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Study on Pollutant Load Management in Situ Pengarengan Using SWAT Model Approach

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ABSTRACT

Modeling is an important approach for understanding complex aquatic systems, particularly in assessing pollutant loads and their effects on water quality. This study aimed to assess pollutant-load distribution and nutrient-related water quality conditions in Situ Pengarengan, Depok, West Java. Modeling was performed using SWAT+ (Soil and Water Assessment Tool Plus), a physically based hydrological model selected because it integrates topographic, land use, soil, and climate data to simulate watershed hydrology and nutrient transport. Secondary data included a Digital Elevation Model (DEM), land use and soil maps, climate data, and laboratory-based water quality data from eight sampling points. The model simulated stream discharge and channel-level nutrient outputs for 2015–2025, while field measurements were obtained from a single sampling campaign on 12 August 2025. The results indicate that pollutant transport in the catchment was mainly associated with runoff from residential and built-up areas and tended to increase during higher-rainfall conditions. In 2025, the simulated Total Nitrogen (TN) and Total Phosphorus (TP) concentrations were 41.183 mg/L and 8.79 mg/L, respectively, whereas measured TN and TP ranged from 1.61 to 3.15 mg/L and 0.23 to 0.44 mg/L. Because complete observed stream-discharge data and long-term water-quality time-series data were unavailable, the comparison was limited to preliminary verification rather than full calibration and validation. Nevertheless, SWAT+ was useful for describing hydrological response and nutrient transport patterns in the catchment.

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1. INTRODUCTION

Pollutant load modeling has been widely used as a scientific approach to understand the relationship between anthropogenic activities, hydrological processes, and water quality degradation. Various studies have shown that increasing urbanization and land-use changes significantly increase surface runoff, which carries pollutants to water bodies (Ridwan & Sarjito, 2024). This condition makes water bodies in urban areas increasingly vulnerable to pollution. Water pollutant loads generally originate from point and non-point sources, with non-point sources reported as the major contributors to pollution in urban watersheds (Kurniadi et al., 2025). Runoff from residential areas, agricultural land, and built-up areas can transport organic matter, nutrients, and suspended solids into water bodies, thereby degrading water quality (Syawal et al., 2016; Andika et al., 2020). Urban runoff management is an important aspect of water-related environmental control in built-up areas. Sustainable drainage strategies can help reduce hydrological pressure and improve runoff management in urban environments (Amin et al., 2025). In addition, pollutant reduction efforts through treatment approaches such as filter and constructed wetland systems have also shown potential for improving wastewater quality before it enters receiving water bodies (Rahayu et al., 2025).

Several studies have shown that increased concentrations of water quality parameters such as Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are closely correlated with domestic activities and unmanaged waste disposal (Syawal et al., 2016; Andika et al., 2020). Elevated BOD and COD concentrations can reduce dissolved oxygen levels and disrupt aquatic ecosystem functioning. In addition to organic parameters, nutrients such as nitrogen and phosphate are also major concerns in water pollution studies. Stated that excessive nutrient accumulation can trigger eutrophication, promote excessive algal growth, and degrade aquatic habitat quality (Sutamihardja et al., 2018; Kintani et al., 2024). Research conducted by (Mulla et al., 2019) noted that conventional water quality monitoring approaches have limited capacity to represent pollution dynamics across space and time. In many cases, field monitoring data are limited, making them less capable of representing long-term variations in pollutant loads at the catchment scale. Therefore, hydrological and water quality modeling has become an important analytical approach in water management studies. In particular, the Soil and Water Assessment Tool (SWAT) model is capable of integrating physical and environmental variables to simulate water flow and pollutant transport processes (Zhou et al., 2023).

The SWAT model, developed by the USDA Agricultural Research Service (USDA-ARS), is a physically based hydrological model used to represent hydrological conditions and pollutant transport in watersheds. It has been widely applied to predict the effects of land management practices on sedimentation, agrochemical pollutants, and water resources in large and complex catchments (Janjić & Tadić, 2023; Aloui et al., 2023). SWAT operates on a daily time step and integrates Geographic Information System (GIS) and Digital Elevation Model (DEM) data to simulate hydrological processes such as infiltration, surface runoff, lateral flow, evapotranspiration, groundwater flow, and flow routing (Ridwan & Sarjito, 2024). Several international studies have demonstrated the efficacy of SWAT in modeling nutrient loads and non-point pollutants. The research results of (Wang et al., 2019; Zhang et al., 2024) reported that SWAT adequately describes the relationship between rainfall, surface runoff, and pollutant distribution. Similar results were also demonstrated in (Zhang et al., 2022) study on non-point nitrogen pollution.

In Indonesia, the use of SWAT in water quality studies and watershed management is also increasing. Research by (Sujarwo et al., 2020) demonstrated that SWAT is effective in identifying pollution source areas and evaluating land management scenarios to reduce pollutant loads. Land use factors in watersheds are identified as key variables in determining the magnitude of pollutant loads. Research conducted by (Assegide et al., 2024) concluded that densely populated residential areas and built-up areas generate higher runoff than vegetated areas, thus contributing significantly to increased water pollution. In addition to land use, climate factors also play a significant role in pollution dynamics. Research conducted by (Kurniyaningrum & Kurniawan, 2023) show that changes in rainfall patterns due to climate change have the potential to increase the frequency and intensity of surface runoff, which carries pollutants into water bodies.

Modeling studies are also widely used to evaluate pollutant load management scenarios. Research by (Li et al., 2021) showed that the application of Best Management Practices (BMPs) simulated through the SWAT model significantly reduced nitrogen and phosphate loads. This confirms the role of modeling as a tool for evaluating environmental policies. In the context of lakes and reservoirs, pollutant load modeling studies are particularly relevant due to the closed nature of water bodies, which are sensitive to pollutant accumulation. Research by (Abidin, 2023) emphasized that urban lakes have a low resilience to pollution, necessitating a modeling-based management approach. Based on the synthesis of various literature studies, it can be concluded that pollutant load modeling is a crucial approach to comprehensively understanding water quality issues. Integrating modeling results with field data and management policies is expected to support sustainable pollution control and water conservation efforts.

2. METHODS

2.1 Study Area

This research took place in the Situ Pangarengan area in Depok City, West Java Province. This area was chosen because it plays a role in supporting the ecosystem and community activities in the surrounding area. The condition of the area can be seen in **Figure 1.**

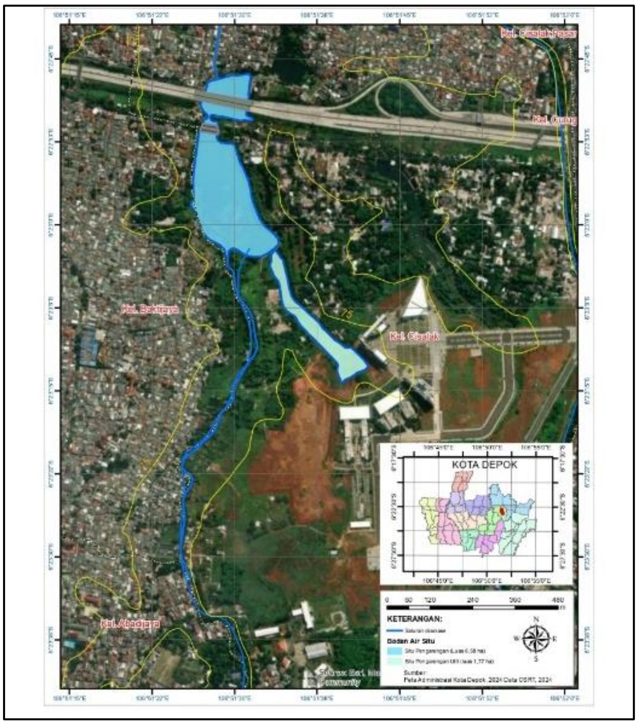

Figure 1. Study area Pengarengan Lake

Figure 1 shows the area of Situ Pengarengan, Depok City, West Java Province. Situ Pengarengan is located at coordinates 6°25' South Latitude, 106°50' East Longitude. It covers approximately 9 hectares and has an average depth of 5 meters.

