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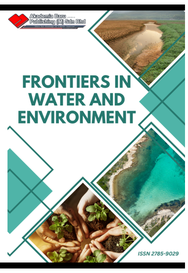

Impacts of Rainfall Variability on Water Quality Parameters in the Setiu River, Malaysia

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ABSTRACT

Water quality status serves as an essential indicator of the river's health and its capacity for beneficial uses, reflecting changes in physical, chemical, and biological factors that are often sensitive to both natural and anthropogenic influences. The Setiu River in Terengganu faces an increasingly critical challenge in understanding the complex relationship between rainfall patterns and water quality dynamics. This study chooses the Setiu River as a case study and aims to address three primary objectives to gain insights into these dynamics: firstly, to examine the relationship between rainfall and water quality across wet and dry seasons; secondly, to analyze seasonal variations in specific water quality parameters in response to differing rainfall patterns; and thirdly, to investigate the relationship between water quality data at upstream and downstream monitoring stations. Rainfall data from the Department of Irrigation and Drainage (DID) and water quality parameter data from the Department of Environment (DOE) for Kampung Buloh and Water Intake Kg Besut stations were analyzed. The results reveal distinct seasonal differences, with correlation analyses showing a significant negative relationship between rainfall and pH during dry seasons, suggesting a dilution effect, and positive correlations between rainfall and NH_3-N, indicating increased ammoniacal nitrogen levels. These findings imply that rainfall exerts substantial seasonal influence on key water quality parameters, with potential implications for ecosystem health, especially under prolonged dry or wet conditions. Nevertheless, a longer duration and more frequent data collection intervals are necessary to capture a comprehensive representation of rainfall's overall effects on river water quality. Future studies should integrate discharge analysis with water quality parameters, which could provide a more detailed understanding of the interactions between rainfall, river flow, and pollution transport. This study contributes valuable knowledge to the broader discourse on river water management, emphasizing the importance of rainfall considerations in riverine health assessments.

1. Introduction

Rivers are essential freshwater sources, supporting agriculture, recreation, irrigation, and industry. River quality reflects its health and utility, as it depends on physical, chemical, and biological

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factors. Globally, river water quality is declining, posing risks to ecosystems and communities [1,2]. Pollution from urban runoff, industrial discharge, and agriculture reaches rivers, affecting biodiversity and human health [3-5]. The Setiu River in Terengganu, Malaysia is a crucial water resource, supporting ecosystems, local livelihoods, irrigation, freshwater aquaculture, and brackish water farming in the Setiu Lagoon [6-9]. Heavy seasonal rainfall in the basin emphasizes the need to understand rainfall's effect on water quality to protect these resources for ecological and human needs [10].

River quality is affected by natural (i.e. geology, soil and climate) and human factors [11]. Hydrological, atmospheric, and geological influences combine with human impacts like mining, waste, and land-use changes [12-14]. Agriculture, for instance, increases nutrient runoff [15] while industry introduces heavy metals [16] and other pollutants [17-20]. Seasonal rain intensifies these issues, especially in tropical areas, where monsoon rains raise sediment, nutrient, and pollutant levels in rivers [21]. Conversely, drier periods may concentrate pollutants due to lower river flow and dilution, highlighting the complexity of managing water quality under varying seasonal conditions [22,23].

However, previous research on rainfall and water quality mainly focused on temperate regions or large rivers, with smaller tropical rivers like the Setiu River less studied [21-25]. Rainfall can affect DO, BOD, COD, pH, and NH3-N, yet these interactions across wet and dry seasons remain unclear. This study aims to fill this gap by analyzing rainfall's effects on water quality in the Setiu River, assessing seasonal and spatial variability, and identifying key indicators that are significantly affected by seasonal changes. Additionally, this study examines water quality at different points along the river to determine whether spatial quality differences align with seasonal changes, offering insights into pollution sources and areas needing targeted management.

Despite extensive research on the relationship between rainfall and water quality in larger river systems and temperate regions, there remains a limited understanding of how rainfall influences water quality in smaller tropical rivers such as the Setiu River [9,26]. Specifically, the seasonal and spatial variations in water quality parameters in these systems are underexplored, leaving critical gaps in knowledge about how rainfall patterns interact with local hydrological and ecological processes [6,27]. Smaller tropical rivers often exhibit unique responses to rainfall due to their catchment characteristics, monsoonal climates, and anthropogenic influences, making them distinct from larger systems [9,17]. Addressing these gaps is essential to better understand and manage the impacts of rainfall on water quality, particularly in regions like Malaysia where these rivers play a vital role in supporting ecological balance and community livelihoods. By investigating rainfall's impact on water quality, this study contributes to river management practices in tropical regions. With Malaysia's high rainfall depths, rainwater is both a resource and a carrier of pollutants [26,27]. Findings will support policy and management strategies for sustaining water quality in wet and dry seasons, allowing adaptable approaches that account for seasonal and spatial variations [9].

Malaysia's DOE monitors river quality through a Water Quality Index (WQI), including DO, BOD, COD, NH_3-N, pH, and TSS. However, this index often lacks the seasonal detail needed for targeted action. Results from this study will complement WQI assessments by clarifying rainfall's influence on Setiu River quality, suggesting adaptive management approaches to mitigate pollution as climate change shifts rainfall patterns. This framework for sustainable river management emphasizes monitoring seasonal water quality changes to protect river ecosystems and communities [28]. Through long-term analysis, the study will contribute to Malaysia's river management, ensuring the Setiu River continues to support ecological and community needs amid environmental challenges.

2. Methodology
2.1 Study Site

The Sungai Setiu is located in the Setiu district of Terengganu, Malaysia, bordered by Besut to the north, Hulu Terengganu to the west, and Kuala Nerus to the south. The river spans a catchment area approximately 52 km in length and 188 km² in total [9] (Figure 1). Sungai Setiu holds significant value for local communities, serving as a crucial source of water for domestic and agricultural use, irrigation, fishing, and wastewater dilution [29] The average daily temperature in Setiu district ranges from 28 to 33°C, with a slight drop after sunset [9]. The river is also significantly affected by seasonal monsoons, experiencing drier conditions during the southwest monsoon from May to September and wetter conditions during the northeast monsoon from November to March [30].

