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Short-Term Water Quality Assessment at a Monsoon-Affected Caged Fish Farming Site in Malaysia: A Case Study

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Aquaculture in Malaysia is widely practiced to increase production and meet market demand, but its sustainability depends heavily on water quality, which influences fish health and growth. This study evaluated the water quality of a river system used for caged aquaculture, focusing on compliance with Malaysia's Department of Environment (DOE) Class III standards for tolerant, economically valuable species. Water samples were collected from three stations over three consecutive months (December, January and February). Key physicochemical parameters measured included temperature, pH, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solids (TSS). Heavy metals, including aluminium and iron, were also quantified. Pearson correlation and the Kaiser–Meyer–Olkin (KMO) test were used to assess parameter relationships and sampling adequacy. Results showed that temperature and pH fell within Class III limits, while DO was frequently below the recommended 3–5 ppm range, indicating potential oxygen stress. In December, BOD and aluminium exceeded DOE limits, with aluminium reaching 26.05 ppm. Strong correlations were observed between temperature and total dissolved solids and between temperature and salinity. The overall KMO value of 0.590 indicated acceptable sampling adequacy. Overall, the river is suitable for aquaculture, but periodic low DO and elevated aluminium suggest continuous monitoring and management.

Keywords: Fish farming, water quality analysis, Northeast monsoon, heavy metals, case study, data analysis

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Aquaculture is among most common and growing sectors of food production, contributing to food security and economic growth worldwide. Due to its great potential in production and efficiency in utilizing natural water sources, caged fish farming has become one of the most popular aquaculture activities in Malaysia. Water quality plays an important role in these industries as it heavily affects fish health and growth. Good or suitable water physicochemical properties help in creating a sustainable and viable of caged fish farming system [1, 2]. Poor water quality on the other hand led to bad growth performance and susceptible to disease outbreaks contributing to high mortality rates, ultimately threatening the economic viability of aquaculture operations.

In river water system, water quality is influenced by both natural processes and anthropogenic activities which include transformation of land usage, agricultural runoff, industrial and municipal wastewater discharge [3, 4]. Fish metabolism, physiology and behaviour are directly impacted by major physicochemical factors such temperature, dissolved oxygen (DO), pH, salinity and nutrient concentrations [5, 6]. Furthermore, since heavy metals can bioaccumulate in fish tissues and enter the food chain, their presence and accumulation in aquatic environments presents ecological and toxicological risks hence posing health risks to both aquatic organisms and human consumers [7, 8].

In Malaysia, the body that guide the management of water resources were done by the Department of Environment (DOE) using the established National Water Quality Standards (NWQS). In the standard, Class III is specifically designated for water bodies supporting fisheries involving tolerant and economically valuable species [9]. Industry players can refer to the standards to assess the suitability of the water bodies for aquaculture operations thus giving them insight on how to manage them.

However, such management is more difficult by seasonal climatic variations, especially during monsoonal cycles. Malaysia experiences two distinct monsoon seasons, with the Northeast Monsoon (NEM) occurring from November to March. In this

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time, heavy rainfall and increased river discharge might affect pollutant loads, salinity and dissolved oxygen levels, especially riverine system in east coast regions [10, 11]. These seasonal hydrological changes may pose additional risks to aquaculture activities and production due to the uncontrollable water quality parameters that can fall beyond tolerable limits for fish health.

With the aid of regulatory frameworks, localized and seasonal water quality evaluations are crucial to confirming the aquaculture potential in riverine systems, especially during NEM where a lot of hydrological fluctuations will occur. The aim of this study is to evaluate the seasonal variability of water quality in the Pahang River in Jerantut where the caged fish farming system is located. River water sampling was done at three stations (A, B and C) over three consecutive months which are December, January and February, representing the NEM period. Analysis conducted was focused on key water physicochemical parameters and heavy metal content. The results were then compared against DOE Class III standards. Additionally, datasets of results were statistically analysed using Pearson correlation and Kaiser-Meyer-Olkin (KMO) to study the inter-parameter relationships and sampling adequacy. The objective of this research is to provide recommendation based on evidence for improving seasonal water quality management to support a more sustainable aquaculture industry in Malaysian riverine systems. While previous studies have assessed general water quality in Malaysian rivers, few have focused on short-term, monsoon-driven fluctuations at active aquaculture sites. This study addresses that gap by evaluating how seasonal hydrological changes during the Northeast Monsoon directly impact water quality parameters critical to caged fish farming in Jerantut, Pahang.