2.2 Dataset Sources

This study used secondary data obtained from various existing sources, including literature, research reports, and data provided by relevant agencies. Several types of secondary data used in this study are:

2.2.1 Topographic Data

Topographic data consisted of a Digital Elevation Model (DEM) of the study area and the deline ated catchment boundary of Situ Pengarengan. These spatial layers were processed in GIS to describe elevation variability, delineate the watershed and sub-basin boundaries, define the outlet, and extract the river network connected to Situ Pengarengan and the Kalijantung River. The resulting topographic information was then used as input for the SWAT model to represent flow direction, drainage characteristics, and pollutant transport pathways.

2.2.2 Land Use Data

Land use data were derived from land cover maps and supporting satellite imagery for the Situ Pengarengan catchment area. These data were processed in GIS to identify the spatial distribution of major land use classes around the lake and its surrounding drainage area. The land use layer was used as an input to the SWAT model to analyze how land cover conditions influence surface runoff and pollutant loads affecting water quality in Situ Pengarengan.

2.2.3 Climate Data

Includes information on temperature, humidity, rainfall, sunshine duration, wind speed, and wind direction. Climate change can affect rainfall and temperature patterns. Climate data is used to understand the influence of weather on hydrological processes in lakes and rivers. This data was obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG).

2.2.4 Water Quality Data

Water quality data were obtained from laboratory measurements at eight sampling points in Situ Pengarengan. The analyzed parameters included water and air temperature, total suspended solids (TSS), pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen, total phosphorus, oil and grease, phenol, coliform, total coliform, turbidity, and selected metal concentrations. These data were used to describe the existing water quality condition and to support model verification. In addition, the measured values were interpreted with reference to the applicable Indonesian water quality standards and pollution status criteria issued by the Ministry of Environment and Forestry (KLHK), in order to indicate whether the pollution condition at the study site could be categorized as low, moderate, or high.

2.2.5 Biota Test Results

Includes research results on the diversity and health of aquatic biota in Situ Pengarengan. This data is important for understanding the impact of pollution on the lake ecosystem. Biota test data can be obtained from previous research conducted by the testing laboratory, PT. Mutuagung Lestari Tbk.

2.3 Research Stages

2.3.1 Data Collection

The study began with data collection, including DEM and the Situ Pengarengan catchment area boundary (SHP), climate data, land use maps, soil maps, and water quality test results. These datasets were compiled to support SWAT-based modeling and comparison with field measurements. DEM and catchment boundary data were used to represent topography, watershed boundaries, flow direction, and drainage patterns. Climate data were used as hydrometeorological inputs for the simulation. Land use data were used to represent land cover conditions affecting runoff and pollutant generation. Soil data were used to represent infiltration, water retention, and pollutant movement in the soil profile. Water quality test results were used for comparison with the model outputs. A literature review was conducted by collecting and examining relevant journals, books, research reports, and regulations related to water pollution, pollutant loads, hydrological modeling, and the SWAT model. This stage was intended to strengthen the theoretical basis and methodological framework of the study.

2.3.2 Verification of Spatial Input Data

DEM and catchment area data were verified before modeling to ensure that the watershed boundary, outlet location, and drainage network were consistent with the study area conditions. This step was required to prepare reliable spatial inputs for the SWAT model.SWAT modeling was carried out using the prepared topographic, land use, soil, and climate inputs. The simulation period covered 2013–2025, while the reported outputs focused on 2015–2025. The model was used to simulate hydrological response and nutrient dynamics in the Situ Pengarengan catchment. The main outputs analyzed in this study were river flow and channel-level nutrient variables, including Total Nitrogen (TN), Nitrate (NO3), Nitrite (NO2), Ammonium (NH4), Organic Nitrogen, Total Phosphorus (TP), and Soluble Phosphorus.

2.3.3 SWAT Modeling

SWAT modeling was then carried out using the verified spatial data together with climate, land use, and soil data. The model was used to simulate hydrological response and nutrient dynamics in the Situ Pengarengan catchment. The simulation period covered 2013–2025, with the reported results focused on 2015–2025.

2.3.4 SWAT Model Nutrient Output

The main model outputs analyzed in this study were nutrient variables at the channel level, including Total Nitrogen (TN), Nitrate (NO3), Nitrite (NO2), Ammonium (NH4), Organic Nitrogen, Total Phosphorus (TP), and Soluble Phosphorus. River flow output was also used to interpret the hydrological response of the model.

2.3.5 Comparison of SWAT Output With Water Quality Test Results

The simulated SWAT outputs were compared with laboratory-based water quality test results from sampling points in Situ Pengarengan. This stage was conducted to examine whether the model outputs showed patterns consistent with observed water quality conditions. Because complete discharge observation data were not available, this stage was limited to comparison and model verification rather than full calibration and validation.

2.3.6 Conclusion and Suggestions

This study was carried out through several systematic steps, starting from data collection to modeling and analysis. The final stage was drawing conclusions based on the modeling and comparison results, followed by suggestions for water quality management and future research. The overall steps taken in this study are presented in **Figure 2.**

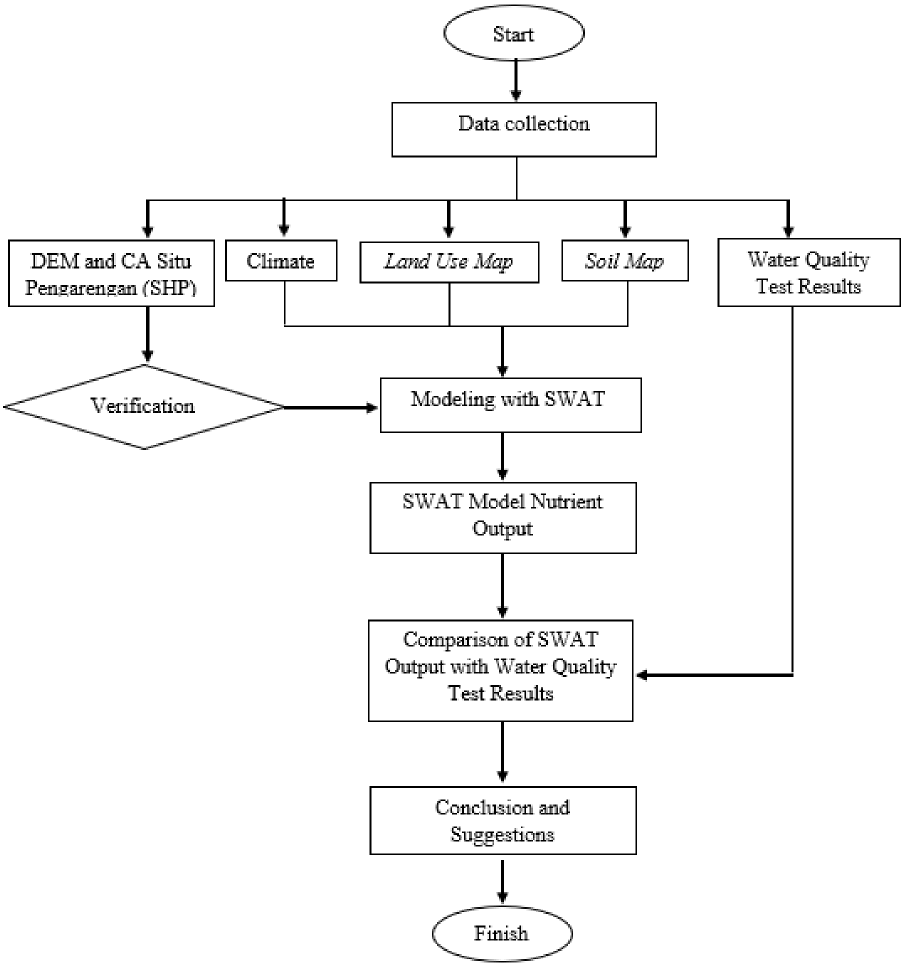

Figure 2. Research Flowchart

As shown in **Figure 2**, the research begins with data collection from various sources, including spatial and climate data. The data are then processed and used in SWAT modeling, followed by comparison with water quality test results. Finally, conclusions are drawn and recommendations are provided for future management and research.

