Discharge and Pollutant Load Variability

Daily wastewater discharge entering the WWTP shows significant fluctuations influenced by industrial operating hours, water consumption patterns, and environmental conditions such as rainfall. Under certain conditions, the discharge may approach or even exceed the design capacity of the treatment units, particularly during peak operational periods. The combination of high discharge and elevated BOD and COD concentrations results in the actual pollutant load received by the WWTP being significantly higher than the design load. This situation may create hydraulic and biological stress on the treatment units, which can reduce treatment efficiency. The analysis indicates that increasing discharge is not always accompanied by a decrease in pollutant concentration through dilution effects. As a result, the risk of system overload remains relatively high. These findings indicate that WWTP operations require an adaptive capacity management approach to accommodate fluctuations in wastewater loads.

4.2. WWTP Influent Characteristics

The results of the wastewater quality data analysis show that the characteristics of WWTP influent have a relatively high level of variability. The concentrations of BOD and COD, which serve as primary indicators of organic load, show significant fluctuations t Conclusionhat reflect differences in industrial activities and production patterns within the industrial area. Influent BOD values occur within a wide range and have a relatively high average value, while COD concentrations show a tendency toward more extreme fluctuations. This condition indicates variations in the types of organic compounds present in the wastewater, some of which are easily biodegradable while others are more resistant to biological treatment processes. The TSS parameter also demonstrates considerable variability, particularly during certain periods associated with production activities or the washing of industrial equipment. In general, the pH value remains within the acceptable range established by regulatory standards, although under certain conditions it approaches the upper or lower limits of the permitted range. The variability of these wastewater quality parameters indicates that the influent entering the WWTP is dynamic and non deterministic. Therefore, planning and performance evaluation approaches that rely solely on average values may not adequately represent actual operational conditions.

4.3. Identified Operational Disruptions

In addition to influent variability, the performance of the WWTP system is also influenced by operational disruptions related to energy supply and equipment reliability. Power interruptions, even if temporary, can lead to a decrease in dissolved oxygen levels within the biological treatment units. This reduction in dissolved oxygen directly affects the efficiency of organic matter decomposition, which can result in increased BOD and COD concentrations in the effluent. Operational disturbances involving pumps and blowers also contribute to system instability from both technical and financial perspectives. Each operational disruption not only increases the risk of non compliance with wastewater quality standards but also raises operational costs due to repair requirements, additional energy consumption, and potential environmental penalties.

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4.4. Identification and Classification of Operational and Financial Risks

a. Identification of Sources of Operational Risk

The identification of operational risks based on the analysis of influent characteristics and operational conditions indicates that WWTP operational risks can be grouped into several main categories. Influent quality risks arise from fluctuations in BOD, COD, TSS, and pH concentrations, which directly affect the stability of biological processes. Hydraulic risks are associated with daily flow variations that may overload the treatment units. In addition, the risk of equipment and utility failure, including pumps, blowers, and power supply systems, represents a critical factor affecting the continuity of WWTP operations. These risks are interrelated and may significantly amplify each other's impacts.

b. Identification of Financial Risks

The identified operational risks have direct implications for financial risk. Variations in organic load and wastewater discharge lead to fluctuations in energy and chemical consumption, which significantly affect operational expenditure. Operational disruptions also increase the likelihood of higher maintenance and repair costs. Furthermore, non compliance with wastewater quality standards may result in financial penalties, administrative sanctions, and a decline in stakeholder trust. Therefore, financial risk does not exist independently but is a direct consequence of operational risk.

c. Risk Classification Using a Structured Approach

All identified risks are classified using a structured approach based on the Risk Breakdown Structure. This approach facilitates systematic analysis by categorizing risks into technical risks, operational risks, financial risks, and external risks.

4.5. Analysis of the Impact of Uncertainty on WWTP Technical Performance

a. Simulation Results on the Impact of Variations in BOD, COD, and Discharge

The simulation results indicate that variations in influent BOD and COD concentrations significantly affect the performance of biological treatment processes. When organic load conditions exceed the design capacity, oxygen demand increases in a nonlinear manner. This increase forces the aeration system to operate at or near its maximum capacity, thereby reducing the operational safety margin. Several simulation scenarios show that spikes in BOD and COD concentrations lead to a decrease in the efficiency of organic matter decomposition, as reflected in higher BOD and COD concentrations in the effluent. These findings suggest that the WWTP system becomes more vulnerable to non compliance with wastewater quality standards under conditions of extreme organic load fluctuations. The results also indicate that BOD and COD function not only as quality indicators but also as critical risk parameters that influence the stability of biological processes. Uncertainty in BOD and COD values increases the probability of technical performance failure. This impact is reflected in the probability of failing to meet quality standards, as indicated by the frequency of critical conditions such as low dissolved oxygen levels and system overload.