EXPERIMENTAL

Chemicals and Materials

Surface water samples were collected at each station using pre-cleaned high-density polyethylene (HDPE) sampling bottles. On-site measurements were performed using a multi-parameter portable water quality probe from Hanna Instruments (pH/EC/DO Multiparameter model HI98194). Heavy metal analysis was performed using Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) following an acid digestion pretreatment. For the digestion procedure, 10 mL of the river water sample was mixed with 5 mL of 65% nitric acid (HNO_3) and heated on a hot plate at 90 °C for 1 hour until the total volume was reduced to approximately 5 mL. The digested sample was then filtered and diluted to 50 mL with deionized water.

Sampling Stations

This study was done at a caged fish farm located in the Pahang River in Jerantut. The fish cages system was arranged in a rectangular layout, consisting of four columns and seven rows of individual cages (Figure **1**). Variations in water quality were assessed based on the fish condition. Three monitoring stations were chosen with station A located outside the fish cage system, acting as a reference point and control for ambient river conditions. Station B is where there are no fish mortality and Station C is where the most fish mortality is recorded, representing stable aquaculture conditions and possible water quality stressors respectively. Three replicate water samples for every station, each measuring 1000 mL, were taken every month for three consecutive months, December, January and February to guarantee consistency and data dependability.

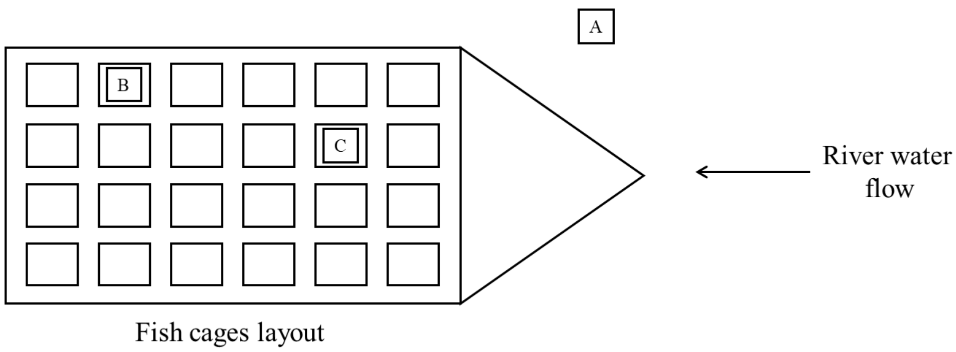

Figure 1. Fish cages layout with labelled sampling stations (A, B, C) in Pahang River, Jerantut.

Physicochemical Analysis

On-site measurements for temperature, pH, salinity, total dissolved solids (TDS) and dissolved oxygen (DO) were performed using a multi-parameter portable water quality probe. Calibration of the probe was conducted using calibration solution provided by the supplier. Water samples for laboratory analysis of chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS) and heavy metal concentrations were preserved on-site by storing in ice-filled containers and transported to the laboratory for further analysis within 24 hours of collection. COD was determined using the closed reflux titrimetric method (APHA Standard Method 5220C). BOD was measured following the 5-day BOD test (APHA Standard Method 5210B) using a BOD incubator maintained at 20°C. TSS were measured gravimetrically by filtering a known volume of water through pre-weighed glass fibre filters, drying at 105°C and weighing the retained solids according to APHA Standard Method 2540D.