3. RESULT AND DISCUSSION

3.1 Verification of Spatial Input Data

In this study, the nearest reach and upstream-downstream tracing methods were used to identify the appropriate channel segment for each sampling point. The nearest reach method identifies the closest channel segment spatially, while upstream-downstream tracing ensures the reach is part of the same flow path and receives contributions from the relevant catchment area. The illustration of the river network and the selected channel segment can be seen in **Figure 3.**

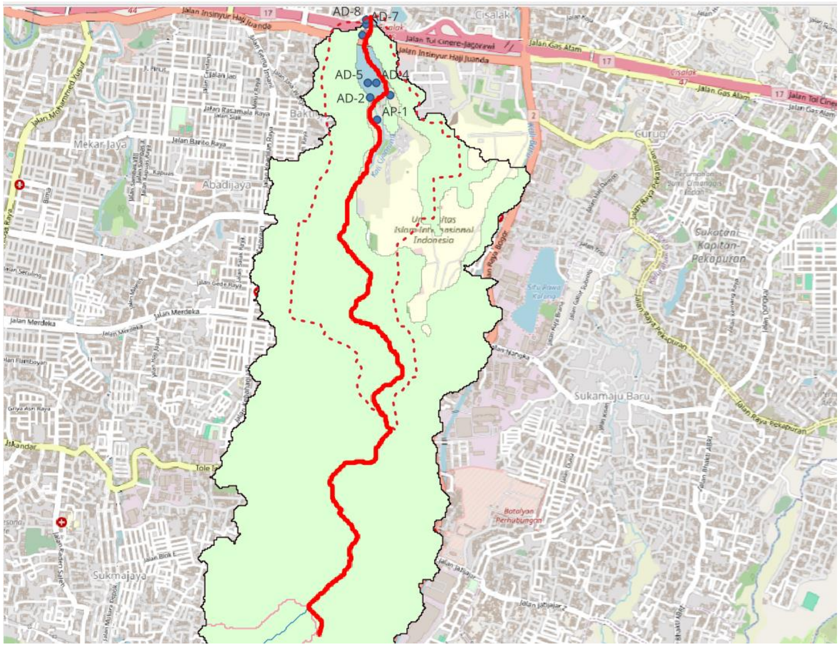

Figure 3. Map of river network and selected channel segment at the research location.

As shown in **Figure 3**, The analysis was performed using QGIS software, where the sampling points (e.g., AP-1, AD-2 to AD-8) were overlaid with the channel reach layer from the SWAT model. The red line in the overlay represents the main channel reach that passes through Situ Pengarengan and flows southward, selected for model output extraction. The light green polygon represents the catchment area, with sampling points within the same hydrological corridor. The selected reach accurately links the field data to model outputs, even for points slightly outside the channel line due to spatial data scale differences. The analysis confirms that all sampling points in Situ Pengarengan and Sungai Cijantung are represented by the main channel segment in the SWAT model. Model output variables, such as river flow and nutrients (nitrogen and phosphorus), were extracted at the channel level, providing a logical connection between field data and model results, despite the lack of calibration and validation

3.2 SWAT Modeling

3.2.1 Climate Input for SWAT

Based on climate data obtained from the West Java Climatology Station, located at latitude -6.50 and longitude 106.75, the study area exhibits a relatively consistent seasonal rainfall pattern throughout the year. The distance between the station and Situ Pengarengan in Depok City is approximately 18.5 km. Although the station is not located directly within the study area, its data were considered relevant because the two areas share similar climatic characteristics. The recorded climate variables, including rainfall, air temperature, and wind speed, were therefore used as input for the SWAT+ model simulation. The average montly rainfall during the period of 2013-2025 is presented in **Figure 4.**

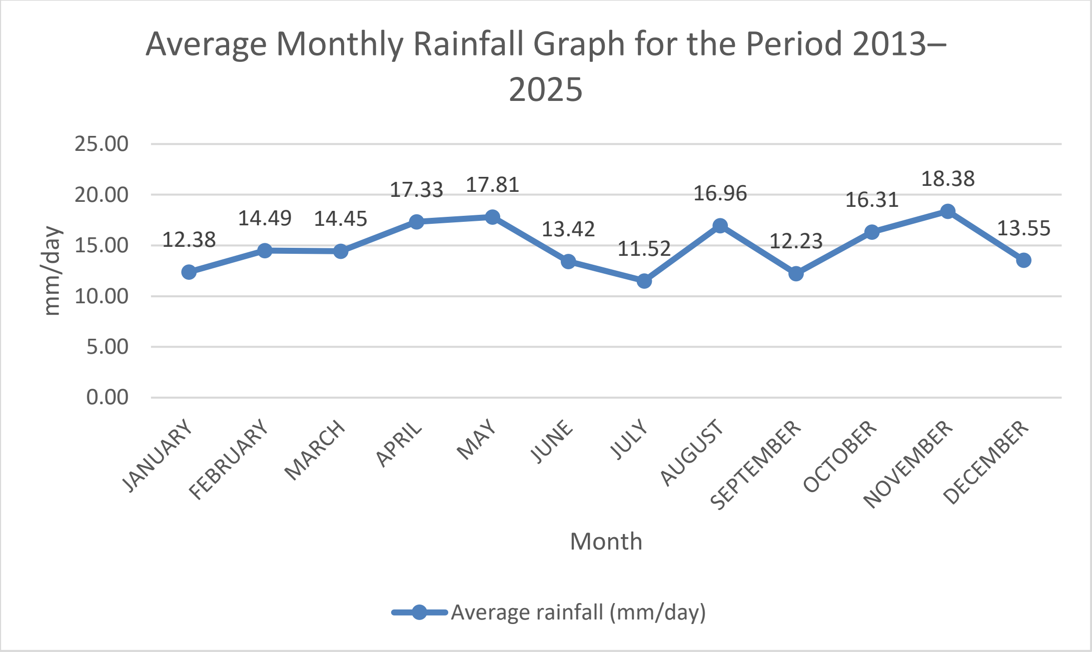

Figure 4. Average Monthly Rainfall Graph for the Period 2013–2025

The analysis in **Figure 4** shows shows that rainfall tends to increase during the rainy season, specifically from April to May, and again rises from October to November. The highest average rainfall occurs in November at 18.38 mm/day, followed by May and April with rainfall values ranging from 17 to 18 mm/day. This reflects the higher intensity of rainfall during the peak rainy season. In contrast, during the dry season, particularly from June to September, rainfall decreases. The daily average rainfall during this period is generally below 14 mm/day, with the lowest values occurring in July, around 11–12 mm/day. This reduction in rainfall indicates a decrease in water supply to the hydrological system of the study area.

3.3 Simulated River Flow

The river flow data in this study was obtained from the SWAT+ model simulation at the channel scale, with a monthly resolution from January 2015 to December 2025. The output data from the SWAT+ model represents the flow in the main river channel, which flows towards Sungai Cijantung and is associated with the Situ Pengarengan hydrological system. As no field observation data for river flow was used, model calibration and validation were not performed, and the analysis focused on the flow patterns and the model's hydrological response.

3.4 Maximum and Minimum Simulated Discharge

Based on the flow data analysis, the maximum flow (QMAX) was recorded in September 2015 with a value of 2.435 m^3/s, indicating the peak river flow during that period. This event may have been influenced by a combination of high rainfall during the rainy season, as well as the contributions from surface runoff and baseflow interacting with each other.

