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Tidal And Seasonal Effects on Water Quality in the Matang Mangrove Forest Reserve, Malaysia

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Abstract

The Matang Mangrove Forest Reserve (MMFR) in Malaysia, known for its sustainable management, However, the specific relationships between tidal dynamics, seasonal changes, and water quality parameters within MMFR remain understudied. This study investigates the effects of tidal and seasonal fluctuations on water quality by examining seven parameters—Dissolved Oxygen, Salinity, Temperature, Total Dissolved Solids, pH, Turbidity, and Electric Conductivity—alongside river characteristics such as width, depth, and velocity. In-situ measurements were conducted across dry and wet seasons at both high and low tides to capture variability in water quality. The findings indicate that tidal cycles and seasonal changes significantly influence the parameters studied, with distinct patterns observed in relation to tidal conditions. For instance, salinity and turbidity levels were found to increase during high tide, influenced by seawater intrusion, while dissolved oxygen and temperature varied with seasonal rainfall and evaporation. These fluctuations not only reflect the hydrological processes within MMFR but also highlight the sensitivity of water quality to environmental conditions. Understanding these relationships is essential for developing adaptive management strategies that address the challenges posed by climate change and human impacts.

Keywords: mangrove ecosystems, Matang Mangrove Forest Reserve, seasonal variation, tidal influence, water quality

1. Introduction

Mangrove forests are among the most productive and biologically complex ecosystems on the planet. They form dense root networks that trap sediments and prevent coastal erosion, significantly contributing to shoreline stability. Additionally, mangroves provide essential habitats and breeding grounds for diverse marine and terrestrial species, making them a critical source of biodiversity. These ecosystems support many endangered and economically important species, reinforcing the biodiversity that sustains the surrounding environment.

Adapted to coastal environments, mangroves thrive along sheltered shorelines, lagoons, riverbanks, and estuaries (Anu et al., 2024). Found in over 120 tropical and subtropical countries, these salt-tolerant forests occupy areas where freshwater and saltwater mix (Kindgard et al., 2023). Mangrove species possess specialized adaptations—such as salt filtration and intricate root systems—that enable them to withstand fluctuating tides and salinity levels (Thom et al., 1984; Tomlinson, 1986). Beyond their ecological roles, mangroves offer substantial economic and cultural value for local communities by providing resources such as fish, timber, and honey that support livelihoods. They also attract tourists interested in biodiversity and ecotourism, bolstering local economies. For example, the fisheries supported by mangroves generate millions in annual revenue, highlighting their economic significance.

Moreover, mangroves serve as potent carbon sinks, storing carbon both above ground in their biomass and below ground in sediment layers, helping mitigate the effects of climate change (Alongi, 2014). Studies indicate that mangroves can sequester more carbon than many terrestrial forests, underscoring their role in global carbon budgets (Jakovac et al., 2020). This carbon sequestration capacity makes mangroves essential in strategies to reduce atmospheric carbon and meet global climate targets.

However, rapid coastal development and industrialization pose severe threats to mangrove ecosystems, leading to habitat loss and pollution (Cahyaningsih et al., 2022; FAO, 2007; Kumar & Phillip, 2024). Urban expansion, aquaculture, and agriculture have historically contributed to significant mangrove deforestation, particularly in Southeast Asia (Bernardino et al., 2020; Deng et al., 2020). Globally, mangrove forests are declining by an estimated 1% annually (Miththapala, 2008; Jennerjahn et al., 2021), with additional losses attributed to coastal erosion (Blasco, 1991). This degradation threatens the essential roles mangroves play in coastal protection and biodiversity conservation.

These changes disrupt natural hydrology and salinity levels that are crucial for the survival of mangrove species. Climate change further complicates this scenario, primarily through sea-level rise, increased storm intensity, and altered rainfall patterns (Ward et al., 2016). Rising sea levels can submerge mangrove areas, especially where sediment accretion cannot keep pace, leading to 'coastal squeeze,' where mangroves are trapped between rising seas and human developments. Nonetheless, it is important to note that mangrove vegetation can tolerate certain levels of disturbance (Govindasamy et al., 2008). Altered weather patterns, such as increased drought or intense rainfall, also affect water quality and salinity, impacting health and resilience.

Pollutants from agriculture, urban runoff, and industrial discharge accumulate in mangrove areas, impacting water quality and posing health risks to aquatic species. Pollutants—including heavy metals, pesticides, and organic waste—can alter critical water quality parameters such as pH, turbidity, and dissolved oxygen, with downstream effects on ecosystem functionality.

Mangroves help stabilize coastlines, buffer against storms, filter water, regulate local climates, and maintain groundwater balance. They serve as natural barriers that prevent soil erosion and minimize tidal surge impacts (Silanpaa et al., 2024), while also supporting diverse marine and terrestrial species. These ecosystems enhance local livelihoods by providing resources for forestry, fishing, and tourism (Blasco & Aizpuru, 2002; Dahdouh-Guebas et al., 2005; Duke et al., 2007).

To maintain healthy growth and reproduction, mangroves rely on specific water quality conditions. Parameters such as dissolved oxygen, salinity, and pH are crucial for species survival, as fluctuations can influence biochemical processes and nutrient availability. Turbidity affects light penetration and photosynthesis, which are essential for primary productivity. Meanwhile, electric conductivity and total dissolved solids (TDS) provide insights into salinity levels and the presence of dissolved ions, critical for the health of salt-tolerant mangrove species.