Heavy Metal Analysis

Water samples for heavy metal analysis were acidified to pH < 2 with concentrated nitric acid and analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) following EPA Method 6020B. The metals analysed included lead (Pb), zinc (Zn), silver (Ag), bismuth (Bi), potassium (K), magnesium (Mg), gallium (Ga), aluminium (Al), nickel (Ni), cobalt (Co), chromium (Cr), calcium (Ca), iron (Fe), barium (Ba), manganese (Mn), copper (Cu) and cadmium (Cd). Certified reference materials, reagent blanks and duplicate samples were used to ensure analytical accuracy and precision. Verification was done according to laboratory quality assurance procedure for detection limits and method recovery rates.

Data Analysis

The physicochemical and heavy metal concentrations were summarized and compared to the NWQS for Class III of the DOE Malaysia, which apply to fisheries including common, commercially valuable and tolerant fish species. Statistical data analysis was done through Pearson correlation coefficients to assess the relationships among key water quality parameters, using a two-tailed significance test. The dataset's suitability for Principal Component Analysis (PCA) was assessed using the KMO measure of sampling adequacy. KMO values greater than 0.5 are deemed suitable and getting more significant when closing to value 1.000. XLSTAT 2021 (Addinsoft, New York, USA) was used for all statistical studies.

RESULTS AND DISCUSSION

Physicochemical Water Quality Parameters

Table 1 summarizes the monthly monitoring data for temperature, pH, salinity, TDS, DO, COD, BOD, TSS and a few heavy metals. The temperature values, which ranged from 25.70°C to 26.65°C, were comparatively constant throughout all locations and months. According to DOE Class III guidelines, these values are well within the permissible ambient temperature fluctuation of ±2°C. The pH values remained consistently within the acceptable range of 5 to 9, with recorded values are between 6.81 and 6.96, suggesting no concern over the acidity or alkalinity of the water at the moment.

Table 1. Summary of all the tested data compared to DOE standard Class III (Fishery III - Common, of economic value and tolerant species).

Parameters	Unit	**December**			**January**			**February**			**DOE standard Class III**
		A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	
Temperature	°C	25.73	25.74	25.7	26.62	26.65	26.63	26.59	26.62	26.61	26 °C + 2 °C
pH		6.88	6.89	6.89	6.86	6.92	6.96	6.81	6.92	6.91	5 - 9
Salinity	psu	0.0206	0.0206	0.0204	0.0443	0.0448	0.0447	0.0418	0.0421	0.0414	-
TDS	ppm	23.93	24	23.23	48.56	49	48.67	45.68	46	45.66	-
DO	ppm	3.63	3.29	4.19	3.25	1.53	1.58	2.61	3.31	1.97	3 - 5
COD	ppm	33	44	34	-	-	-	37	38	36	50
BOD	ppm	6	8	8	-	-	-	2	2	2	6
TSS	ppm	-	-	-	-	-	-	119	142	101	150
Pb	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.02 (0.01)
Na	ppm	5.24	1.56	4.71	2.23	2.45	2.15	7.82	12.86	13.89	-
Zn	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.4
Ag	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.0002
Bi	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-
K	ppm	1.21	0.96	1.41	1.22	1.33	1.14	2.98	2.79	2.61	-
Mg	ppm	0.489	0.38	0.71	1.12	1.27	1.1	1.12	1.15	1.16	-
Ga	ppm	< 0.1	< 0.1	< 0.1	< 0.1	0.16	0.16	< 0.1	< 0.1	0.17	-
Al	ppm	0.63	0.69	2.7	1.94	2.12	0.86	12.45	21.1	26.05	0.5 (0.06)
Ni	ppm	< 0.1	< 0.1	< 0.1	0.18	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.9
Co	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-
Cr	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	1.4 (0.05)
Ca	ppm	0.79	0.61	2.32	4.38	4.71	4.4	4.07	4.13	4.75	-
Fe	ppm	0.37	0.33	0.51	1.25	1.29	0.41	1.56	1.68	1.66	1
Ba	ppm	0.02	0.01	0.43	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-
Mn	ppm	0.02	0.02	0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Cu	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-
Cd	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.01 (0.001)

DO concentrations showed notable temporal fluctuations (Figure **2**). January showed extremely low values, especially at Stations B and C (1.53–1.58 ppm), while December measurements frequently met the 3–5 ppm threshold. Although there were some increases in February, some stations were still below the standard limit. These findings suggest that the river may experience periodic oxygen stress, which could negatively affect fish health and metabolic activities. COD values ranged from 33 to 44 ppm in December and from 36 to 38 ppm in February, all remaining below the 50 ppm limit. BOD concentrations were higher in December, peaking at 8 ppm at Stations B and C, exceeding the 6 ppm threshold. However, BOD decreased significantly to 2 ppm across all stations in February, indicating improvement in organic load reduction.

