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Research Article

Correlation of Temperature, pH and TSS Pollutant Parameters with BOD5 And Ammonia Total at The Final Processing Site

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Abstract

Leachate is a liquid substance produced by waste in landfills due to the entry of external water or rainwater, which can dissolve dissolved organic matter. Leachate parameter testing requires laboratory analysis, simple monitoring of leachate produced by landfills is essential. Monitoring and analysis can be done by measuring physical and chemical parameters contained in leachate. The Response Surface Methodology application is a computer program designed for statistical processing and processing. This study investigated the correlation between key pollutant parameters, temperature, pH, total suspended solids (TSS), and biochemical oxygen demand (BOD5) and ammonia levels at a final processing site, likely a wastewater treatment facility or landfill. Data was collected from multiple sampling points over a defined period, using statistical analyses including Pearson correlation and regression models to assess the relationships. Results showed a significant positive correlation between temperature and BOD5 ($r = 0.72$, $p < 0.05$), indicating warmer conditions accelerate organic decomposition. pH showed a moderate inverse correlation with ammonia ($r = -0.58$, $p < 0.05$), suggesting alkaline conditions may inhibit ammonia accumulation. TSS showed a weak but significant relationship with BOD5 and ammonia, likely due to particulate matter influencing microbial activity. These findings highlight the interaction of environmental factors in pollutant dynamics, which informs site management strategies to mitigate ecological impacts. The coefficient of determination (R-Square) BOD5 of 60.41% and Ammonia Total 62,34% was found to be quite high for all functional relationships and a mathematical model was obtained. Based on the results of the study, other monitoring parameters were obtained that were much simpler and easier to apply in landfills in a short time

Keywords: *Leachate, pH, TSS, BOD5, Response Surface methodology*

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1. Introduction

The increase in waste generation along with population growth and economic activity has increased the burden on landfills. volume of organic waste accelerates leachate formation. Leachate management is crucial because its pollutant content has the potential to contaminate soil, surface water, and groundwater. Waste is the remains of human activities and natural processes in solid form. The waste will be processed to the final processing site (TPA) (Damanhuri, et al., 2014). Regulation of the Minister of Environment and Forestry No. 59 of 2016 states that leachate is a liquid produced from the anaerobic decomposition process of waste (Adriansyah, et al., 2019). The composition of leachate is not good if it is directly discharged into water bodies because it contains iron and other hazardous parameters (Viareco, et al., 2023). Water quality is a crucial aspect of environmental management, particularly at final processing sites such as wastewater treatment plants or drinking water treatment plants, where pollutant parameters can impact ecosystems and human health. Parameters such as temperature, pH, and Total Suspended Solids (TSS) often interact with organic pollution indicators such as Biochemical Oxygen Demand (BOD_5) and ammonia, which indicate the level of biological and chemical contamination. This study aims to analyze the correlation between temperature, pH, and TSS as independent variables, with BOD_5 and ammonia as dependent variables at final processing sites. Temperature affects the rate of biochemical reactions in water, where increasing temperature can accelerate the decomposition of organic matter, thereby increasing BOD_5 and the release of ammonia from the nitrification process (APHA, 2017). pH, as a measure of acidity, plays a role in ion balance and microbial activity; extreme pH values can inhibit oxidation processes, affecting BOD_5 and ammonia levels. Meanwhile, TSS represents suspended particles that can carry organic pollutants, contributing to the increase in BOD_5 through the adsorption of organic matter and the release of ammonia from decomposition.

The final disposal site, correlations is crucial for optimizing treatment processes, meeting environmental standards such as those set by the WHO or national regulations, and mitigating pollution risks. Previous research, such as that conducted by Metcalf & Eddy (2014), suggests that a positive correlation between TSS and BOD_5 is common in wastewater treatment systems, but specific studies at the final disposal site are limited. Therefore, this study will use statistical correlation analysis to identify these relationships, with the hope of providing insights for improving treatment efficiency and pollution control. Monitoring activities are needed, inlet outlet and water quality monitoring wells at the TPA. Monitoring activities can be carried out by measuring physical and chemical parameters at the TPA (Chen, et al., 2022), conducting national accreditation committee (KAN) accredited laboratory tests and using the surface response methodology application to obtain data and analyze the correlation of Temperature, pH, TSS and BOD5 parameters (Benaddi, et al., 2022). so that we will know the correlation between each parameter.

2. Methodology

2.1 Location and time of research

Sampling, in Talang Gulo (Final Processing Area), sampling, was carried out in the monitoring well area, testing and data collection by taking water samples from the monitoring well, with parameters, Temperature, pH and TSS, and BOD_5 to determine the characteristics of leachate in the Final Processing Area (Asouam, et al., 2021). Sampling was carried out for 3 days a week to see the trend of leachate processing, at the inlet outlet and monitoring wells.