On the other hand, the minimum flow (QMIN) was recorded in November 2023 with a value of 0.0331 m³/s, showing the lowest flow condition during the simulation period. The low flow values during this period are attributed to the dry season, with low rainfall and reduced surface runoff. During this time, the river flow relies more on baseflow, which is sustained by groundwater reserves from previous wet periods, the simulation results shown in **Figure 5.**

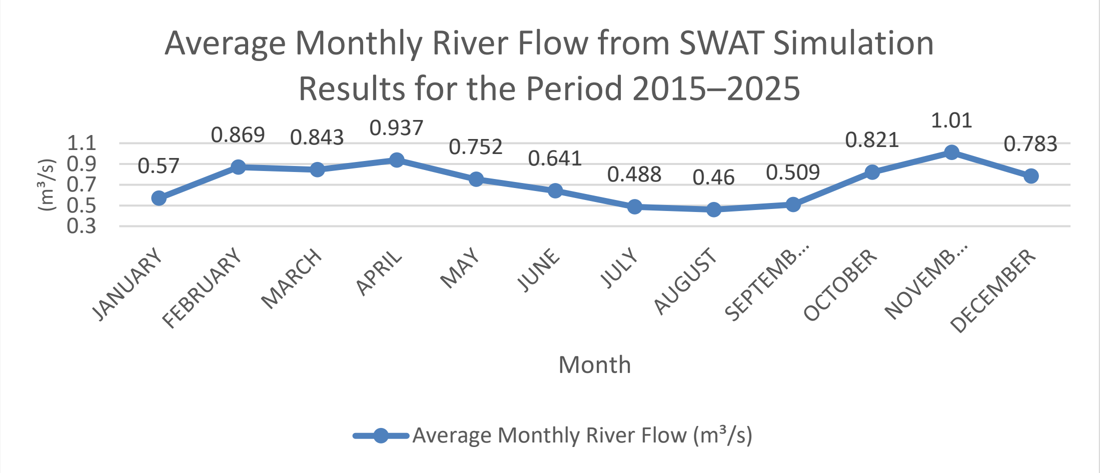

Figure 5. Results for the Period 2015–2025

As shown in **Figure 5** illustrates the monthly average flow pattern for the period 2015–2025. The highest flow values were observed in November (1.010 m³/s), which coincides with the peak rainfall in the same month. Conversely, the lowest flow occurred in July (0.488 m³/s), which represents the peak of the dry season with minimal rainfall. The graph in Figure 4.5 shows a clear relationship between rainfall and river flow, where high rainfall months tend to produce high flow, and dry months exhibit a significant decrease in flow. This indicates that the SWAT+ model successfully represents the logical relationship between rainfall and river flow, despite some discrepancies in the exact flow values during certain months.

3.5 Interpretation of Simulated Flow Results

Although the SWAT+ model shows a consistent pattern with the trends in rainfall and river flow, it is important to note that the simulated flow values depend on the input parameters and model assumptions. Therefore, the flow calculated from the SWAT+ simulation may not accurately reflect real-world conditions, especially when compared to observational data, which can vary due to temporal differences, spatial variations, and external factors such as land use changes, vegetation cover, or artificial disturbances not included in the model.

Thus, the comparison of the maximum flow (QMAX) recorded in September 2015 and the minimum flow (QMIN) in November 2023 provides a general overview useful for evaluating the model's overall trends. However, these simulated results still require further verification if observational flow data becomes available in the future.

3.6 SWAT Model Nutrient Output

This study focuses on nutrient dynamics and flow, using the SWAT model to analyze Total Nitrogen (TN), Nitrite (NO2), Nitrate (NO3), Ammonia (NH4), Total Phosphorus (TP), and Dissolved Phosphorus over the period from 2013 to 2025.

3.6.1 Total Nitrogen (TN)

The variation of Total Nitrogen (TN) concentrations over the simulation period provides insight into nutrient dynamics in the study area. The temporal trend of TN levels from 2015 to 2025 is presented in **Figure 6.**

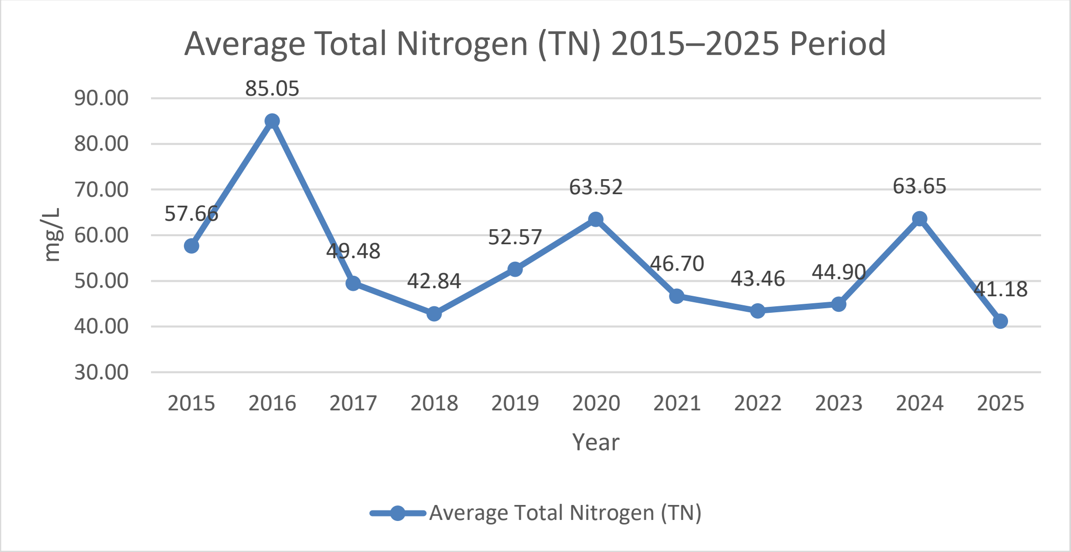

Figure 6. Average Total Nitrogen (TN) 2015–2025 Period

As shown in **Figure 6** The SWAT model simulation showed significant fluctuations in Total Nitrogen (TN) levels between 2015 and 2025. The highest concentration occurred in 2016, with 85.047 mg/L, followed by a decline, reaching its lowest in 2023 at 44.903 mg/L. The predicted concentration for 2025 is 41.183 mg/L, indicating an overall decrease in nitrogen levels, likely due to improved management or environmental conditions.

3.6.2 Nitrate (NO3)

The variation in nitrate (NO_3) concentrations reflects the dynamics of nitrogen in the study area over time. Changes in NO_3 levels are influenced by environmental conditions and land use activities within the watershed. The temporal trend of NO_3 concentrations from 2015 to 2025 is presented in **Figure 7.**