Salinity and TDS levels showed increasing trends from December to February. Even though NWQS does not have specific range for these parameters, high TDS might affect fish osmoregulation. TSS measurements taken in February ranged from 101 to 142 ppm is within the 150 ppm limit, indicating that suspended particles concentrations are generally within tolerable levels for fish survival.

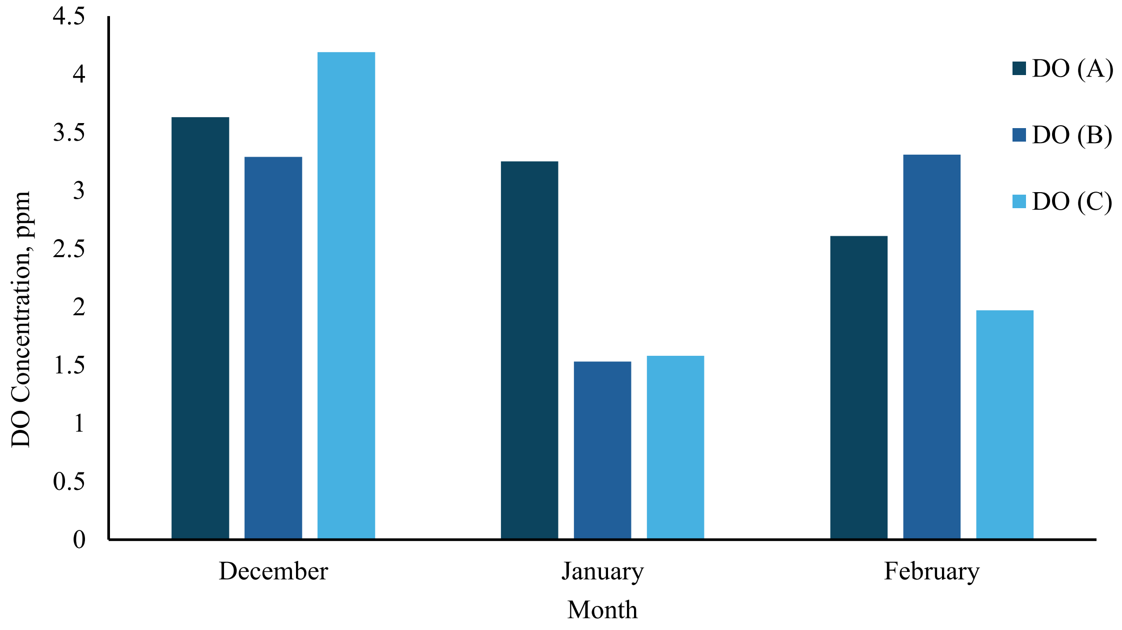

Figure 2. DO concentrations throughout December, January and February at three stations (A, B, C).