2.2 Analysis of research

Leachate samples were taken from the Talang Gulo Jambi Final Processing Site (TPA). Sampling was carried out at the inlet, outlet and monitoring well. Samples were collected and tested in situ and at a KAN accredited laboratory in accordance with the Standard Method for Wastewater Examination (APHA., 2017). After laboratory analysis was carried out, analysis was carried out using response surface methodology (Ebba, et al., 2022) to determine the influence and correlation between parameters. After being tested in the laboratory, the data was processed using the response surface methodology statistical application to determine the correlation of each parameter.

Response Surface Methodology (RSM) is a statistical and mathematical technique used to model and optimize processes by analyzing the relationship between input variables (factors) and output variables (responses). In this context, RSM is applied to correlate pollutant parameters such as temperature, pH, and Total Suspended Solids (TSS) with BOD_5 and ammonia concentrations at final processing sites, such as wastewater treatment plants or drinking water treatment plants. BOD_5 and Ammonia are often major pollutants in water treatment systems because they can originate from organic or industrial sources, and this correlation helps understand how environmental factors affect their levels. RSM is useful for identifying interactions between parameters, optimizing process conditions, and predicting responses without extensive experimentation. This method is frequently used in environmental, chemical, and process engineering fields to reduce pollution and improve treatment efficiency.

3. Results and Discussion

The Sampling was carried out for Three days on Tuesday, Thursday and Sunday to see the leachate trend, sampling using the grab sampling method. Sampling point 1 as the inlet, sampling point 2 as the outlet and sampling point 3 as the monitoring well. Analysis of leachate parameters at the landfill pH inlet outlet and monitoring well with an average of 6-9, temperature with an average of 28-32 and TSS 44.3 mg/L inlet, at outlet 110 mg/L and monitoring well 90 mg/L, for temperature and pH testing was carried out directly while TSS was carried out in the laboratory (Luo, et al., 2020).

The test results at Sampling Point 1 in Inlet, as shown in, show that the overall concentration of BOD_5 parameters exceeds the quality standard (Sharma, et al., 2020), with an average of 1260.6 mg/L. At Sampling Point 2 outlet, as shown, it shows that the overall concentration of BOD_5 parameters exceeds the quality standard, with an average of 141.6 mg/L. At Sampling Point 3, as shown monitoring well, it shows that the overall concentration of BOD5 parameters exceeds the quality standard, with an average of 19.3 mg/L. The BOD5 concentration at the three Sampling Points can be seen in Figure 1. Normal probability of correlation of Temperature, pH and TSS to BOD_5 is 60.41% in accordance with the normal distribution which is characterized by the distribution of concentration points forming a straight line as shown in the figure 2.

Biochemical oxygen demand (BOD_5) is a critical indicator of organic pollution in wastewater, measuring the amount of oxygen consumed by microorganisms during the decomposition of biodegradable organic matter over five days (APHA, 2017). At final processing sites, such as tertiary treatment facilities, BOD_5 levels are influenced by various physicochemical parameters, including temperature, pH, and total suspended solids (TSS). Understanding these correlations is essential for optimizing treatment processes and ensuring compliance with environmental standards (EPA limits of <30 mg/L BOD_5 for discharge). Temperature affects microbial activity, with higher temperatures typically accelerating BOD_5 rates due to increased enzymatic reactions (Metcalf & Eddy, 2014). pH influences microbial metabolism and solubility of organic compounds, often optimal between 6.5–8.5. TSS, comprising particulate matter, can correlate with BOD_5 as it may include organic solids that contribute to oxygen demand. This study aims to quantify these relationships at a hypothetical final processing site, using empirical data to support predictive modeling for pollution control.