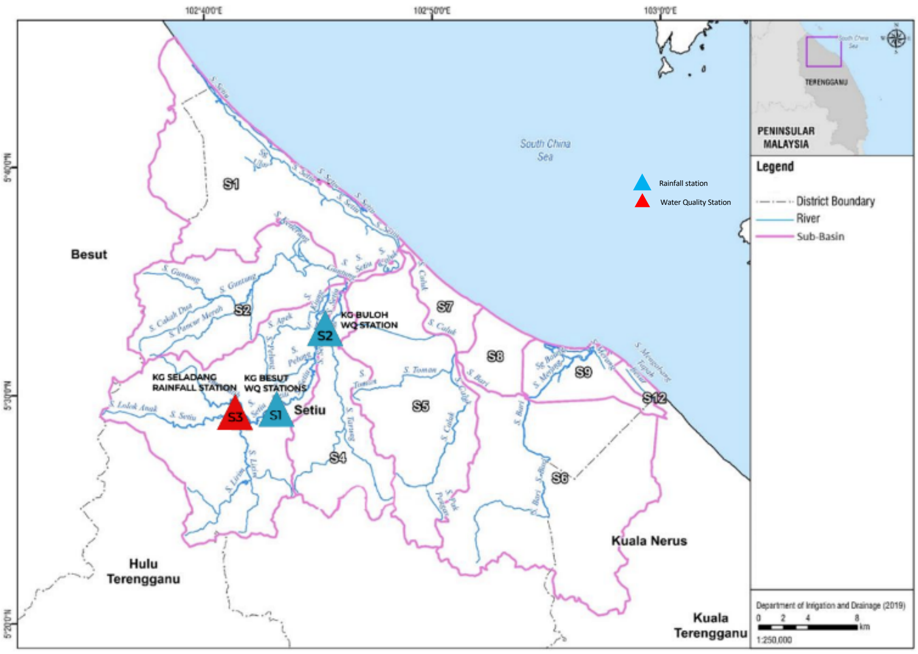


Fig. 1. Rainfall station at Kg. Seladang and water quality station at Kampung Buloh and Water Intake Kampung Besut

1.1 Data Acquisition

Daily rainfall data were obtained from the Department of Irrigation and Drainage (DID) at 0680071RF located in Kg. Seladang, Setiu (5°28'59.32"N, 102°40'37.59"E) (Figure 1). The water quality data were obtained from the Department of Environment (DOE) for two (2) stations, which are 4TSTU004 (Kampung Buloh) 102.744656 N, 5.522247 E and 4TSTU007 (US Water Intake Kampung Besut) 102.708586 N, 5.484308. There were six (6) parameters that acquired from DOE, including Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solid (SS), pH and Ammonia Nitrogen (NH_3-N). All the data were collected bimonthly from January to November for five (5) years during 2018-2022.

2.3 Data analysis

For this study, data analysis included statistical and time series analyses is done to examine rainfall patterns in the Setiu River region. Trend and regression analyses were conducted to determine the relationship between rainfall and key water quality parameters. Additionally, correlation analysis is done to assess seasonal variations in these relationships during dry and wet seasons, while T-test analysis distinguished differences between these seasonal impacts.

3. Results

3.1 Rainfall and Water Quality Trends (2018–2022)

Daily rainfall data for the Setiu River is illustrated in Figure 2. The monthly precipitation data reveal considerable variability over these years. In January 2018, rainfall totalled 694 mm, while 2022 recorded a marked decrease to just 27 mm. February 2022 stands out with an unusually high total of 1,464.5 mm, suggesting a unique meteorological event. From March to June, rainfall amounts fluctuate across the years, with notable peaks in June 2020 reaching 590.5 mm, contrasting with lower totals observed in 2018 and 2022. July and August also exhibit variable patterns, with peak values occurring in 2019 and 2020. September continues this variability, while October consistently records significant rainfall contributions each year. November shows particularly high values, especially in 2018 and 2019, and December concludes with substantial totals, peaking at 1,768 mm in 2022. This diverse pattern highlights the significant influence of monsoon seasons on rainfall distribution, providing essential insights into the seasonal dynamics that impact the Setiu River's water quality.

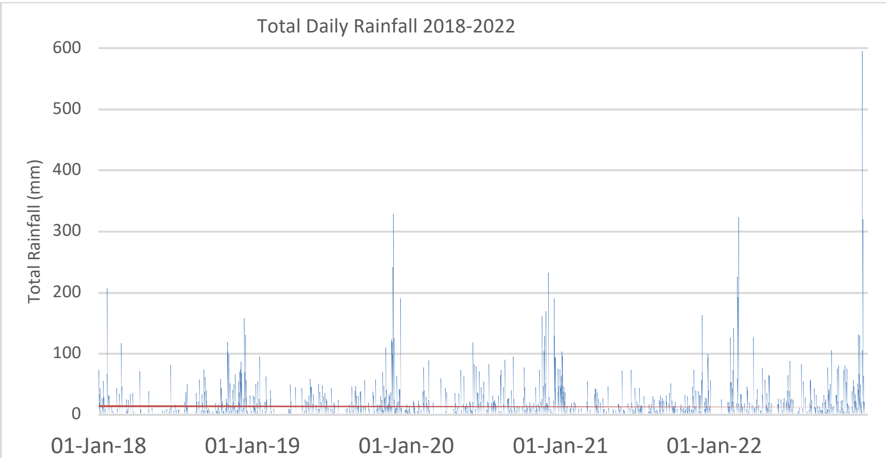


Fig. 2. Daily rainfall (mm) from 2018 to 2022 at Kg. Seladang Station, Setiu, Terengganu with the average shown on the graph

The yearly rainfall data from 2018 to 2022 reveals distinct patterns. Total precipitation in 2018 was 4,393.5 mm, which increased slightly to 4,661.5 mm in 2019. Interestingly, 2020 saw a more significant rise, reaching 5,219 mm. In 2021, rainfall decreased to 3,797 mm. However, 2022 stands out with an extraordinary increase, reaching a peak of 6,859 mm. Table 1 presents annual precipitation statistics from 2018 to 2022, highlighting notable variability in rainfall patterns. In 2018, the mean annual rainfall was 12.10 mm, contributing to a total of 4,393.5 mm. Fluctuations followed in subsequent years, with 2020 reaching a peak mean rainfall of 14.26 mm and a total of 5,219 mm. In contrast, 2021 recorded a lower mean of 10.46 mm, totalling 3,797 mm. The year 2022 stands out as an outlier, with a significantly higher mean rainfall of 19.05 mm and a total of 6,859 mm which is moderate La-Nina year and caused floods in many places in Malaysia [31]. Water quality index was calculated for average of each year from 2018-2022 and both stations shows similar patterns. However, WQI in early years showed slightly lower value for Kg. Buloh station, implying higher pollutants transported to the river during that year (Table 2) (i.e. [32]).

Table 1
Statistical analysis of rainfall data from 2018-2022 (*www.met.gov.my)

Year	N	Mean (mm)	Std. Error	Std. Dev.	Variance	Min (mm)	Max (mm)	Total (mm)	El-Nino/La-Nina*
2018	365	12.10	1.31	24.99	624.71	0	207	4393.5	Moderate El-Nino
2019	365	12.81	1.56	29.78	886.82	0	328.5	4661.5	Moderate El-Nino
2020	366	14.26	1.53	29.19	851.94	0	232.5	5219.0	Moderate La-Nina
2021	365	10.46	0.99	18.91	357.54	0	163.5	3797	Moderate La-Nina
2022	365	19.05	2.50	47.37	2243.56	0	596	6859	Moderate La-Nina

Table 2
Water quality data and classification for both Kg.Buloh and Kg. Besut Stations