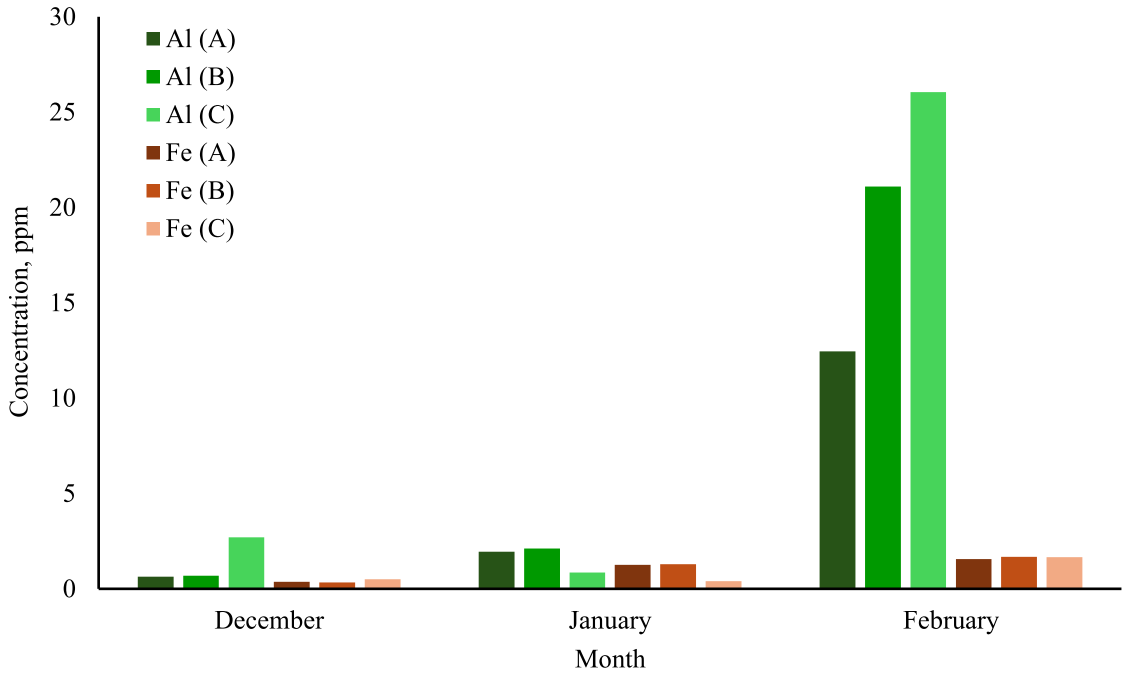

Figure 3. Al and Fe concentrations throughout December, January and February at three stations (A, B, C).

Heavy Metals Concentrations

Heavy metal concentrations were assessed relative to DOE Class III standards (Table 1). Most heavy metals, including Pb, Zn, Ag, Bi, Co, Cr, Cu and Cd, were consistently below detectable or in acceptable ranges. However, Al concentrations raised significant concerns, with values exceeding the DOE limit of 0.5 ppm at all stations, especially in February, where readings reached 26.05 ppm at Station C. Such elevated levels are known to interfere with fish gill function, potentially leading to respiratory distress [12, 13]. Fe levels ranged from 0.33 to 1.68 ppm, surpassing the 1.00 ppm limit in January and February. Prolonged exposure to elevated iron concentrations may result in sediment accumulation on fish gills, affecting respiration and survival rates [14, 15]. The elevated concentrations of Al and Fe observed can be attributed to both natural geological conditions and surrounding land-use activities. Some areas in Pahang watershed are underlain by lateritic soils, which are naturally rich in Al and Fe oxides and become highly susceptible to erosion and leaching during heavy monsoon rainfall. Thus, increased runoff during the Northeast Monsoon likely mobilized both dissolved and particulate-bound metals into the river system [16]. At the same time, the caged fish farm is located adjacent to oil palm plantation areas, where land clearing, drainage modification, fertilizer use and exposed soil surfaces are known to enhance sediment and metal export into the river water system. Figure **3** summarize the fluctuations of Al and Fe throughout the three months at point A, B and C.

Other elements such as Na, K, Mg and Ca showed temporal variations but do not have defined thresholds under DOE Class III for direct evaluation. These parameters, however, are essential for fish osmoregulation and mineral balance, thus their natural variability should be monitored.

Statistical Analysis

The Pearson correlation matrix heatmap (Figure **4**) and respective p-values (Table 2) revealed significant relationships between several parameters. Temperature, TDS and salinity exhibited strong positive correlations (r = 0.99), indicating their linear relationship across sampling periods. A notable negative correlation was observed between temperature and DO (r = −0.718), suggesting that increasing temperature may worsen the oxygen depletion. BOD was strongly negatively correlated with Na (r = −0.720), K (r = −0.836) and Mg (r = −0.778), implying that higher ionic content might be related with reduced BOD. This is possibly due to changes in microbial activity or pollutant load occurrence.