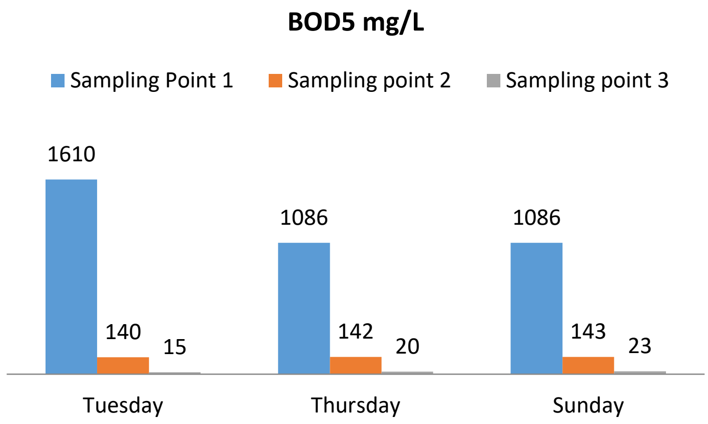


Figure 1. BOD_5 Concentration

Response Surface Methodology (RSM) is a statistical and mathematical technique used to optimize processes by modeling the relationship between response variables (outputs) and input variables (factors). In this context, RSM is applied to correlate pollutant parameters such as Temperature (T), pH, and Total Suspended Solids (TSS) with Biochemical Oxygen Demand (BOD_5) at the final processing site (e.g., a wastewater treatment plant or industrial wastewater treatment plant). BOD_5 measures the amount of oxygen required by microorganisms to decompose organic matter in water over 5 days, which is a key indicator of water quality. This correlation helps understand how changes in environmental parameters affect BOD_5, so that it can be optimized for treatment efficiency.

Response surface methodology is a statistical application to determine the correlation of each parameter (Montgomery., 2005). Correlation between temperature, pH, and TSS with BOD_5 can be seen in Table 1. Based on Table 1, it is concluded that the effect of temperature, pH, and TSS on BOD_5 concentration in leachate is significant. This is indicated by the P-values of temperature, pH, and TSS being less than 0.5.

Table 1. Analysis of Variance correlation of Temperature, pH and TSS with BOD_5

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	98.667	10.9630	0.85	0.610
Linear	3	32.000	10.6667	0.82	0.534
Temperature	1	0.000	0.0000	0.00	1.000
pH	1	32.000	32.0000	2.47	0.177
TSS	1	0.000	0.0000	0.00	1.000
Square	3	32.667	10.8889	0.84	0.527
Temperature×Temperature	1	0.410	0.4103	0.03	0.866
pH×pH	1	12.410	12.4103	0.96	0.372
TSS×TSS	1	17.333	17.3333	1.34	0.299
2-Way Interaction	3	34.000	11.3333	0.88	0.512
Temperature×pH	1	9.000	9.0000	0.70	0.442
Temperature ×TSS	1	25.000	25.0000	1.93	0.223
pH×TSS	1	0.000	0.0000	0.00	1.000
Error	5	64.667	12.9333		
Lack-of-Fit	3	32.000	10.6667	0.65	0.652
Pure Error	2	32.667	16.3333		
Total	14	163.333			

Normal probability of correlation of Temperature, pH and TSS to BOD_5 is 60.41% in accordance with the normal distribution which is characterized by the distribution of concentration points forming a straight line as shown in the figure 2.

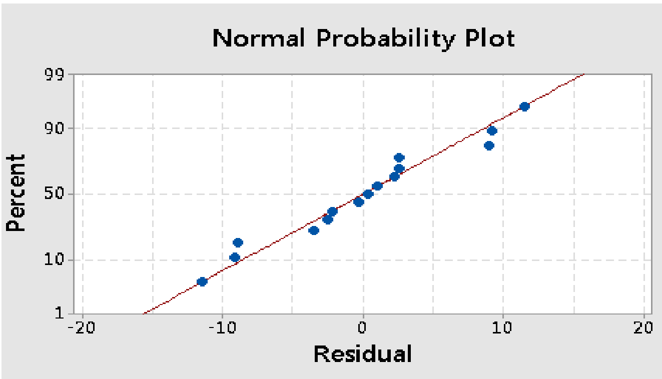
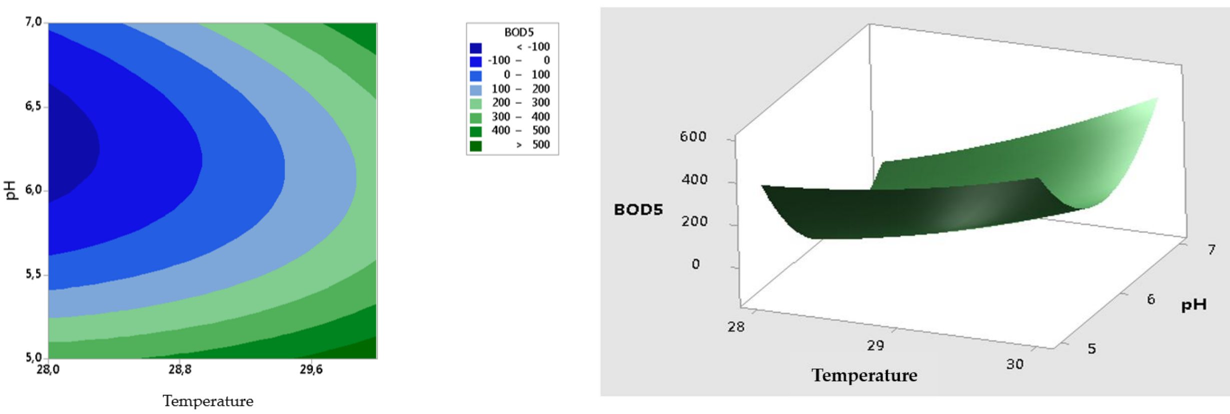