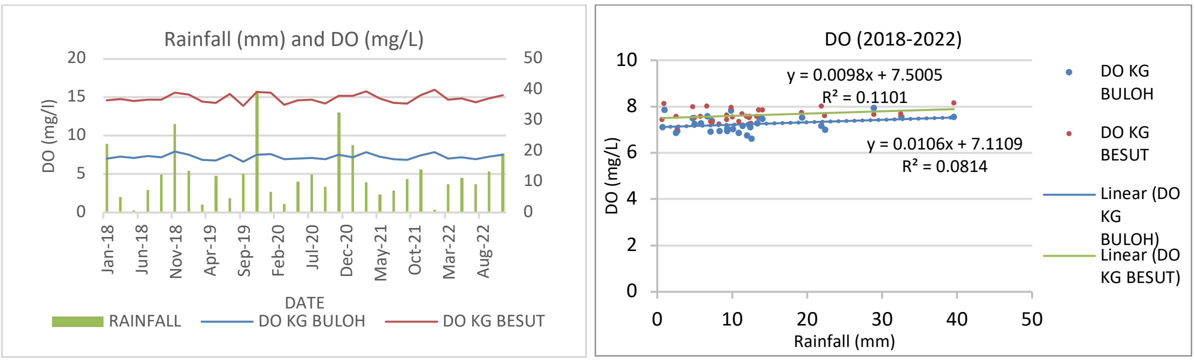
Station	Year	DO (mg/L)	BOD (mg/L)	COD (mg/L)	SS (mg/L)	pH	WQI	Class
Kg. Buloh	2018	7.3	3.5	12.5	127.5	7.2	85	II
	2019	7.1	3.7	12	192	6.7	84.3	II
	2020	7.2	2.6	14.5	184.7	6.7	86.2	II
	2021	7.3		6.2	40.4	6.7	93.5	I
	2022	7.3	1.5	12.7	64	6.6	91.7	I
Kg. Besut	2018	10.1	6.5	13.5	36.5	8.34	90.5	II
	2019	10.4	5.5	12.5	18.5	9.6	94.5	II
	2020	7.5	2.8	14	107.4	6.6	89.2	II
	2021	7.7	1	9.3	80.5	6.8	92.8	I
	2022	7.9	1.3	10.5	25.8	6.7	93.3	I

3.2 Statistical Analysis of Rainfall and Water Quality Parameters in Setiu River
3.2.1 Trend and regression analysis of rainfall and water quality parameters in Setiu River

To assess patterns and relationships between rainfall and water quality parameters, a regression analysis of mean rainfall data with water quality metrics for Setiu River was conducted. The trend of dissolved oxygen (DO) (Figure 3(a)) at both Kg Buloh and Kg Besut stations was analyzed alongside rainfall data collected in January, March, May, July, September, and November during the study period. Results reveal variable DO levels at both locations, with Kg Besut consistently showing slightly higher values than Kg Buloh.

Notably, DO levels display a recurrent increase in November, possibly due to cooler temperatures and increased atmospheric oxygen [33]. Rainfall patterns in November 2019 and 2020 hint at a potential inverse relationship with DO, underscoring the complexity of environmental interactions influenced by precipitation [34]. Additionally, the data indicate a typical seasonal pattern during the Northeast Monsoon (NEM) in February 2018 compared to the inter-monsoon period in April 2018. This seasonal pattern shows higher pH and lower levels of water temperature, DO, and salinity during the NEM, potentially resulting from sediment resuspension and runoff of nutrients and organic matter triggered by river discharge and water column mixing. This effect is higher pronounced during the NEM and lower during the inter-monsoon period [35].

The regression analysis (Figure 3(b)) demonstrated a positive linear trend between mean rainfall (independent variable) and DO (dependent variable) at both stations. The coefficients of determination (R^2) were 0.11 for Kg Besut and 0.08 for Kg Buloh, indicating a moderate yet not strongly significant relationship between mean rainfall and DO levels at both locations.

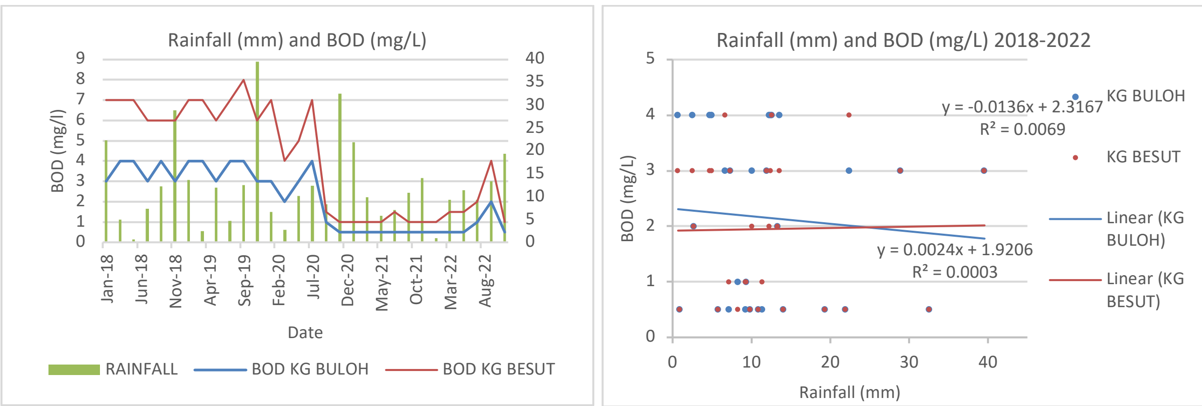


(a) (b)

Fig. 3. (a) Daily Rainfall and DO trend and (b) Linear regression for rainfall and DO

For mean rainfall and biochemical oxygen demand (BOD) (Figure 4(a)), Kg Besut consistently shows lower BOD levels compared to Kg Buloh, indicating potentially better water quality at Kg Besut. Both locations experience fluctuations in BOD, with notable decreases recorded in September 2020 and January 2021. Rainfall patterns appear to influence water quality, with elevated BOD levels observed during months of higher precipitation, particularly in November 2019 and November 2020.

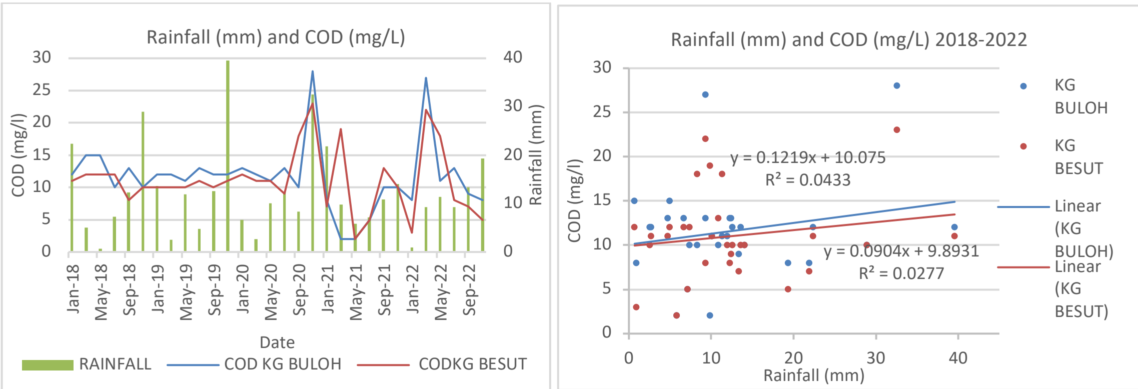
In the regression analysis (Figure 4(b)), a positive linear trend is observed between mean rainfall (independent variable) and BOD (dependent variable) at Kg Besut station, while Kg Buloh station shows a negative linear trend. The coefficients of determination (R^2) are 0.0003 for Kg Besut and 0.0069 for Kg Buloh, indicating an extremely weak and statistically insignificant relationship between rainfall and BOD at both locations. Additionally, most stations recorded high BOD levels alongside low dissolved oxygen (DO) levels, reflecting an inverse relationship between BOD and DO concentrations, as commonly observed in previous studies [36]. This inverse relationship supports established findings that as BOD levels increase due to organic matter decomposition, DO levels tend to decrease, underscoring the oxygen depletion effect in water bodies under increased organic load conditions.