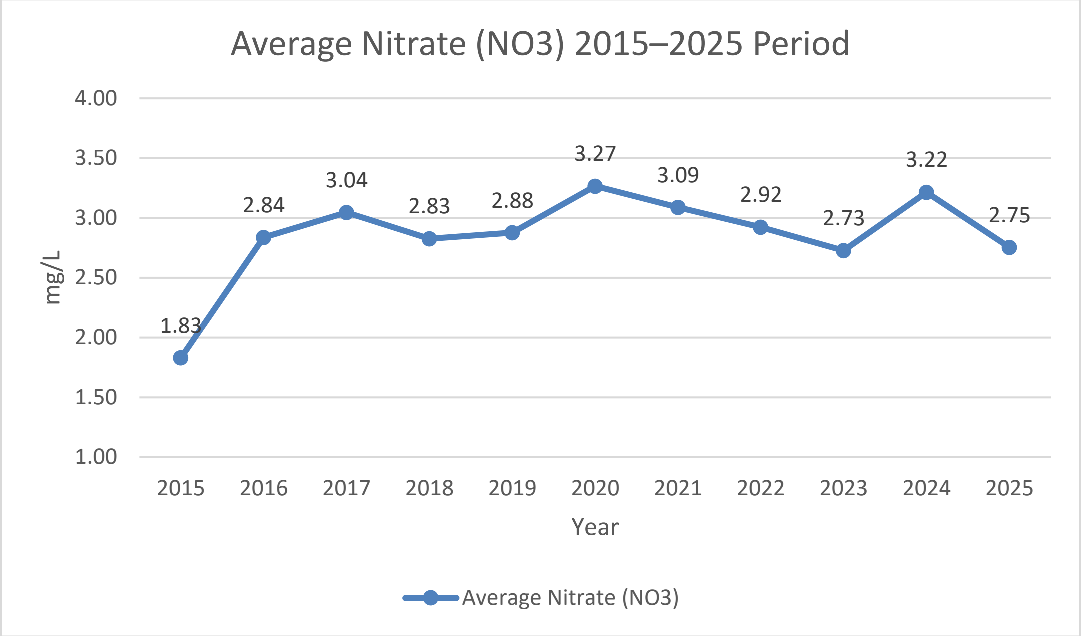

Figure 7. Average Nitrate (NO3) 2015–2025 Period

As shown in **Figure 7**, the highest concentration was recorded in 2016 at 3.27 mg/L, followed by a decrease, with a predicted value of 2.75 mg/L in 2025. The lowest value occurred in 2015 at 1.83 mg/L, increasing in 2016 and later decreasing gradually. Overall, the simulation indicates a decreasing trend in NO3 from 2015 to 2025, which could reflect improvements in nitrogen management or natural factors reducing Nitrate levels. This trend is crucial for planning measures to reduce nitrogen pollution in the river.

3.6.3 Nitrite (NO2)

Changes in nitrite (NO_2) concentrations indicate nitrogen dynamics in the study area over time. These fluctuations are influenced by environmental conditions and activities in the watershed. The trend in NO_2 concentrations during the 2015–2025 period can be seen in **Figure 8**.

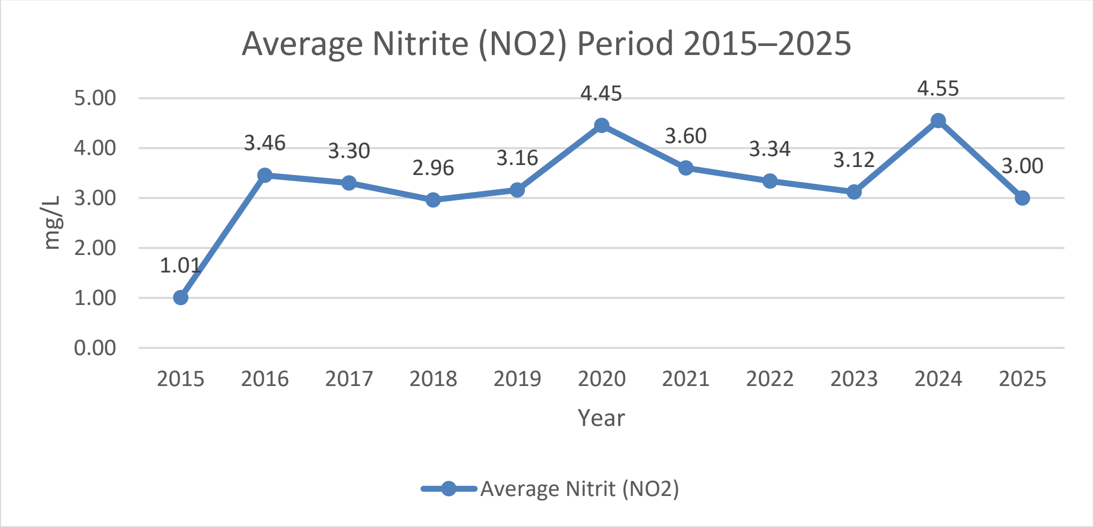

Figure 8. Average Nitrite (NO2) 2015–2025 Period

As shown in **Figure 8**, the highest concentration occurred in 2020 at 4.45 mg/L, with a decline thereafter. By 2025, the concentration is predicted to be 3.00 mg/L, lower than previous years. The lowest value was in 2015 at 1.01 mg/L. Overall, the simulation indicates a decreasing trend in NO2 levels, suggesting possible improvements in Nitrite management or environmental changes.

3.6.4 Amonium (NH4)

Changes in ammonium (NH_4) concentrations indicate the dynamics of water quality in the study area during the observation period. NH_4 values can be influenced by environmental conditions, rainfall, and human activities around the watershed. The trend in NH_4 concentrations during the 2015–2025 period can be seen in **Figure 9**.

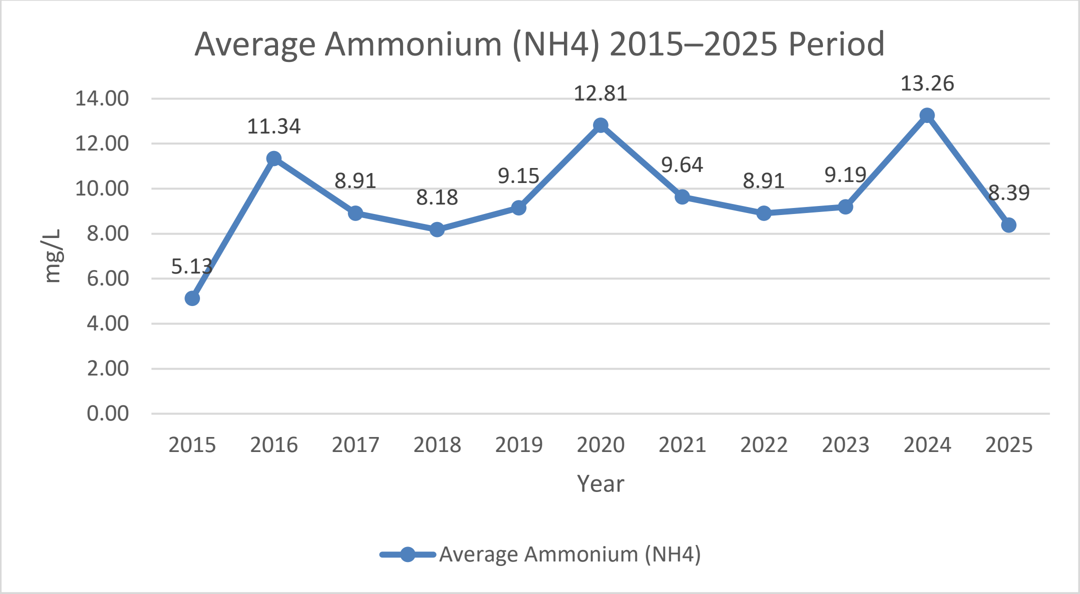

Figure 9. Average Ammonium (NH4) 2015–2025 Period

The SWAT simulation shows significant fluctuations in Ammonium (NH4) levels from 2015 to 2025. **Figure 9** illustrates the average NH4 concentrations during this period. The highest concentration occurred in 2024 at 13.26 mg/L, with previous peaks in 2016 (11.34 mg/L) and 2020 (12.81 mg/L). These fluctuations are likely influenced by seasonal factors, weather conditions, and human activities affecting river flow. Overall, the NH4 concentration shows an increasing trend with notable peaks, highlighting the influence of external factors on water quality.

3.6.5 Organic Nitrogen

Changes in organic nitrogen concentrations indicate water quality conditions during the observation period. These values can be influenced by human activities, natural processes, and environmental conditions in the watershed. Trends in organic nitrogen concentrations during the 2015–2025 period can be seen in **Figure 10**.