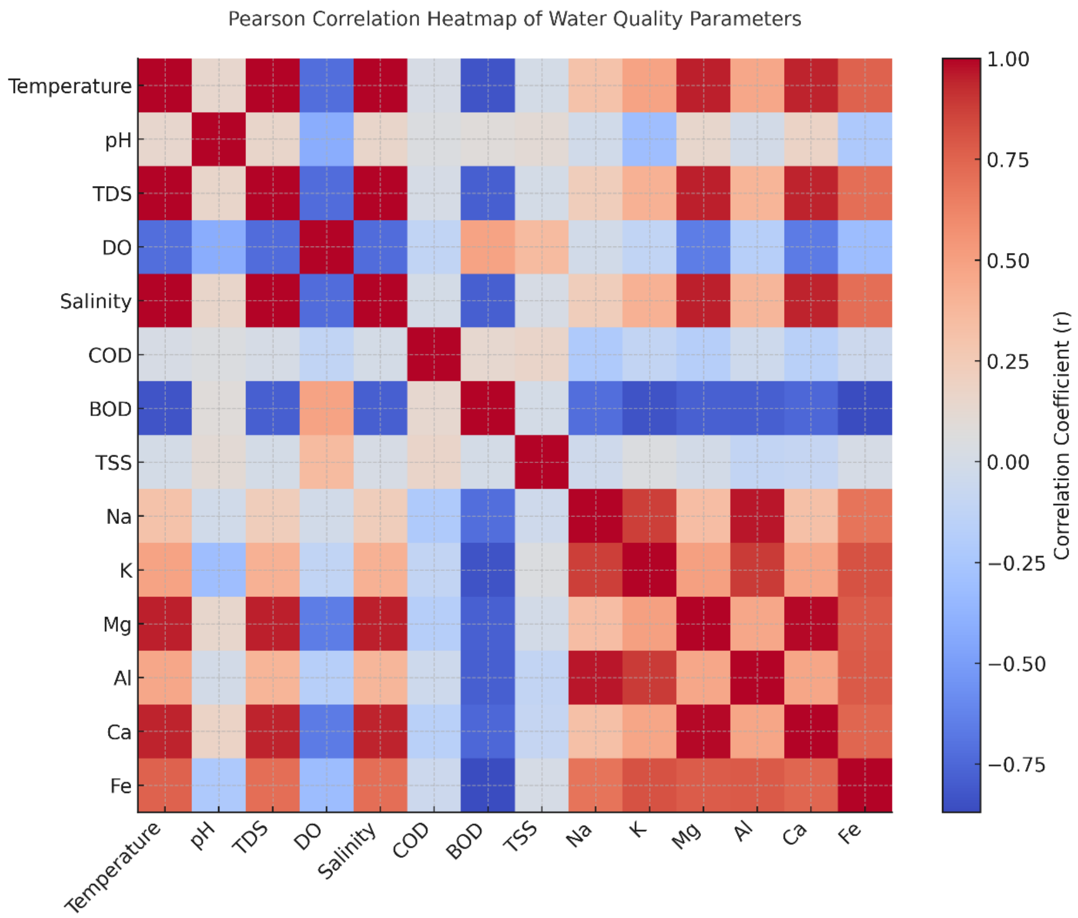

Figure 4. Pearson correlation heatmap showing relationships among water quality parameters with red indicates strong positive correlations, while blue indicates strong negative correlations.

Table 2. p-values throughout multiple parameters.