(a) (b)

Fig. 4. (a) Daily Rainfall and BOD trend (b) Linear regression for rainfall and BOD

The trend for mean rainfall and Chemical Oxygen Demand (COD) (Figure 5(a)) reveals distinct patterns, with Kg Besut consistently showing lower COD levels than Kg Buloh. The lowest COD values were recorded in May 2021 at both stations, while the highest COD value (27 mg/L) was observed in March 2022 at Kg Buloh. In the regression analysis (Figure 5(b)), the relationship between mean rainfall (independent variable) and COD (dependent variable) shows a positive linear trend for Kg Besut station and a negative linear trend for Kg Buloh station. The coefficients of determination (R^2) for Kg Besut and Kg Buloh are 0.0277 and 0.0433, respectively, indicating a weak and statistically insignificant relationship between rainfall and COD at both locations. This suggests that as rainfall increases, COD levels tend to decrease due to the dilution effect of leachate on COD concentrations, as supported by findings from [37].



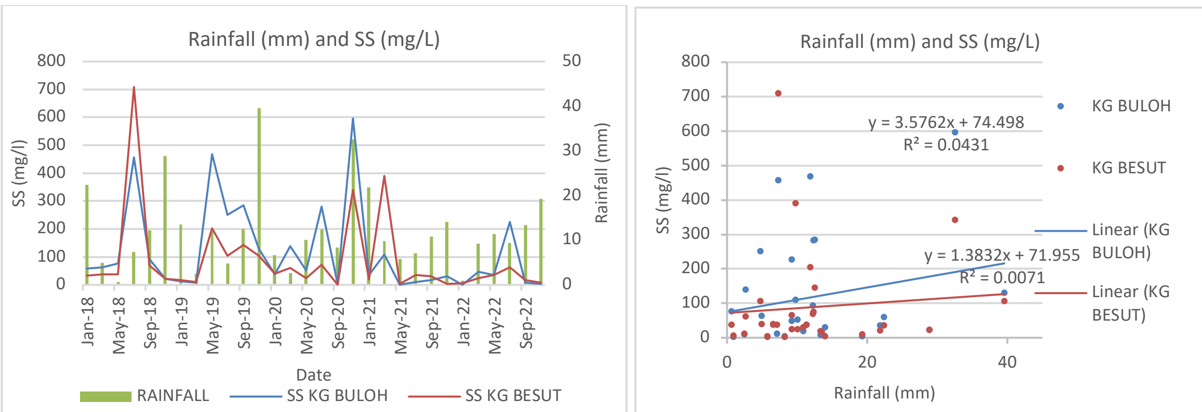
(a) (b)

Fig. 5. (a) Daily Rainfall and COD (b) Linear regression for rainfall and COD

The trend for mean rainfall and Suspended Solids (SS) concentrations (mg/L) (Figure 6(a)) shows that in Kg Buloh, the highest SS concentration occurred in November 2020, reaching 596 mg/L alongside elevated rainfall of 32.53 mm. This peak likely results from increased sediment transport during heavy precipitation events. In contrast, the lowest SS concentration was recorded in January 2019 at 13 mg/L, correlating with moderate rainfall levels.

In Kg Besut, the highest SS concentration was observed in July 2018, reaching 709 mg/L, while the lowest occurred in January 2022 at 5 mg/L, indicating comparatively cleaner water during this period. January 2019 and January 2022, which saw the lowest rainfall, align with the lowest SS concentrations in Kg Buloh and Kg Besut, respectively.

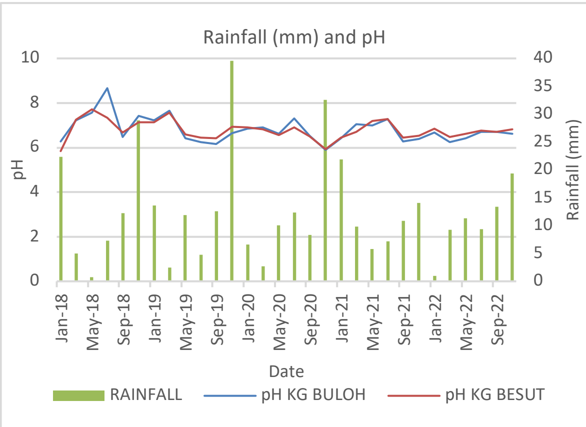
The regression analysis (Figure 6(b)) revealed a positive linear trend between mean rainfall (independent variable) and SS concentrations (dependent variable) for both Kg Buloh and Kg Besut stations. However, the coefficients of determination were low: R^2 for Kg Besut at 0.0071 ($P = 0.657$) and R^2 for Kg Buloh at 0.0431 ($P = 0.271$). These p-values indicate that the linear trendlines based on mean rainfall do not provide statistically significant explanatory power for SS concentrations at either location. This suggests that mean rainfall alone may not be a strong predictor for SS concentrations, indicating a need for additional factors to improve the accuracy of the predictive model.



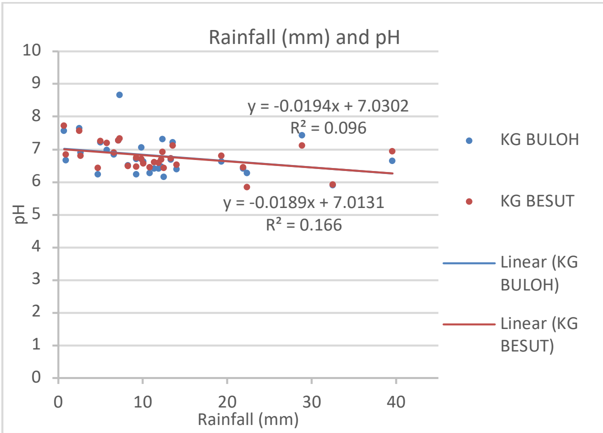
(a) (b)

Fig. 6. (a) Daily Rainfall and SS trend and (b) Linear regression for rainfall and DO

The trend for mean rainfall and pH levels (Figure 7(a)) indicates that in Kg Buloh, pH values range from approximately 5.8 to 8.7, reflecting a broad spectrum of acidity. The lowest pH was recorded in November 2020 at 5.9, while the highest occurred in July 2018 at 8.664. This variation suggests a significant shift in water acidity, potentially influenced by environmental factors such as rainfall or soil (Aizat. In Kg Besut, pH levels fluctuate between approximately 5.7 and 7.7, with the lowest pH observed in January 2018 at 5.8 and the highest in May 2018 at 7.7. The regression analysis (Figure 7(b)) revealed a negative linear relationship between mean rainfall (independent variable) and pH (dependent variable) for both Kg Besut and Kg Buloh stations [10]. The coefficients of determination (R^2) were 0.166 for Kg Besut ($p < 0.025$) and 0.096 for Kg Buloh ($p > 0.096$). This indicates that the relationship between mean rainfall and pH is significant for Kg Besut, suggesting that variations in mean rainfall meaningfully affect pH levels at this station. In contrast, for Kg Buloh, the p-value exceeds 0.05 ($p > 0.096$), indicating that the relationship is not statistically significant at the conventional level. Consequently, the negative correlation between mean rainfall and pH in Kg Buloh may not be strong enough to be deemed significant based on the available data.