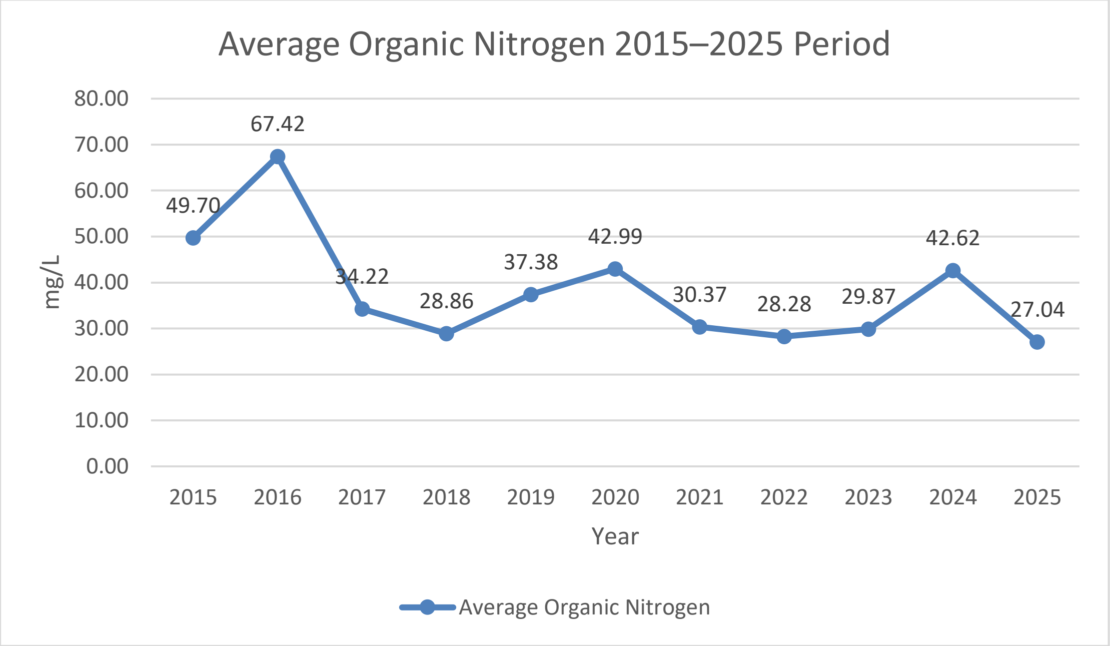

Figure 10. Average Organic Nitrogen 2015–2025 Period

As shown in **Figure 10**, the highest concentration occurred in 2016 at 67.42 mg/L, followed by a sharp decrease in 2017 to 28.86 mg/L. Overall, the trend shows a decline in organic nitrogen levels from 2016 to 2025, with a final value of 27.04 mg/L in 2025, indicating improved nitrogen management or favorable environmental changes.

3.6.6 Total Phosphorus (TP)

Total Phosphorus (TP) is an important indicator of water quality, as high concentrations can trigger eutrophication. Changes in TP levels are influenced by environmental conditions and human activities in the watershed. The trend of TP concentrations from 2015 to 2025 is shown in **Figure 11**.

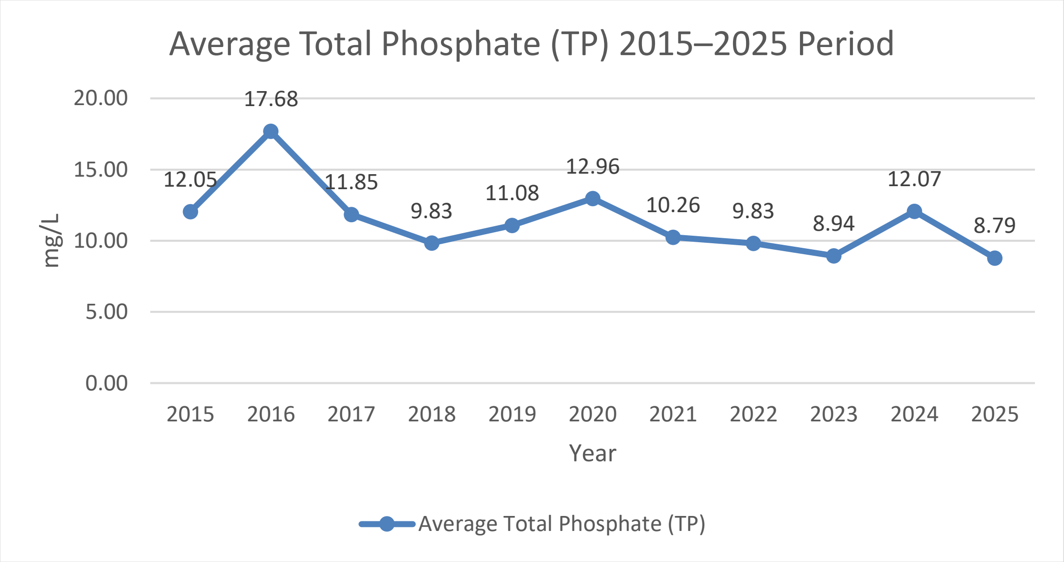

Figure 11. Average Total Phosphate (TP) 2015–2025 Period

As shown in **Figure 11**, Total Phosphorus (TP) concentration is an important water quality indicator, as high phosphorus levels can lead to eutrophication. The SWAT simulation shows significant fluctuations in TP from 2015 to 2025. In 2016, TP peaked at 17.68 mg/L, then decreased steadily. By 2025, TP is predicted to reach 8.79 mg/L, indicating improvements in phosphorus management or favorable environmental factors. The overall trend shows a decrease in TP from 2016 to 2025, which suggests positive changes in phosphorus management.

3.6.7 Soluble Phosphorus

Soluble phosphorus is an important parameter in assessing water quality, especially in relation to eutrophication. Its concentration can be influenced by environmental conditions and human activities in the watershed. The trend of soluble phosphorus concentrations from 2015 to 2025 is shown in **Figure 12.**

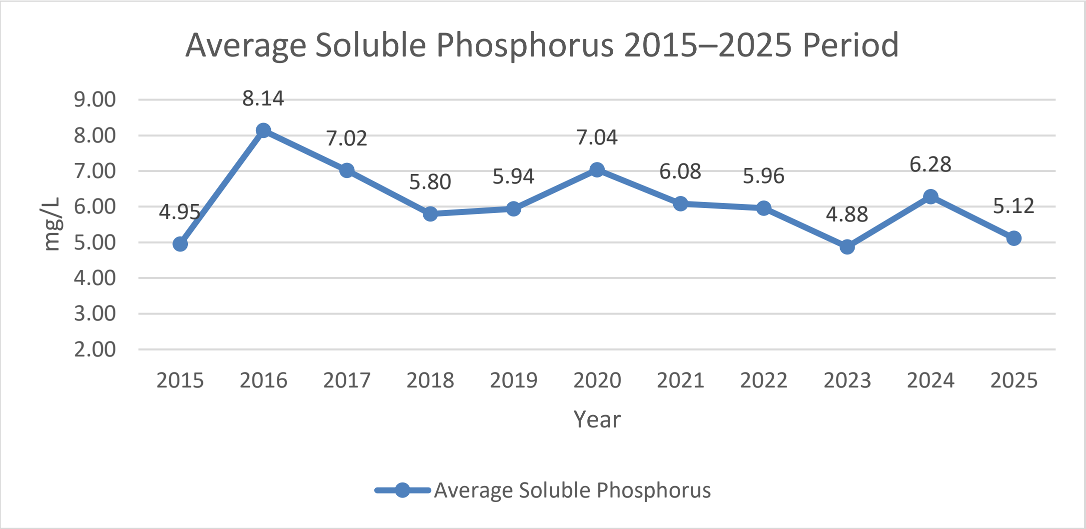

Figure 12. Average Soluble Phosphorus 2015–2025 Period

As shown in **Figure 12**, Soluble Phosphorus contributes to eutrophication, affecting water quality and aquatic life. The SWAT simulation results from 2015 to 2025 show fluctuations in soluble phosphorus levels, with a decrease in 2025. In 2015, the level was 4.95 mg/L, peaking at 8.14 mg/L in 2016, before gradually decreasing to 5.12 mg/L by 2025. This decline suggests improvements in phosphorus management and better water quality. Overall, the trend indicates a decrease in soluble phosphorus, which is essential for maintaining optimal water quality.