Parameters	Temp.	pH	TDS	DO	Salinity	COD	BOD	TSS	Na	K	Mg	Al	Ca	Fe
Temp.	**0**	0.715	**<0.0001**	**0.029**	**<0.0001**	0.969	**0.006**	0.986	0.422	0.189	**<0.0001**	0.212	**0.000**	**0.019**
pH		**0**	0.684	0.271	0.679	0.903	0.833	0.780	0.957	0.423	0.706	0.993	0.640	0.560
TDS			**0**	**0.026**	**<0.0001**	0.980	**0.012**	0.985	0.549	0.271	**<0.0001**	0.302	**0.000**	**0.032**
DO				**0**	**0.024**	0.765	0.186	0.350	0.973	0.774	0.058	0.661	0.052	0.420
Salinity					**0**	0.971	**0.013**	0.957	0.572	0.276	**0.000**	0.321	**0.000**	**0.036**
COD						**0**	0.727	0.677	0.573	0.780	0.648	0.910	0.686	0.905
BOD							**0**	1.000	**0.029**	**0.005**	**0.014**	**0.012**	**0.021**	**0.002**
TSS								**0**	0.937	0.901	0.989	0.793	0.821	0.975
Na									**0**	**0.002**	0.373	**<0.0001**	0.392	**0.040**
K										**0**	0.168	**0.001**	0.203	**0.007**
Mg											**0**	0.208	**<0.0001**	**0.014**
Al												**0**	0.204	**0.012**
Ca													**0**	**0.022**
Fe														**0**

*Highlighted values are within significance p-value range (p<0.05) between the two parameters.

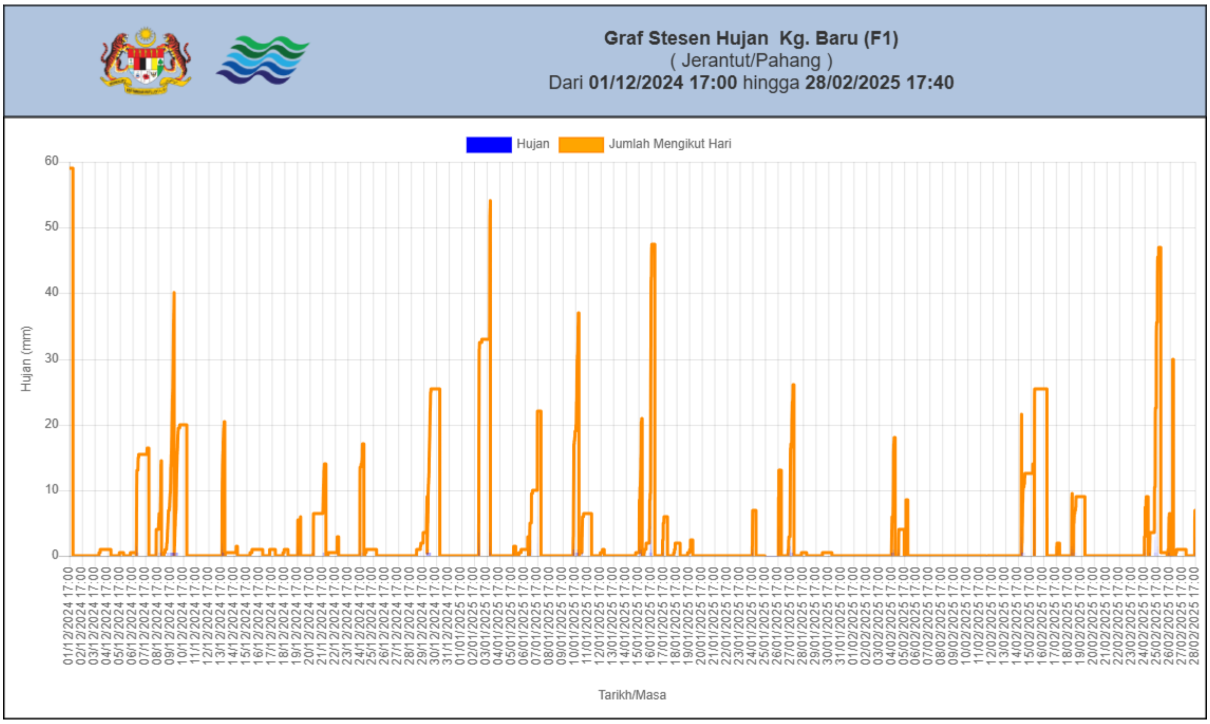

Figure 5. Daily rainfall recorded at the Kg. Baru rain station in Jerantut, Pahang from December 2024 to February 2025.