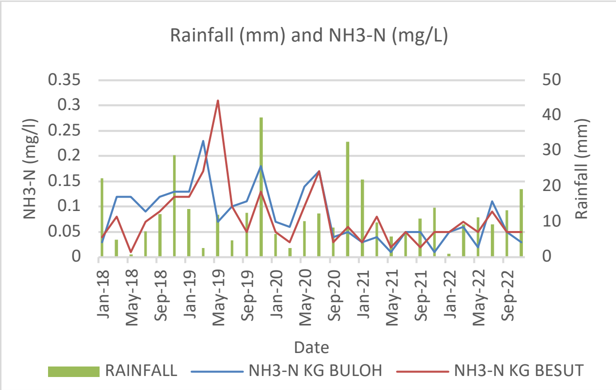
(a)

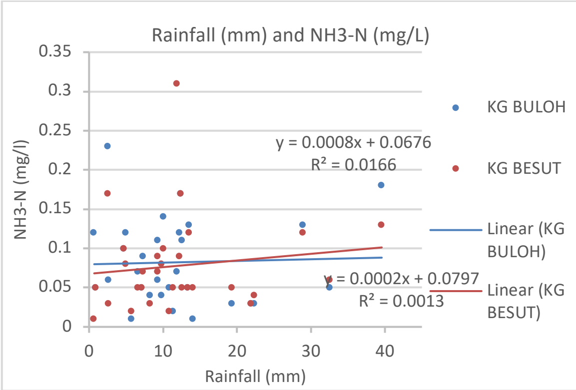


(b)

Fig. 7. (a) Daily Rainfall and pH trend for both station (b) Linear regression for rainfall and pH

The trend for mean rainfall and Ammonia Nitrogen (NH3-N) (Figure 8(a)) showed Both stations show fluctuations in NH_3-N levels over the recorded months. In Kg. Besut, NH_3-N concentrations range from 0.01 to 0.31, while Kg. Buloh ranges from 0.01 to 0.23. Observing the trends, there are noticeable increases in NH_3-N concentrations in certain months, particularly in May 2019 for Kg. Besut and March 2019 for Kg. Buloh. Furthermore, analyzing the dataset for Kg. Buloh, the NH_3-N concentration is generally lower compared to Kg. Besut. Meanwhile, the regression analysis (Figure 8(b)) showed a positive equation with a linear trendline for independent (Mean Rainfall) and dependent (NH_3-N) variables for both Kg. Besut station and Kg. Buloh station. The value of the coefficient of determination, R^2 for Kg. Besut (0.0166), p>0.497 and R^2 for Kg. Buloh (0.096), p>0.850. The relationship between mean rainfall and NH_3-N (Ammonia Nitrogen) levels in water for Kg. Besut and Kg. Buloh stations. For Kg. Besut, the positive equation and a low coefficient of determination (R^2) at 0.0166 indicate a weak correlation. The p-value exceeding 0.497 suggests that this relationship might not be statistically significant, indicating potential fluctuations in NH_3-N levels unrelated to rainfall or the need for a more comprehensive dataset.





(a) (b)

Fig. 8. (a) Daily Rainfall and NH_3-N trend for both station (b) Linear regression for rainfall and NH_3-N

3.2.1 Correlation analysis of rainfall and WQ Parameter in Setiu River based on Seasonal Changes

The correlation analysis of rainfall with six water quality parameters during the dry season at the Kg. Besut station revealed distinct variations. As shown in Table 3 and 4, there is a strong negative correlation of -0.648 between rainfall and pH, indicating that increased rainfall may lead to a decrease in water pH. This phenomenon can be attributed to the dilution effect, where rainwater, being naturally acidic, influences the overall acidity of the water body.

The current study emphasizes the seasonal fluctuations in the physico-chemical characteristics and chlorophyll-a (Chl-a) concentration of the Setiu lagoon estuary, which is impacted by human activities related to agriculture and aquaculture. Data show that during the Northeast Monsoon (NEM) in February 2018, compared to the inter-monsoon season in April 2018, there is a typical seasonal pattern of higher pH and lower water temperature, dissolved oxygen (DO), and salinity. This pattern may be linked to the resuspension of sediments and runoff of nutrients and organic material caused by river discharge and water column mixing, which is more pronounced during the NEM and less so during the inter-monsoon season [35,38].

Additionally, rainfall positively correlates with ammonia nitrogen (NH3-N) at 0.373. This finding is consistent with research by [37], which suggests that the concentration of ammonia nitrogen in the Sungai Setiu Basin is primarily due to point source discharges, including household and organic waste from nearby agricultural activities. At high concentrations, ammonia nitrogen is considered toxic to aquatic life, implying that increased precipitation may enhance the presence of NH3-N in water.

Dissolved oxygen (DO) exhibits negative correlations with various factors, including rainfall, chemical oxygen demand (COD), suspended solids (SS), and pH. This suggests that increased rainfall, along with elevated levels of COD and SS, is associated with reduced DO levels. These findings are crucial for assessing water quality, as low DO can adversely impact aquatic ecosystems and indicate potential pollution.

Interestingly, there is a positive correlation of 0.134 between biochemical oxygen demand (BOD) and DO, suggesting a parallel increase in both parameters. This unexpected relationship warrants further investigation, as it challenges conventional expectations that BOD and DO are inversely related. Previous research by [40] supports the idea that BOD concentration is typically inversely proportional to DO concentrations, a phenomenon observed in many previous studies [37]

Furthermore, the positive correlation of 0.413 between BOD and NH3-N suggests a potential synergy between organic pollutants and ammonium nitrogen levels in water bodies, indicating that these substances may co-occur during pollution events along the stream. This finding aligns with the work of [41]. A strong positive correlation of 0.453 between SS and BOD highlights the close association between suspended solids and organic pollutants, suggesting that the presence of one can serve as an indicator for the other. This relationship is attributed to the capacity of suspended solids to adsorb organic matter and microorganisms [42].