b. Analysis of the Risk of Non Compliance with Quality Standards

Daily discharge variability has a significant impact on the hydraulic performance of the WWTP system. Simulation results show that when discharge approaches or exceeds the design capacity, the hydraulic retention time in the main treatment units decreases. This reduction limits the contact time between microorganisms and organic substrates, resulting in lower treatment efficiency. In extreme scenarios, peak discharge conditions may cause short circuiting in sedimentation units, leading to increased TSS concentrations in the effluent. These findings indicate that uncertainty in daily discharge is a major risk factor that may trigger technical failure, particularly in WWTP systems designed with limited hydraulic safety margins. Previous studies on WWTP biological processes indicate that aerobic biological treatment can

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improve wastewater treatment efficiency when key parameters such as pH, temperature, and dissolved oxygen are properly controlled. Other studies have analyzed the quality of wastewater entering WWTP systems using parameters such as TSS, TDS, MLSS, and SV30. From a financial perspective, WWTP analysis must consider operational costs, including energy and chemical consumption, as well as the risk of penalties due to non compliance with quality standards. However, financial evaluations are often conducted using deterministic approaches that do not account for uncertainty in input parameters or operational fluctuations. Probabilistic simulation methods, such as Monte Carlo simulation, provide a more comprehensive approach for analyzing operational cost risks and the probability of non compliance in WWTP systems, particularly in industrial areas. Despite their advantages, these probabilistic approaches are still rarely applied in WWTP research. Therefore, further studies are needed to develop models that integrate technical and financial variables into a single analytical framework. This indicates that WWTP research still has significant potential for development, particularly in the areas of risk analysis, biological process efficiency, financial evaluation, and the application of probabilistic simulation methods.

Uncertainty represents a major challenge in WWTP operations, especially in industrial areas. Key sources of uncertainty include fluctuations in daily wastewater discharge, which can affect treatment efficiency and increase operational costs. Variations in organic load influence biological process performance and increase the risk of violating effluent quality standards. Disruptions in energy supply and chemical availability also affect treatment performance and operational expenses. Differences in wastewater characteristics among industrial tenants further complicate treatment processes and increase the risk of non compliance. Therefore, effective risk management is essential to ensure the sustainability of WWTP operations. Risk management involves identifying risk sources, analyzing their potential impacts, developing mitigation strategies, and implementing monitoring systems to evaluate WWTP performance and detect potential problems. Effective risk management can improve the operational sustainability of WWTP systems and reduce financial risks. This research is expected to provide both theoretical and practical contributions by supporting the development of simulation based risk management approaches in industrial wastewater treatment systems. In addition, this study contributes to the advancement of knowledge and technology in the field of environmental risk management.

V. Conclusion

The quality of liquid waste produced varies greatly and depends on type and production process used. In order to avoid environmental pollution and meet effluent quality standard regulations, wastewater treatment system or WWTP is required which is able to adapt to variations in waste characteristics. However, current WWTP planning is still dominated by deterministic approach which is less able to anticipate the reality of uncertainty in field, including fluctuations in discharge, changes in 3BOD and COD concentrations and volatility in operational costs. These conditions often lead to inaccurate cost estimates, failure to meet environmental standards and emergence of significant financial risks. Its concluded that probabilistic simulation approach is needed which is able to model these uncertainties and provide basis for more fundamental and adaptive decision-making. The findings of this study are linear problems defined as integrated problem formulations that use structured approach to classify risks identified and then classified using the Risk Breakdown Structure approach to facilitate further analysis. Risks are categorized into technical risks, operational risks, financial risks and external risks. The effect of BOD and COD variability on process efficiency. Simulation results indicate that variations in influent BOD and COD concentrations significantly affect the performance of biological processes and when organic load conditions are higher than the design value, oxygen demand increases nonlinearly. The increase in oxygen demand causes the aeration system to work at maximum capacity, so that operating margins become very limited. number of simulation scenarios, spikes in BOD and COD cause decrease in efficiency of organic material decomposition as indicated by increasing BOD and COD concentrations in effluent. These conditions indicate that the WWTP system becomes more vulnerable to non-compliance with quality standards when extreme fluctuations in organic

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loads occur. These findings indicate that BOD and COD not only serve as quality standard parameters but also as risk parameters that determine the stability of biological processes. Uncertainty in BOD and COD values directly increases the probability of WWTP technical performance failure. Impact of Daily Discharge Variability on Hydraulic Performance Daily discharge variability has significant impact on hydraulic performance of WWTP system. Simulation results indicate that when discharge conditions approach or exceed design capacity, hydraulic retention time (HRT) in main treatment unit decreases. This decrease in HRT has significant impact on reducing the contact time between microorganisms and organic substrates, thus decreasing treatment efficiency. In some extreme scenarios, peak discharge causes short-circuiting in sedimentation unit, resulting in increased TSS concentrations in effluent. This analysis indicates that daily discharge uncertainty is major risk factor which could trigger technical failure, particularly in WWTPs designed with limited hydraulic safety factors.

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