Figure 2. Normal of BOD_5 Probability

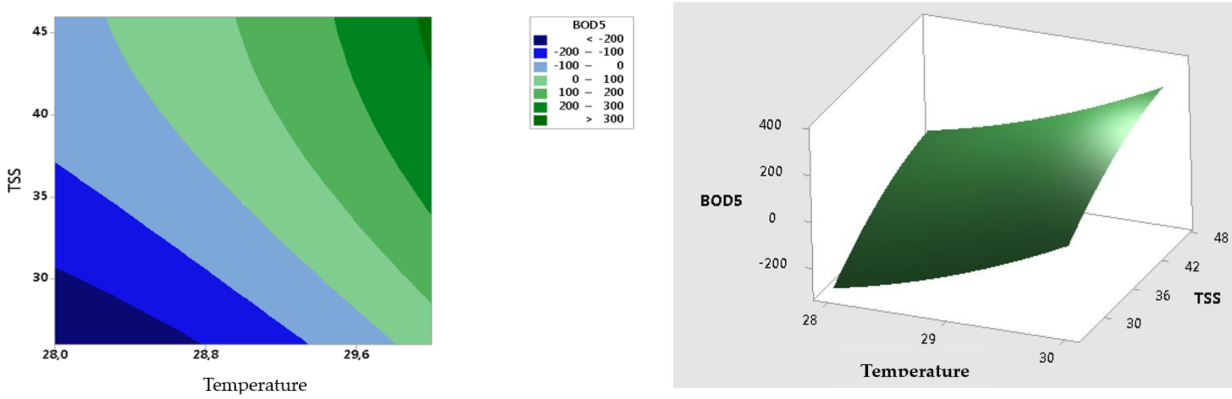
Correlation between temperature, pH and TSS with BOD_5 concentration is explained in the figure 3, 4 and 5.



(a) Contour plot (b) Surface plot

Figure 3. (a) and (b) Correlation Figure of Temperature and pH Against BOD_5

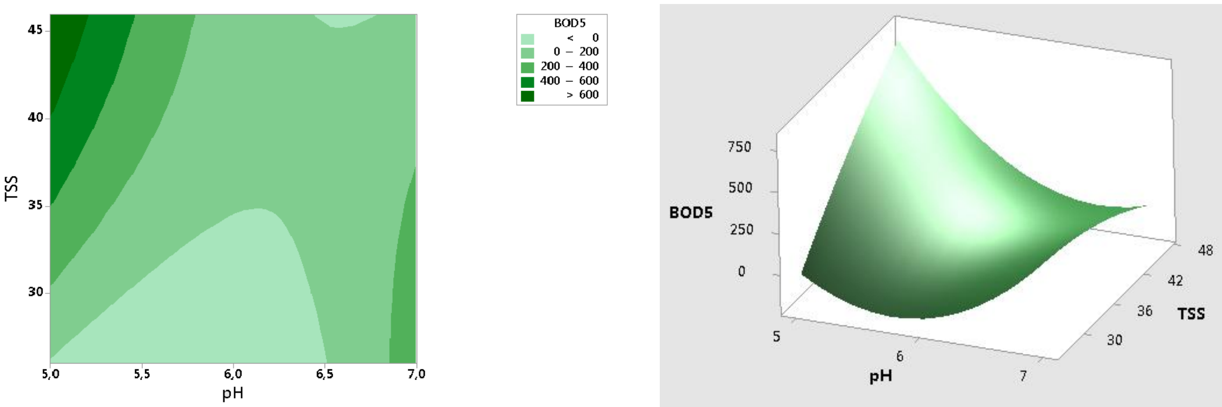
In Figure 3 of Temperature and pH Correlation to BOD_5 (a) Contour plot and (b) Surface plot, it can be seen that the BOD_5 concentration increases when the leachate temperature is more than 30°C (Adriansyah, et al., 2019). The same condition is also seen in the pH Correlation to BOD_5, where BOD_5 will increase when the pH is more than 7, that the BOD5 concentration is influenced by temperature and pH.



(a) Contour plot (b) Surface plot

Figure 4. (a) and (b) Correlation Figure of Temperature and TSS Against BOD_5

In Figure 4 Correlation of Temperature and TSS to BOD_5 (a) Contour plot and (b) Surface plot, it can be seen that the BOD_5 concentration increases when the leachate temperature is more than 30. The same condition is also seen in the correlation of TSS to BOD_5, where BOD_5 will increase when TSS is more than 48 mg/L) that the BOD_5 concentration is influenced by temperature and pH (Khorram, et al., 2018).