Table 3
Correlation of rainfall and water quality parameter during dry season at Kg Besut Station

Variables	RAINFALL	DO	BOD	COD	SS	pH	NH_3-N
RAINFALL	**1**	-0.093	0.027	0.027	-0.048	**-0.648**	0.373
DO	-0.093	**1**	0.134	-0.102	-0.230	-0.210	0.288
BOD	0.027	0.134	**1**	-0.020	0.453	0.058	0.413
COD	0.027	-0.102	-0.020	**1**	0.101	-0.336	-0.082
SS	-0.048	-0.230	0.453	0.101	**1**	0.238	0.211
pH	**-0.648**	-0.210	0.058	-0.336	0.238	**1**	-0.246
NH3-N	0.373	0.288	0.413	-0.082	0.211	-0.246	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 4
Correlation of rainfall and water quality parameter during dry season (P Value) at Kg Besut Station

Variables	RAINFALL	DO	BOD	COD	SS	pH	NH_3-N
RAINFALL	**0**	0.752	0.928	0.926	0.870	**0.012**	0.189
DO	0.752	**0**	0.648	0.729	0.429	0.472	0.318
BOD	0.928	0.648	**0**	0.945	0.104	0.843	0.143
COD	0.926	0.729	0.945	**0**	0.730	0.240	0.781
SS	0.870	0.429	0.104	0.730	**0**	0.414	0.469
pH	**0.012**	0.472	0.843	0.240	0.414	**0**	0.397
NH3-N	0.189	0.318	0.143	0.781	0.469	0.397	**0**

At the Kg. Buloh station, different variations in water quality parameters are also observed. As shown in Table 5 and 6, there is a negative correlation of -0.349 between rainfall and dissolved oxygen (DO), suggesting that increased rainfall may lead to a reduction in DO levels. Extended wet periods typically have more direct negative effects on DO than indirect ones, with greater rainfall associated with decreased DO levels. The timing of DO measurements is particularly crucial, as respiration predominates during the night, while photosynthesis raises DO levels during midday [43]. Conversely, the positive correlation of 0.133 between DO and biochemical oxygen demand (BOD) indicates a modest association between higher DO levels and increased organic pollution. This finding aligns with previous research by [40], which highlighted that BOD concentrations are generally inversely proportional to DO concentrations, a phenomenon documented in numerous studies [37]. BOD exhibits strong positive correlations with chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N), with correlation coefficients of 0.658 and 0.803, respectively. These robust relationships suggest a close link between the presence of organic pollutants and concentrations of both COD and NH_3-N in water bodies, which is critical for pollution management and environmental conservation efforts [44].

The positive correlation of 0.731 between COD and NH_3-N further emphasizes the interdependence of these two parameters, indicating that factors influencing one may also impact the other. This association is particularly relevant for assessing the potential sources and impacts of nitrogen compounds in water. The correlation matrix also reveals interesting patterns between physical and chemical variables. For instance, the positive correlation of 0.510 between suspended solids (SS) and pH suggests that as SS levels increase, the water tends to become more alkaline. This unexpected finding warrants further investigation into the mechanisms influencing water pH at varying suspended solid concentrations. Previous studies, including those by [45] and [46] have also noted significant relationships between total suspended solids and turbidity. Interestingly, while the relationship between total suspended solids and pH diminished in the physicochemical model, it re-emerged when bacteriological factors and heavy metals were considered [16]. Higher total suspended solid values indicated a favorable pH range for water quality [47].

Table 5
Correlation of rainfall and water quality parameter during dry season at Kg Buloh Station

Variables	Rainfall	DO	BOD	COD	SS	pH	NH_3-N
Rainfall	**1**	-0.349	-0.031	0.053	0.131	-0.417	0.033
DO	-0.349	**1**	0.133	-0.062	-0.077	0.370	-0.016
BOD	-0.031	0.133	**1**	**0.658**	**0.564**	0.117	**0.803**
COD	0.053	-0.062	**0.658**	**1**	0.376	-0.117	**0.731**
SS	0.131	-0.077	**0.564**	0.376	**1**	0.269	0.510
pH	-0.417	0.370	0.117	-0.117	0.269	**1**	0.200
NH3-N	0.033	-0.016	**0.803**	**0.731**	0.510	0.200	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 6
Correlation of rainfall and water quality parameter during dry season (P Value) at Kg Buloh Station

Variables	Rainfall	DO	BOD	COD	SS	pH	NH_3-N
Rainfall	**0**	0.222	0.915	0.858	0.654	0.138	0.912
DO	0.222	**0**	0.649	0.834	0.793	0.193	0.957
BOD	0.915	0.649	**0**	**0.011**	**0.036**	0.691	**0.001**
COD	0.858	0.834	**0.011**	**0**	0.185	0.692	**0.003**
SS	0.654	0.793	**0.036**	0.185	**0**	0.353	0.062
pH	0.138	0.193	0.691	0.692	0.353	**0**	0.492
NH3-N	0.912	0.957	**0.001**	**0.003**	0.062	0.492	**0**

3.3 Correlation Analysis of Rainfall and WQ Parameter in Setiu River during wet season

The correlation analysis of rainfall with six water quality parameters during the wet season at Kg. Besut station revealed significant variations. One notable finding in Table 7 and 8 is the strong negative correlation of -0.648 between rainfall and pH. This suggests that increased rainfall is associated with a decrease in water pH, likely due to the dilution effect of rainwater, which is naturally more acidic and influences the overall acidity of the water body. Such a relationship underscores the importance of understanding how weather patterns impact water quality and acidity. Negative correlations were also observed between dissolved oxygen (DO) and rainfall, chemical oxygen demand (COD), suspended solids (SS), and pH, with correlation coefficients of -0.093, -0.102, -0.230, and -0.210, respectively. These results indicate that higher levels of DO are linked to lower rainfall, reduced COD, lower SS, and less acidic conditions. This aligns with the general understanding that rainfall and pollutants can negatively affect DO levels in water bodies.

Biochemical oxygen demand (BOD) shows positive correlations with DO (0.134), COD (0.058), SS (0.453), and ammonia nitrogen (NH_3-N) (0.413). The positive association with DO is unexpected and warrants further investigation. However, the positive correlations with COD, SS, and NH_3-N suggest a cohesive relationship among organic pollutants, suspended solids, and ammonium nitrogen concentrations in the water. Understanding these connections is essential for assessing the overall pollution load in water bodies. The correlation matrix also reveals intriguing relationships between SS and other variables. The positive correlation of SS with BOD (0.453) highlights the simultaneous presence of organic pollutants and suspended solids. Additionally, the positive correlation of SS with pH (0.238) indicates that as SS levels increase, the water tends to become more alkaline. These interconnections emphasize the need for a holistic approach to water quality management that considers both chemical and physical aspects.