3.7 Water Quality Test Results

This section discusses the water quality test results obtained from 8 sampling points scattered across Situ Pengarengan. The study aims to provide an overview of the water quality conditions in the lake, focusing on relevant water quality parameters such as Total Nitrogen (TN), Total Phosphorus (P), Dissolved Iron (Fe), and Dissolved Oxygen (DO).

3.7.1 Soluble Phosphorus

Total Nitrogen (TN) is an important parameter for evaluating water quality in aquatic systems. Its concentration is influenced by inputs from domestic activities, agriculture, and other sources within the watershed. The spatial distribution of TN concentrations at different sampling points is shown in **Figure 13.**

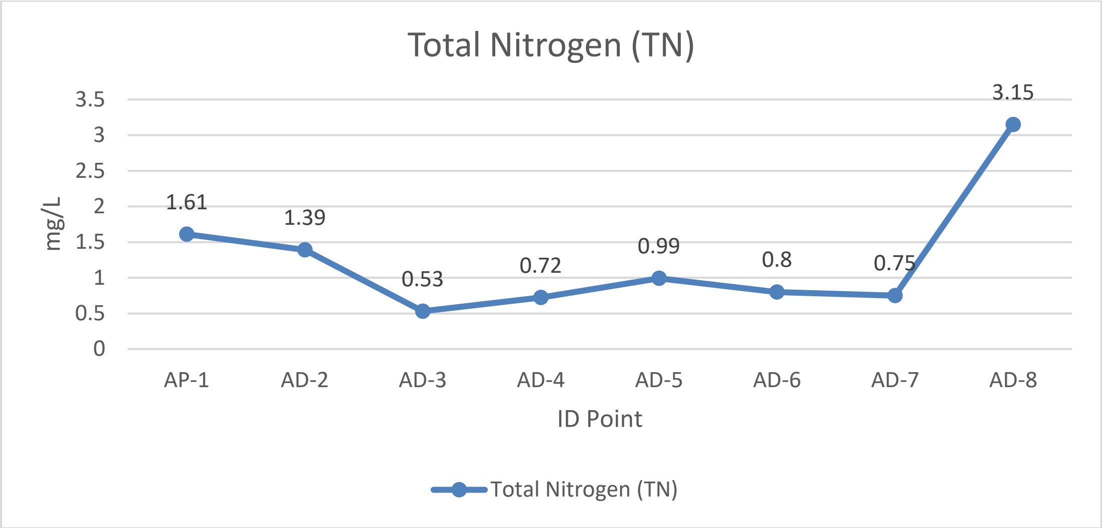

Figure 13. Total Nitrogen Test Results

As shown in **Figure 13**, Total Nitrogen (TN) is a key parameter reflecting water quality. It originates from sources like domestic waste and agriculture. The results show significant variations in TN levels between sampling points. The AP-1 (inlet) point recorded 1.61 mg/L of TN, while AD-8 (outlet) showed a much higher 3.15 mg/L, indicating pollutant accumulation along the water flow. The data suggests that TN levels increase as water moves from inlet to outlet, emphasizing the need for better nitrogen management and monitoring.

3.7.2 Total Phosphorus (TP)

Total Phosphorus (TP) is an important parameter in assessing water quality, especially related to eutrophication. Its concentration can vary depending on pollution sources and natural processes within the watershed. The spatial distribution of TP concentrations at different sampling points is shown in **Figure 14.**

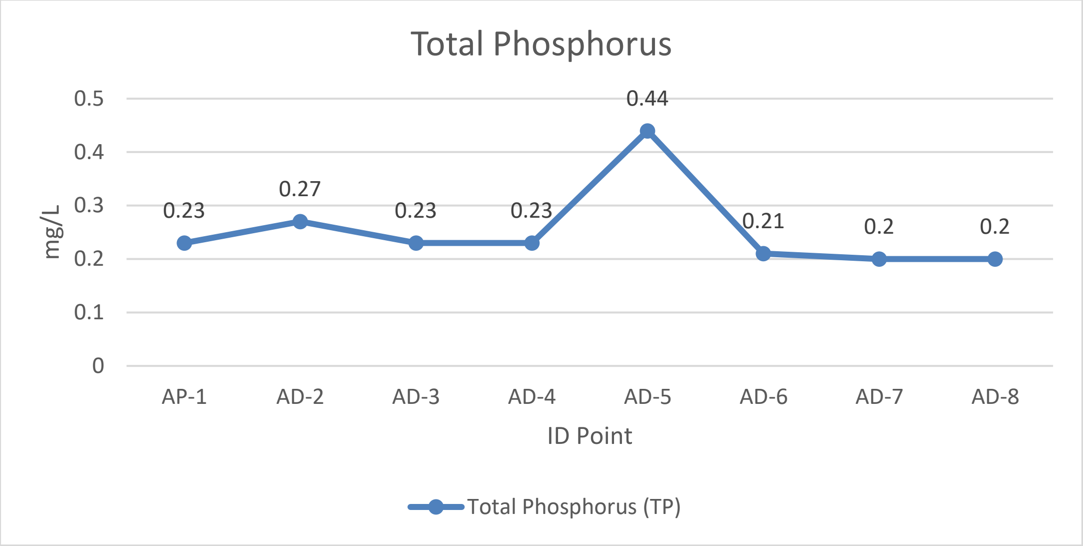

Figure 14. Total Phosphorus Test Results

As shown in **Figure 14**, Total Phosphorus (TP) is a key water quality parameter that influences eutrophication. In this study, TP levels were measured at 8 sampling points in Situ Pengarengan, including the inlet (AP-1) and outlet (AD-8). The AP-1 (inlet) had a 0.23 mg/L concentration, while the highest concentration, 0.44 mg/L, was recorded at AD-5, indicating accumulation. The concentration decreased towards the outlet, with AD-6, AD-7, and AD-8 showing lower values around 0.2 mg/L.

This pattern suggests a reduction in TP levels from the inlet to the outlet, likely due to natural processes or water flow dynamics.

3.7.3 Dissolved Iron (Fe)

Dissolved iron (Fe) is an important parameter in assessing water quality in aquatic systems. Its concentration can be influenced by natural processes and human activities within the watershed. The spatial distribution of dissolved iron concentrations at different sampling points is shown in **Figure 15**.

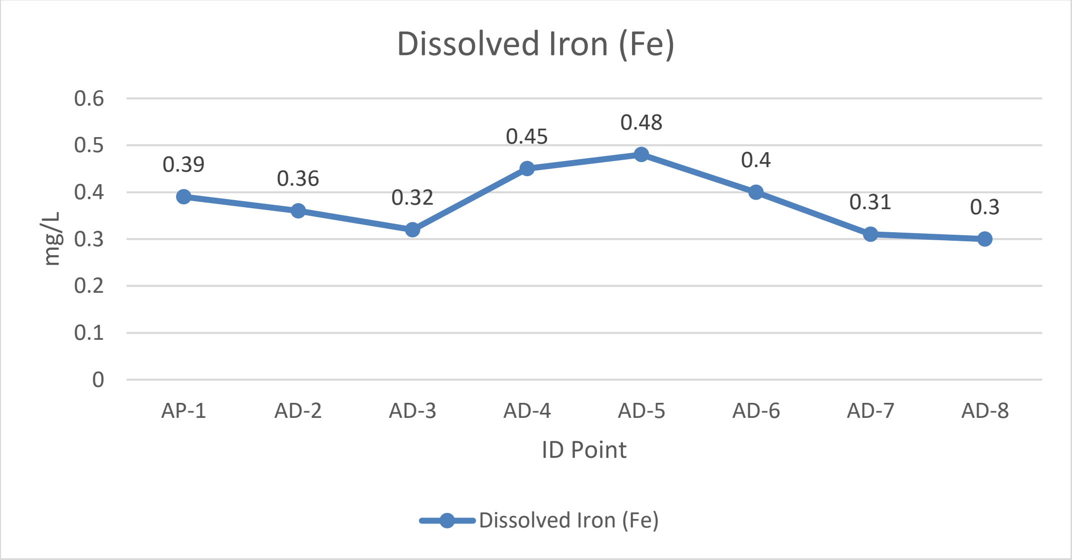

Figure 15. Dissolved Iron (Fe) Test Results

As shown in **Figure 15**, dissolved iron is a key water quality parameter, impacting aquatic ecosystems. Excessive levels can reduce oxygen in water and harm aquatic life. Iron concentrations fluctuated, with the AP-1 (inlet) recording 0.39 mg/L, dropping slightly at AD-2 and AD-3. Higher concentrations of 0.45 mg/L and 0.48 mg/L were found at AD-4 and AD-5, likely due to accumulation. Iron levels then decreased towards the outlet, with AD-8 at 0.30 mg/L. Overall, iron concentrations were lower at the outlet, indicating a reduction along the flow path.