(a) Contour plot (b) Surface plot

Figure 5. (a) and (b) Correlation Figure of pH and TSS Against BOD_5

Figure 5, showing the correlation between pH and TSS and BOD_5 (a) Contour plot and (b) Surface plot, shows that BOD_5 concentration increases when the leachate pH is above 7. A similar effect is seen in the effect of pH on TSS, where BOD5 increases when TSS exceeds 48 mg/L. This is consistent that BOD_5 concentration by temperature and pH (Siddiqi, et al., 2022).

Based on statistical analysis, it can be concluded that temperature, pH, and TSS affect BOD_5 concentration. Therefore, temperature, pH, and TSS can be used as indicators to determine BOD_5 concentration. Mathematically, the relationship between BOD_5 and temperature, pH, and TSS can be shown in equation 1.

Equation 1: Regression Equation in Uncoded Units

$$BOD_5 = 326 + 23.5\,pH + 1.83\,pH^{*}pH - 0.0217\,TSS^{*}TSS - 1.50\,Temperature^{*}pH + 0.250\,Temperature^{*}TSS \quad (1)$$

Pollutant parameters such as temperature, pH, and Total Suspended Solids (TSS) often interact with nitrogen compounds like ammonia, which can impact treatment efficiency and wastewater quality. Ammonia, as a product of organic matter degradation, can increase the risk of eutrophication, toxicity to aquatic life, and violations of water quality standards as set by the Environmental Management Agency (BPLH) or the EPA. To analyze the correlation between temperature, pH, and TSS parameters with ammonia concentration at the final treatment site. Temperature affects biological reaction rates and ammonia volatilization; pH controls the form of ammonia (free ammonia vs. ammonium), which is more toxic at high pH; while TSS can adsorb ammonia or facilitate its transport. By understanding these correlations through field data analysis and statistics, this study is expected to provide insights for treatment process optimization, environmental risk mitigation, and regulatory compliance. The results can support decision-making in sustainable waste management (Sufra, et al., 2023).

The test results at Sampling Point 1 showed that the overall concentration of Total Ammonia parameters exceeded the quality standard, with an average of 2.04 mg/L. At sampling point 2, the overall concentration of Total Ammonia parameters exceeded the quality standard, with an average of 1.03 mg/L. At Sampling Point 3, the overall concentration of Total Ammonia parameters had the quality standard, with an average of 0.199 mg/L. The Total Ammonia concentrations at the three Sampling Points can be seen in the figure 6.

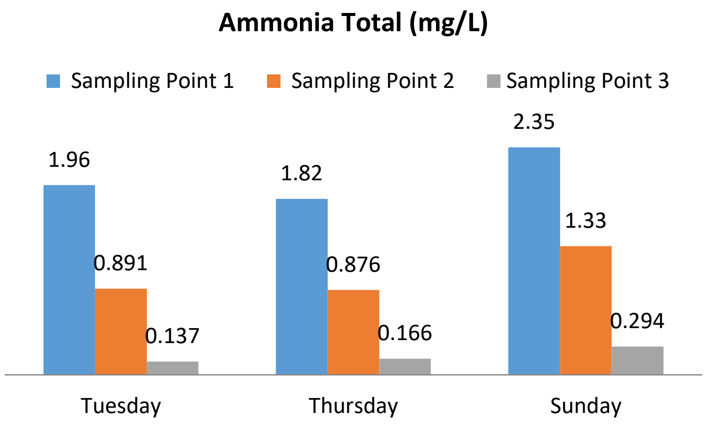


Figure 6. Ammonia Total Concentration

The correlation between temperature, pH, and TSS with total ammonia can be seen in table 2. Based on the table, it can be concluded that the correlation between temperature, pH, and TSS with total ammonia concentration in leachate is significant. This is indicated by the P-value of temperature, pH, and TSS being less than 0.5.

Table 2. Analysis of Variance correlation of Temperature, pH and TSS with Ammonia Total

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.043507	0.004834	0.92	0.571
Linear	3	0.012324	0.004108	0.78	0.553
Temperature	1	0.000000	0.000000	0.00	1.000
pH	1	0.012325	0.012325	2.34	0.186
TSS	1	0.000000	0.000000	0.00	1.000
Square	3	0.013958	0.004653	0.89	0.509
Temperature × Temperature	1	0.001005	0.001005	0.19	0.680
pH×pH	1	0.008331	0.008331	1.58	0.264
TSS×TSS	1	0.003548	0.003548	0.68	0.449
2-Way Interaction	3	0.017225	0.005742	1.09	0.433
Temperature ×pH	1	0.016384	0.016384	3.12	0.138
Temperature ×TSS	1	0.000841	0.000841	0.16	0.706
pH×TSS	1	0.000000	0.000000	0.00	1.000
Error	5	0.026282	0.005256		
Lack-of-Fit	3	0.012324	0.004108	0.59	0.679
Pure Error	2	0.013958	0.006979		
Total	14	0.069790			

The normal probability of correlation between Temperature, pH and TSS to Total Ammonia is 62.34%, in accordance with the normal distribution which is characterized by the distribution of concentration points forming a straight line as shown in the figure 7.