Table 7
Correlation of rainfall and water quality parameter during wet season at Kg Besut Station

Variables	Rainfall	DO	BOD	COD	SS	pH	NH_3-N
Rainfall	**1**	-0.093	0.027	0.027	-0.048	**-0.648**	0.373
DO	-0.093	**1**	0.134	-0.102	-0.230	-0.210	0.288
BOD	0.027	0.134	**1**	-0.020	0.453	0.058	0.413
COD	0.027	-0.102	-0.020	**1**	0.101	-0.336	-0.082
SS	-0.048	-0.230	0.453	0.101	**1**	0.238	0.211
pH	**-0.648**	-0.210	0.058	-0.336	0.238	**1**	-0.246
NH3-N	0.373	0.288	0.413	-0.082	0.211	-0.246	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 8
Correlation of rainfall and water quality parameter during wet season (P Value) at Kg Besut Station

Variables	Rainfall	DO	BOD	COD	SS	pH	NH_3-N
Rainfall	**0**	0.752	0.928	0.926	0.870	**0.012**	0.189
DO	0.752	**0**	0.648	0.729	0.429	0.472	0.318
BOD	0.928	0.648	**0**	0.945	0.104	0.843	0.143
COD	0.926	0.729	0.945	**0**	0.730	0.240	0.781
SS	0.870	0.429	0.104	0.730	**0**	0.414	0.469
pH	**0.012**	0.472	0.843	0.240	0.414	**0**	0.397
NH3-N	0.189	0.318	0.143	0.781	0.469	0.397	**0**

At Kg. Buloh station, the correlation analysis reveals different variations, as shown in Table 9 and 10. A notable finding is the negative correlation of -0.349 between rainfall and dissolved oxygen (DO), indicating that increased rainfall is associated with decreased DO levels. This relationship may be attributed to the introduction of contaminants into water bodies during heavy rainfall, adversely affecting the oxygen availability crucial for aquatic life.

Conversely, the positive correlation of 0.133 between DO and biochemical oxygen demand (BOD) presents an intriguing dynamic. Typically, one might expect higher dissolved oxygen levels to coincide with lower levels of organic pollutants; however, this finding suggests a more complex interaction between these variables.

BOD shows strong positive correlations with chemical oxygen demand (COD) and ammonium nitrogen (NH3-N) at 0.658 and 0.803, respectively. These robust associations highlight the close connection between organic pollutants and both COD and NH3-N concentrations. The interdependence of COD and NH3-N is further demonstrated by the positive correlation of 0.731 between these two indicators, indicating a shared fluctuation that is vital for understanding the origins and potential impacts of nitrogen compounds in water bodies.

Additionally, the correlation matrix reveals interesting patterns between physical and chemical variables. The positive correlation of 0.510 between suspended solids (SS) and NH3-N suggests a potential link between the presence of suspended solids and higher concentrations of ammonium nitrogen. This association may offer insights into the transport of nutrients within the water system, further informing water quality management strategies.

Table 9
Correlation of rainfall and water quality parameter during wet season at Kg Buloh Station

Variables	Rainfall	DO	BOD	COD	SS	pH	NH_3-N
Rainfall	**1**	-0.349	-0.031	0.053	0.131	-0.417	0.033
DO	-0.349	**1**	0.133	-0.062	-0.077	0.370	-0.016
BOD	-0.031	0.133	**1**	**0.658**	**0.564**	0.117	**0.803**
COD	0.053	-0.062	**0.658**	**1**	0.376	-0.117	**0.731**
SS	0.131	-0.077	**0.564**	0.376	**1**	0.269	0.510
pH	-0.417	0.370	0.117	-0.117	0.269	**1**	0.200
NH3-N	0.033	-0.016	**0.803**	**0.731**	0.510	0.200	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 10
Correlation of rainfall and water quality parameter during wet season (P Value) at Kg Buloh Station

Variables	Rainfall	DO	BOD	COD	SS	pH	NH_3-N
Rainfall	**0**	0.222	0.915	0.858	0.654	0.138	0.912
DO	0.222	**0**	0.649	0.834	0.793	0.193	0.957
BOD	0.915	0.649	**0**	**0.011**	**0.036**	0.691	**0.001**
COD	0.858	0.834	**0.011**	**0**	0.185	0.692	**0.003**
SS	0.654	0.793	**0.036**	0.185	**0**	0.353	0.062
pH	0.138	0.193	0.691	0.692	0.353	**0**	0.492
NH3-N	0.912	0.957	**0.001**	**0.003**	0.062	0.492	**0**

3.4 T-test Analysis of WQ Parameter in Setiu River based on Seasonal Changes
3.4.1 T-test Analysis of Rainfall and WQ Parameter in Setiu River for Kg. Buloh Station based on seasonal changes

A T-test analysis was conducted to determine the mean differences of water quality (WQ) parameters in the Setiu River for Kg. Buloh station between dry and wet seasons (Table 11). The T-test for paired samples assessing the difference between the means of "DO Wet" and "DO Dry" yielded a 95% confidence interval of (0.136, 0.735). The observed t-value was 3.294, which exceeds the critical value of 2.262, and the p-value was 0.009, which is less than the alpha level of 0.05. Consequently, the null hypothesis (H0), stating that the difference between the means is equal to 0, is rejected in favor of the alternative hypothesis (Ha), indicating a significant difference between the DO levels in wet and dry conditions. This suggests that DO levels are significantly higher during the wet season. Seasonal stratification due to temperature variations in water density may contribute to these higher DO levels during rainy periods [48]

The T-test for paired samples comparing "BOD Wet" and "BOD Dry" produced a 95% confidence interval of [-0.944, -0.156]. The observed t-value was -3.161, surpassing the critical value of -2.262, with a p-value of 0.012, which is less than 0.05. Thus, the null hypothesis is rejected, suggesting a significant difference in BOD levels, with "BOD Wet" being significantly higher than "BOD Dry." This increase in BOD during the wet season is likely due to rainfall washing organic materials off the land [9]

The T-test assessing the difference between "COD Wet" and "COD Dry" showed a 95% confidence interval of [-3.200, 5.800]. The observed t-value was 0.654, which is lower than the critical value of 2.262, and the p-value was 0.530, greater than 0.05. Therefore, there is insufficient evidence to reject the null hypothesis, indicating that the difference in COD levels between wet and dry conditions is not statistically significant.

The T-test for "SS Wet" and "SS Dry" revealed a 95% confidence interval of [-263.695, 122.795]. The observed t-value was -0.825, which is below the critical value of 2.262, and the p-value was 0.431, exceeding the alpha level of 0.05. Hence, there is insufficient evidence to reject the null hypothesis, suggesting that the difference in SS levels between wet and dry conditions is not statistically significant.

The T-test comparing "pH Wet" and "pH Dry" produced a 95% confidence interval of [-0.900, 0.521]. The observed t-value was -0.602, which is lower than the critical value of 2.262, and the p-value was 0.562, greater than 0.05. Therefore, there is insufficient evidence to reject the null hypothesis, indicating that the difference in pH levels between wet and dry conditions is not statistically significant.

The T-test for "NH3-N Wet" and " NH3-N Dry" yielded a 95% confidence interval of [-0.054, 0.018]. The observed t-value was -1.142, below the critical value of 2.262, and the p-value was 0.283, which is greater than 0.05. Consequently, there is insufficient evidence to reject the null hypothesis, suggesting that the difference in NH3-N levels between wet and dry conditions is not statistically significant.

Overall, the analysis highlights significant differences in DO and BOD levels between wet and dry seasons, while COD, SS, pH, and NH3-N levels show no statistically significant variations.