3.7.4 Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is an essential parameter for evaluating water quality and aquatic ecosystem health. Its concentration is influenced by environmental factors such as temperature, pH, and organic matter decomposition. The spatial distribution of DO levels at different sampling points is shown in **Figure 16.**

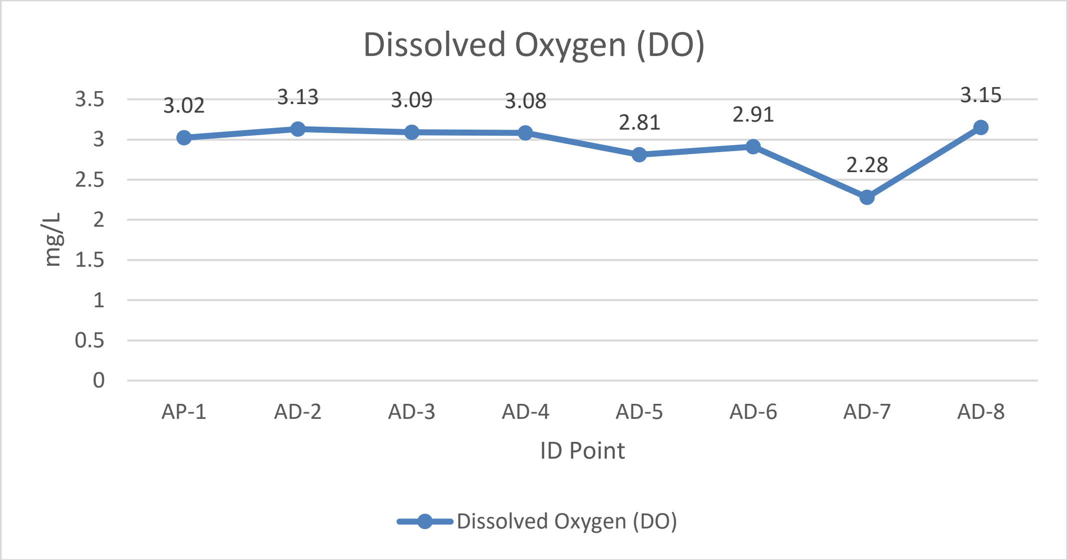

Figure 16. Dissolved Oxygen (DO) Test Results

As shown in **Figure 16**, Dissolved Oxygen (DO) is a key water quality parameter vital for aquatic life. It is influenced by factors like temperature, pH, and organic decomposition. Low DO levels indicate pollution or water degradation. DO levels remained stable at the inlet (AP-1) (3.02 mg/L), decreased at AD-6 to 2.28 mg/L, likely due to organic decomposition, and peaked at the outlet (AD-8) with 3.15 mg/L. The fluctuations in DO indicate varying water quality along the flow path, with the increase at the outlet suggesting aeration or environmental changes.

3.8 Comparison of SWAT Output With Water Quality Test Results

3.8.1 Comparison of Total Nitrogen (TN)

The SWAT model simulated annual average Total Nitrogen (TN) concentrations from 2015 to 2025, with the highest simulated value recorded in 2016 (85.047 mg/L) and a lower simulated value in 2025 (41.183 mg/L). Field measurement data were only available from a single sampling campaign conducted on 12 August 2025 at eight sampling points in Situ Pengarengan. The measured TN concentrations were 1.61 mg/L at the inlet (AP-1) and 3.15 mg/L at the outlet (AD-8). Therefore, no field data were available to confirm the simulated TN value for 2016.

Given the large discrepancy between the simulated TN values and the field measurements, the model outputs in this study cannot be interpreted as actual concentrations at the sampling points. This comparison was used only as a limited verification step, because the field data represent point measurements from a single sampling event, whereas the SWAT outputs were extracted at the channel level and represent broader catchment-scale conditions. Full calibration and validation were not performed due to the unavailability of complete observed river discharge data.

3.8.2 Comparison of Total Phosphorus (TP)

The SWAT model simulated annual average Total Phosphorus (TP) concentrations from 2015 to 2025, with the highest simulated value recorded in 2016 (17.68 mg/L) and a lower simulated value in 2025 (8.79 mg/L). Field measurement data were available only from the sampling campaign conducted on 12 August 2025. The measured TP concentrations were 0.23 mg/L at the inlet (AP-1) and 0.44 mg/L at one of the observed points, indicating substantially lower values than the simulated outputs.

This large discrepancy shows that the simulated TP values should be interpreted cautiously and cannot be treated as quantitatively reliable representations of actual field concentrations. In the absence of complete discharge observations and longer time-series water quality data, the model results in this study are more appropriately used to describe relative simulation tendencies within the catchment rather than to provide calibrated quantitative predictions. Therefore, the comparison with field data was limited to model verification only.

3.8.3 Verification Analysis

The comparison between SWAT model outputs and field water quality measurements showed substantial differences in the absolute values of TN and TP. However, these results should be interpreted cautiously because this study did not include full model calibration and validation. Complete observed river discharge data were not available, and the water quality dataset was limited to a single sampling campaign conducted on 12 August 2025 at eight sampling points in Situ Pengarengan. Therefore, statistical performance measures such as NSE or R^2 were not applied in this study. The comparison was used only as a limited verification step to examine the general relationship between simulated outputs and observed field conditions. In this context, the SWAT results are more appropriately interpreted as preliminary modeling outputs for initial analysis, rather than as fully validated quantitative predictions.

4. CONCLUSION

Based on the field water quality measurements and SWAT simulation results, it can be concluded that Situ Pengarengan shows indications of nutrient-related water quality degradation rather than being directly classified as having a high pollution level. Field measurements showed that Total Phosphorus (TP) at several sampling points ranged from 0.21 to 0.44 mg/L, exceeding the reference value of 0.2 mg/L, while Dissolved Oxygen (DO) at most points ranged from 2.28 to 3.15 mg/L, lower than the reference minimum of 4 mg/L. These conditions indicate nutrient enrichment and reduced oxygen availability in the water body. In addition, Total Nitrogen (TN) concentrations increased from 1.61 mg/L at the inlet to 3.15 mg/L at the outlet, suggesting accumulation along the flow path.

The SWAT simulation indicates that pollutant transport in the Situ Pengarengan catchment is mainly associated with non-point source inputs, particularly runoff from residential and built-up areas, with greater contribution during periods of higher rainfall. The model outputs were useful for describing the spatial distribution of simulated nutrient loads and hydrological response in the catchment. However, because complete observed river discharge data and long-term water quality time-series data were not available, the model results in this study should be interpreted as preliminary outputs for initial analysis rather than as fully calibrated quantitative predictions. Overall, this study suggests that the combination of field measurements and SWAT-based simulation can support an initial understanding of pollutant transport and water quality conditions in Situ Pengarengan. The approach may therefore be used as a preliminary scientific basis for future monitoring, model improvement, and water quality management in the study area

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