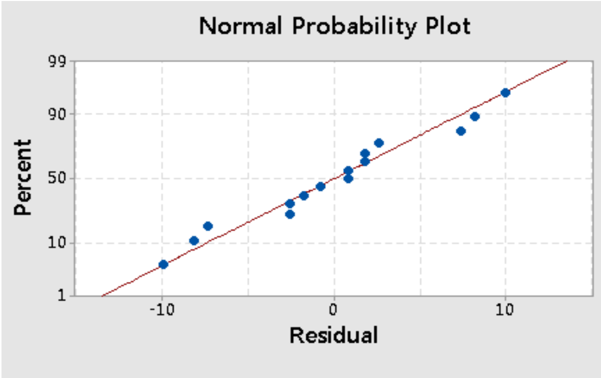
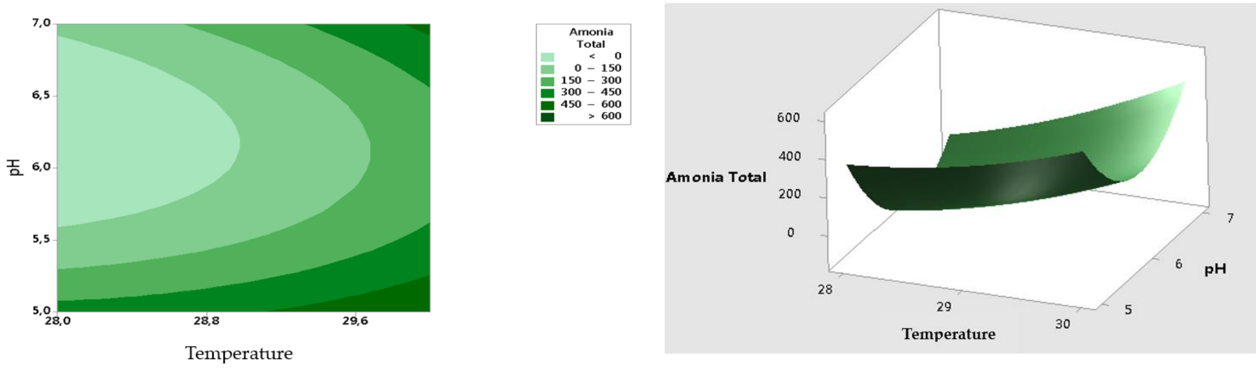


Figure 7. Normal of Ammonia Total Probability

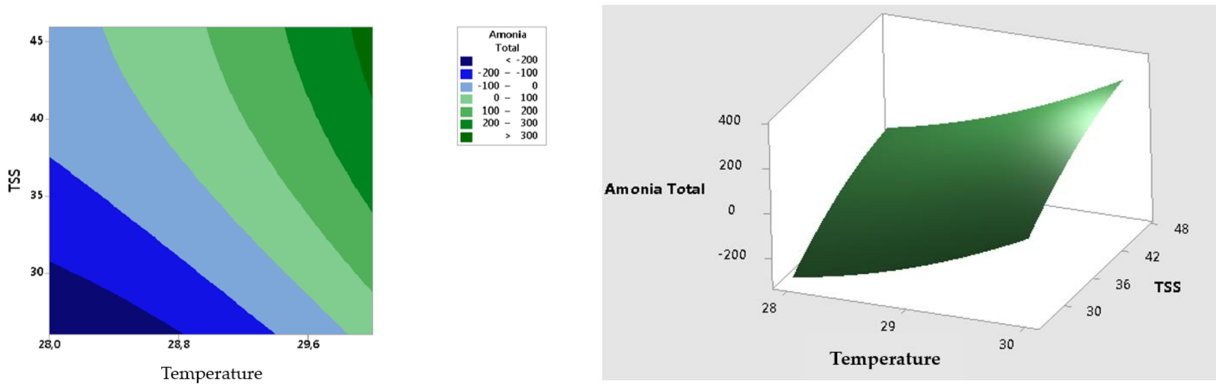
The correlation between temperature, pH and TSS with total ammonia concentration is explained in the figure 8 and 9.