Table 11
T-test analysis of water quality parameter during dry and wet season at Kg. Buloh Station

Parameter	Mean	T	P (2-tailed)
DO (mg/l) Dry	0.735	3.294	0.009
DO (mg/l) Wet	0.136		
BOD (mg/l) Dry	-0.156	-3.161	0.012
BOD (mg/l) Wet	-0.944		
COD (mg/l) Dry	5.800	0.654	0.530
COD (mg/l) Wet	-3.200		
SS (mg/l) Dry	122.795	-0.825	0.431
SS (mg/l) Wet	-263.695		
pH (mg/l) Dry	0.521	-0.602	0.562
pH (mg/l) Wet	-0.900		
NH3-N (mg/l) Dry	0.018	-1.142	0.283
NH3-N (mg/l) Wet	-0.054		

3.4.2 T-test analysis of rainfall and WQ Parameter in Setiu River for Kg. Besut Station

A T-test analysis was conducted to determine the mean differences of water quality (WQ) parameters in the Setiu River for Kg. Besut station between dry and wet seasons (Table 12). The T-test for paired samples comparing "DO Wet" and "DO Dry" revealed a 95% confidence interval of [0.195, 0.619]. The observed t-value was 4.341, which is greater than the critical value of 2.262, and the p-value was 0.002, lower than the alpha level of 0.05. This provides sufficient evidence to reject the null hypothesis (H0), indicating that the difference in DO levels between wet and dry conditions is statistically significant. The higher DO levels during the rainy season may be attributed to seasonal stratification resulting from variations in water density [49]

The T-test assessing the means of "BOD Wet" and "BOD Dry" showed a 95% confidence interval of [-0.668, 0.568]. The observed t-value was -0.183, which is less than the critical value of 2.262, and the p-value was 0.859, exceeding the alpha level of 0.05. Therefore, there is insufficient evidence to reject the null hypothesis, suggesting that the difference in BOD levels between wet and dry conditions is not statistically significant. Any observed discrepancy is likely due to random chance, and the alternative hypothesis (Ha) is not supported.

The T-test for "COD Wet" and "COD Dry" resulted in a 95% confidence interval of [-2.071, 2.271]. The observed t-value was 0.104, significantly lower than the critical value of 2.262, with a p-value of

0.919, which is much higher than 0.05. This indicates no compelling evidence to reject the null hypothesis, suggesting that the difference in COD levels between wet and dry conditions is not statistically significant. Any observed discrepancy is likely due to random chance, and the alternative hypothesis (Ha) is not supported.

The T-test comparing "SS Wet" and "SS Dry" yielded a 95% confidence interval of [-241.749, 110.649]. The observed t-value was -0.842, which is lower than the critical value of 2.262, and the p-value was 0.422, exceeding the alpha level of 0.05. Consequently, there is insufficient evidence to reject the null hypothesis, indicating that the observed difference in SS levels between wet and dry conditions is not statistically significant. Any observed variation may be due to random chance, and the alternative hypothesis (Ha) is not supported.

The T-test investigating the difference between "pH Wet" and "pH Dry" produced a 95% confidence interval of [-0.584, 0.381]. The observed t-value was -0.475, which is lower than the critical value of 2.262, and the p-value was 0.646, greater than the alpha level of 0.05. Therefore, there is insufficient evidence to reject the null hypothesis, suggesting that the observed difference in pH levels between wet and dry conditions is not statistically significant, and any observed variation may be due to random chance. The alternative hypothesis (Ha) is not supported.

The T-test comparing " NH_3-N Wet" and " NH_3-N Dry" resulted in a 95% confidence interval of [-0.041, 0.037]. The observed t-value was -0.116, which is lower than the critical value of 2.262, and the p-value was 0.910, exceeding the alpha level of 0.05. Thus, there is insufficient evidence to reject the null hypothesis, suggesting that the observed difference in NH_3-N levels between wet and dry conditions is not statistically significant, with any observed variation likely due to random chance. The alternative hypothesis (Ha) is not supported. In summary, the analysis indicates a statistically significant difference in DO levels between wet and dry seasons, while BOD, COD, SS, pH, and NH_3-N levels do not exhibit significant variations between the two conditions.

Table 12
T-test analysis of water quality parameter during dry and wet season at Kg. Besut Station

Parameter	Mean	T	P (2-tailed)
DO (mg/l) Dry	0.619	4.341	0.002
DO (mg/l) Wet	0.195		
BOD (mg/l) Dry	0.568	-0.183	0.859
BOD (mg/l) Wet	-0.668		
COD (mg/l) Dry	2.271	0.104	0.919
COD (mg/l) Wet	-2.071		
SS (mg/l) Dry	110.649	-0.842	0.422
SS (mg/l) Wet	-241.749		
pH (mg/l) Dry	0.381	-0.602	0.562
pH (mg/l) Wet	-0.584		
NH3-N (mg/l) Dry	0.018	-1.142	0.283
NH3-N (mg/l) Wet	-0.054		

Seasonal variations in the Setiu River have significant ecological implications, particularly in how they influence aquatic life and ecosystem services. Changes in water quality parameters, such as dissolved oxygen (DO), pH, and nutrient concentrations, directly affect the habitat conditions for aquatic organisms, including fish, invertebrates, and microorganisms [9,50]. For instance, lower DO levels during the wet season, associated with increased rainfall and pollutant runoff, can create hypoxic conditions that threaten sensitive aquatic species [51,52]. Conversely, higher DO levels in the dry season may support more robust ecological functions but could also lead to stratification, altering nutrient cycling [19]. These variations not only impact biodiversity but also disrupt ecosystem services, such as fisheries, water purification, and nutrient regulation, which are essential for the livelihoods of local communities [9]. Understanding these dynamics is critical for developing targeted conservation strategies and sustainable water resource management practices that maintain the ecological balance and functionality of the Setiu River [28,53].

4. Conclusions

This study deeply investigated the relationship between rainfall variability and water quality parameters in the Setiu River, Setiu, over the period from 2018 to 2022. The results highlighted distinct patterns and relationships observed during both the dry and wet seasons. Notably, dissolved oxygen (DO) levels at Kg Buloh and Kg Besut demonstrated variability, with a consistent increase in November likely linked to cooler temperatures and enhanced atmospheric oxygen levels. Correlation analyses revealed strong negative correlations between rainfall and pH, indicating a dilution effect, as well as positive correlations between rainfall and ammonium nitrogen (NH_3-N) during the dry season. Conversely, the wet season showed negative correlations between DO and various factors, underscoring the adverse effects of increased rainfall and associated pollutants on oxygen levels. Interestingly, the observed positive correlations between biochemical oxygen demand (BOD) and DO challenge conventional expectations, suggesting a need for further exploration into their complex interaction. T-test analyses for Kg Buloh and Kg Besut stations confirmed significant differences in DO levels between wet and dry conditions, with wet periods favoring higher DO levels. However, the variations in BOD, chemical oxygen demand (COD), suspended solids (SS), pH, and NH_3-N between seasons were inconclusive, indicating different responses to seasonal changes. To address these findings, several proactive steps can be taken to enhance water quality management. Recommendations include extending the duration of future research and reducing interval times between sampling, while integrating methodologies such as multivariate analyses and field experiments to better establish causative relationships between rainfall and water quality parameters. This approach can lead to a deeper understanding of the interactions between rainfall variability and water quality parameters in the Setiu River.

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