The seasonal fluctuations observed in this study can be directly attributed to the hydrological impacts of the NEM. Recorded rainfall from the Kg. Baru meteorological rain station in Jerantut showing highest precipitation in December, with several daily rainfall exceeding 40–60 mm/day, indicating intense rainfall. Rainfall frequency and intensity getting low in January, where daily rainfall generally ranged between 20–50 mm/day. The frequency of rainfall became less by February, with the majority of daily rain staying below 20–45 mm/day (Figure 5) [17]. This observed frequent rainfall during the season resulting in increased surface runoff and elevated river discharge.

Strong positive relationships between temperature, TDS, salinity, Mg and Ca ($r > 0.94$; $p < 0.0001$) are associated with these conditions, suggesting the mobilization of minerals from lateritic soils during high-flow occurrences. Concurrently, runoff supplied organic matter, which increased microbial oxygen demand and decreased DO levels, as evidenced by the negative connection between temperature and DO ($r = -0.718$; $p = 0.029$) and the significant relationships of BOD with key ions and metals ($p < 0.05$).

The sharp increase in Al and Fe contents during peak rainfall is supported by significant correlations with Na, K and Mg (Al: $r = 0.465–0.964$, $p < 0.05$; Fe: $r = 0.689–0.816$, $p < 0.05$). This suggests erosion of lateritic soils and iron-rich sediments that are commonly found in the area. These soil-metal wash-ins become worse by land uses such as nearby palm plantation, which is known to accelerate soil erosion and colloidal metal mobilization during monsoon storms.

The KMO study (Table 3) yielded an overall sampling adequacy score of 0.590 for PCA, which is considered adequate but low since the significant value is above 0.800 and closer to 1.000. Good sampling adequacy was demonstrated by variables such as K (0.633), Ca (0.699) and Fe (0.740), indicating their importance in influencing the dynamics of water quality. Because of the low KMO value and limited dataset that covered only three months, PCA's reliability was judged to be insufficient, therefore it was not performed. Larger data collection over longer time periods is recommended to enhance the dataset and enable more trustworthy multivariate analysis.

Implications for Caged Fish Farming

While many parameters are generally within DOE Class III standard range, the water quality shows a few significant problems which are dissolved oxygen depletion and excessive quantities of aluminium. Prolonged oxygen stress poses a major threat to fish health and survival, particularly during the NEM season. Because they risk fish respiration and gill function, focus needs to be shifted towards the extremely high Al. Given the results of the study on seasonal susceptibility, strategic management measures to overcome these issues are recommended. Examples of these include aeration systems, waste management strategies and more robust pollution controls, particularly during monsoon seasons when risks are greater. Long-term monitoring is essential to track changes over multiple seasons and confirm the effectiveness of mitigation strategies.

Table 3. Kaiser-Meyer-Olkin measure of sampling adequacy.

Temperature	0.571
pH	0.500
TDS	0.561
DO	0.506
Salinity	0.571
COD	0.186
BOD	0.625
TSS	0.106
Na	0.537
K	0.633
Mg	0.595
Al	0.617
Ca	0.699
Fe	0.740
KMO	0.590

CONCLUSION

Based on Malaysia's DOE Class III requirements, this study evaluated the seasonal water quality of a river system during the Northeast Monsoon to assess its appropriateness for caged fish farming. Even when pH, temperature, COD and TSS were all within safe limits, dissolved oxygen levels frequently fell below the 3 mg/L threshold, indicating potential oxygen stress for fish. Elevated BOD in December also suggested temporary organic contamination. Iron and aluminium levels beyond DOE recommendations put fish health at danger, with aluminium reaching critical levels of 26.05 ppm. Statistical study confirmed the relationships between metal pollution, organic load and oxygen depletion; however, the low amount of data prevented further PCA. The river generally shows seasonal issues due to oxygen and metal stress. Maintaining sustainable fish farming, particularly during the monsoon season, requires regular monitoring and management interventions like aeration and pollution control.

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