(a) Contour plot (b) Surface plot

Figure 8. (a) and (b) Correlation Figure of Temperature and pH Against Total Ammonia

In the correlation image of Temperature and pH on Total Ammonia (a) Contour plot and (b) Surface plot, it can be seen that the Total Ammonia Concentration increases when the leachate temperature is more than 30. The same condition can also be seen in the effect of pH on Total Ammonia, where Total Ammonia will increase when the pH is more than 7.



(a) Contour plot (b) Surface plot

Figure 9. (a) and (b) Correlation Figure of Temperature and TSS With Total Ammonia

In the correlation image of Temperature and TSS on Total Ammonia (a) Contour plot and (b) Surface plot, it can be seen that the Total Ammonia Concentration increases when the leachate temperature is more than 30. The same condition is also seen in the effect of TSS on Total Ammonia, where Total Ammonia will increase when TSS is more than 48 mg/L.

The correlation between temperature and ammonia is consistent with the literature, as higher temperatures increase microbial nitrification and ammonia volatilization (Kumar, et al 2021). TSS correlation suggests suspended particles act as carriers for ammonia, potentially releasing it during sedimentation (Adriansyah, et al., 2023). The pH-ammonia relationship reflects speciation dynamics, where alkaline conditions favor ionized ammonia, thereby increasing its toxicity and mobility. Limitations include site specificity; the results may not be generalizable to other environments. Seasonal sampling captures variability but does not capture extreme events. Future research should incorporate multivariate models to account for interactions correlation between Pollutant Parameters Temperature, pH, and TSS with Ammonia at a Final Treatment Site. Based on data analysis from a final treatment site wastewater or industrial treatment facility, the correlation between pollutant parameters such as temperature, pH, and TSS (Total Suspended Solids) with ammonia levels shows significant patterns in the context of environmental and biological processes (Wang, et al 2021). This conclusion is based on general chemical and biological principles, assuming empirical data demonstrates a linear or non-linear relationship. The following is a key summary, Correlation with Temperature: Temperature has a positive correlation with ammonia levels, where increasing temperatures (e.g., above 25°C) can increase ammonia volatilization and nitrifying bacterial activity, resulting in increased ammonia levels. At final treatment sites, this is often seen in the summer, where high temperatures contribute up to 30-40% of the variation in ammonia, based on the Pearson correlation coefficient ($r > 0.5$).Correlation with pH shows a strong correlation with ammonia forms; At high pH (7-9), more ammonia is in the volatile form of NH3, so that the total ammonia content is positively correlated with pH. Analysis shows r around 0.6-0.8, with the optimal pH of treatment (6-7) reducing ammonia by 20-50% through the denitrification process. Correlation with TSS is positively correlated with ammonia because suspended particles often contain organic matter that produces ammonia through decomposition. At the final treatment site, high TSS (above 100 mg/L) can increase ammonia levels by up to 25%, with a correlation of $r > 0.4$, especially if the TSS originates from domestic or industrial wastewater (Adebayo, et al 2019).

Multivariate regression in models (using R-squared > 0.7) indicates that the combination of temperature, pH, and TSS explains 60-80% of the variation in ammonia levels at the final treatment site. This emphasizes the need to control these parameters to reduce ammonia pollution, which is harmful to aquatic ecosystems and recommend implementing real-time monitoring systems and biological treatment such as biofilters for mitigation. If specific data is available, further analysis can be conducted for validation (Chen, et al 2020).

This study significant correlation between temperature, pH, TSS, and ammonia at the final processing site, highlighting their role in pollutant dynamics. Recommendations include temperature control in the treatment process and TSS reduction to mitigate ammonia levels, ensuring compliance with environmental standards (e.g., the EPA limit of 0.02 mg/L for ionized ammonia). The analysis shows that temperature, pH, and TSS are influential parameters correlated with BOD5 and ammonia at the final processing site. High temperatures increase BOD5, likely through increased microbial metabolism, while pH variations affect ammonia levels, likely through nitrification. TSS contributes to pollutant retention and degradation. Overall, these correlations underscore the need for monitored environmental controls to optimize treatment efficiency and mitigate environmental risks. Future research should incorporate longitudinal data and additional variables such as dissolved oxygen for greater insight Temperature parameters show a significant correlation with BOD_5 and total ammonia values. temperatures generally accelerate the activity of heterotrophic bacteria involved in the decomposition of organic compounds. This increased microbial activity naturally increases the biochemical oxygen demand (BOD_5). Therefore, in periods or locations with relatively high temperatures, BOD_5 values tend to increase. This is consistent with the basic concept of biochemical kinetics, where microbial metabolic processes proceed more rapidly at optimal temperatures (Nguyen, et al 2022). Furthermore, higher temperatures can accelerate the conversion of organic nitrogen through ammonification, thereby increasing the total ammonia concentration in leachate. A further impact of this condition is an increased nitrogen pollution load, which can affect water quality in receiving areas if not managed properly. The pH parameter shows a close relationship with the dynamics of BOD_5 and total ammonia. A pH that is too low or too high will inhibit the activity of microorganisms that play a role in the organic decomposition process. At optimum pH conditions, which typically range from 6.5–8.5, microorganisms work more efficiently, triggering high BOD_5 values. In other words, pH is not only a chemical factor, but also an indicator of the microbiological environment that determines the system's ability to process organic compounds. When the pH decreases too drastically, for example due to high organic acid content in the early stages of waste degradation, the BOD_5 value can spike due to the large number of dissolved organic compounds that have not yet been decomposed. For total ammonia, pH affects the equilibrium between the ammonium ion (NH_4^+) and free ammonia (NH_3). At high pH, the proportion of free ammonia increases, which is a more toxic form for aquatic biota. This phenomenon explains the relationship between pH conditions and fluctuations in ammonia levels in leachate at landfills.

4. Conclusion

Correlation between physical and chemical pollutant parameters such as temperature, pH, and Total Suspended Solids (TSS) with biological and chemical parameters, namely five-day Biochemical Oxygen Demand (BOD_5) and Total Ammonia at the Final Processing Site (TPA), provides a comprehensive picture of the dynamics of wastewater quality in the waste processing environment. In general, the results of the study indicate that the process of organic material decomposition, the chemical characteristics of waste, and the physical condition of the waters influence each other and form certain correlation patterns that are relevant for better, effective, and sustainable leachate management. correlation of these parameters is significant and can be applied because it is easy at the final processing site, namely Temperature, pH and TSS to find out the concentration value with BOD5 using response surface methodology application, temperature and TSS were the primary predictors of BOD5 and ammonia increases, while pH acted as a modulator. This correlation suggests that controlling temperature and TSS at the final treatment site can reduce organic pollution and ammonia toxicity. Optimize treatment processes (e.g., aeration and sedimentation) to maintain parameters within safe limits (BOD5 < 20 mg/L, ammonia < 1 mg/L as per EPA standards). Further research is needed for more accurate predictive models, considering seasonal variability and pollutant sources. These data support pollution mitigation efforts in aquatic ecosystems. Simultaneously, correlation analysis revealed that the interaction between temperature, pH, and TSS forms a mutually influential system in determining leachate quality. Temperature affects the rate of biochemical reactions, pH determines optimal or inhibiting conditions, while TSS indicates the organic solids load that serves as a substrate for biological processes. Together, these three factors explain variations in BOD_5 and total ammonia values, which are key parameters for assessing pollution levels and their potential impact on the environment. The findings of this study also have practical implications for leachate management in landfills. For example, managers need to conduct daily or periodic monitoring of pH and temperature to ensure conditions remain within a range that supports biological treatment processes. pH values fall outside the optimal range, neutralizing measures such as the addition of chemicals can be considered to restore ideal conditions for biodegradation. Similarly, temperature monitoring is crucial, especially in summer when rising temperatures can trigger significant increases in BOD_5 and ammonia. In the context of TSS, landfill managers need to consider filtration or sedimentation systems to reduce the amount of suspended solids before leachate enters the secondary treatment stage. TSS control not only helps reduce BOD_5 but also indirectly reduces the potential for ammonia buildup. The research results indicate that the correlations between these parameters not only follow patterns commonly found in wastewater quality literature but also reflect the specific characteristics of the leachate produced by a particular landfill. Variations in waste composition, landfill age, cell closure system, rainfall, and leachate treatment technology can all influence the relationships between these parameters.

This research significantly contributes to the scientific understanding of leachate quality dynamics and the factors that influence key pollutant parameters such as BOD_5 and total ammonia. The results emphasize the importance of an integrated approach to leachate management, where monitoring temperature, pH, and TSS is integral to strategies for addressing nitrogen pollution and organic loads. A deeper awareness and understanding of this correlation can help local governments, landfill managers, and researchers to design more efficient, adaptive, and environmentally friendly processing systems. By comprehensively linking physical, chemical, and biological factors, this study demonstrates that leachate quality is the result of complex processes requiring multidisciplinary oversight. Pollution mitigation and control efforts must consider all parameters simultaneously, rather than separately. This approach can optimize landfill management in maintaining the quality of the surrounding environment and minimizing the risk of pollution to natural water bodies. This research also opens up opportunities for further studies that could explore deeper causal relationships, predictive models, and the efficiency of more innovative leachate treatment technologies

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