Tides bring fresh seawater, improving oxygenation and nutrient availability while flushing out pollutants and sediment. This tidal movement is vital for maintaining optimal salinity levels and nutrient cycles. Seasonal changes, such as monsoon rains or dry periods, can also alter water quality by introducing freshwater inflows, affecting salinity and potentially changing nutrient levels.

Effective conservation of mangroves depends on accurate classification and monitoring techniques. Advances in remote sensing and aerial photography enable detailed mapping of mangrove ecosystems and assessment of their health, allowing researchers to observe changes driven by human activities (Faridah-Hanum et al., 2019; Liu et al., 2008; Parman et al., 2022). Such techniques facilitate tracking mangrove coverage, evaluating disturbances, and informing conservation strategies (Bhandari et al., 2012). For instance, Ibrahim and Hashim (1990) employed aerial photography to classify mangrove species and quantify their distribution, a method aligned with this study's approach to evaluating mangrove disturbances.

1.1 Matang Mangrove Forest Reserve (MMFR)

In Malaysia, the Matang Mangrove Forest Reserve (MMFR) exemplifies successful mangrove management (Figure 1). Established in the early 1900s, MMFR is one of the best-documented and longest-managed mangrove reserves in the world, spanning over 40,000 hectares and provides an ideal setting to explore how tidal and seasonal variations impact water quality. It is lauded for its sustainable timber harvesting practices, which balance timber production with conservation goals while supporting rich biodiversity and protecting coastal communities.

The Matang Mangrove Forest Reserve (MMFR), located on the west coast of Peninsular Malaysia, spans approximately 40,466 hectares (Muda & Mustafa, 2003) between latitudes 4º 15' and 5º 1' N and longitudes 100º 2' and 100º 45' E. Over time, MMFR has experienced slight fluctuations in size due to restoration efforts, growing from 40,151 hectares in 1990 to 40,466 hectares in 2000, reflecting ongoing conservation efforts.

The MMFR's long history of sustainable management, particularly for charcoal production—has maintained ecological health while supporting local communities. As one of the most extensively studied mangrove forests globally, MMFR has been a focal point for research on sustainable management (Muda & Mustafa, 2003), silviculture (Gong & Ong, 1995), biomass and nutrient cycles (Ong et al., 2004), sediment dynamics, and organic matter recycling (Alongi et al., 2004).

Matang's climate is equatorial, characterized by consistently warm and humid conditions, with annual temperatures ranging from 23.7°C to 33.4°C and humidity levels between 76.5% and 83.5% (Ashton et al., 1999). Rainfall ranges from 2,000 to 3,000 mm annually, ensuring a well-watered region year-round (Harun, 2018). Semidiurnal tides with amplitudes between 1.60 and 2.98 m further influence the mangrove hydrology (JUPEM, 2004).

The MMFR contains eight distinct forest types, each defined by dominant mangrove species and soil types: Accreting Avicennia Forest, Transitional new forest, Berus Forest, Lenggadai forest, Rhizophora forest, Transitional dryland forest, Dryland Forest, and Nypa forest (Zimmer et al., 2020). For instance, Avicennia and

Figure 1. Matang Mangrove Forest Reserve

Sonneratia thrive in soft, frequently flooded soils, while Bruguiera and Rhizophora are better suited to higher, compacted soils submerged only during high tide. Dense thickets of Nypa fruticans (nipah) and Oncosperma horrida (nibong) grow along riverbanks with clay-rich soils, contributing to the forest's biodiversity and ecological complexity.

Despite extensive global and regional research on mangrove ecosystems, limited knowledge exists regarding how tidal and seasonal cycles specifically influence water quality across various parameters. This gap is especially pronounced in tropical mangroves, where environmental conditions centered on water quality and quantity differ significantly from temperate systems, highlighting the need for context-specific studies.

Understanding the relationships between water quality parameters, tidal conditions, and river characteristics in mangroves is critical for developing sustainable management strategies. Insights from such studies can inform guidelines that mitigate climate change impacts, reduce pollution, and enhance ecosystem resilience, benefiting both local biodiversity and coastal communities.

This study aims to investigate the relationships between water quality parameters—Dissolved Oxygen, Salinity, Temperature, Total Dissolved Solids, pH, Turbidity, and Electric Conductivity—and river characteristics (width, depth, and velocity) in the MMFR under varying tidal conditions. By exploring these relationships, the study seeks to enhance our understanding of mangrove ecosystem functions under both natural and anthropogenic pressures. Findings from this research are expected to inform targeted conservation strategies for mangrove ecosystems, emphasizing the importance of water quality monitoring in assessing ecosystem health. Moreover, the study will contribute to a global body of literature that can guide mangrove management practices and restoration efforts in tropical regions facing similar environmental challenges.

2. Methods

2.1 Rainfall and Climate Data Acquisition

Daily rainfall data was acquired from the Department of Irrigation and Drainage (DID), Malaysia. The data were acquired for 25 years from 1989 until 2014. Whereas climate data were acquired from the Department of Meteorology based on its automatic weather stations (AWS) at two stations (Hospital Taiping and Lubok Merbau) (Table 1).

Table 1. The climate data availability in Matang Mangrove Forest Reserve (MMFR)

Data	Station ID	Coordinates	Duration
Monthly Rainfall	4807031 Hospital Taiping	04° 51' 03" E,	1995 -2014
24 Hour Mean Temperature		100° 44' 12" N	2013-2014
24 Hour Mean Relative Humidity			2013-2014
Monthly Rainfall	48623 Lubok Merbau	04° 51' 03" E,	1995-Jan 2015
24 Hour Mean Temperature		100° 44' 12" N	
24 Hour Mean Relative Humidity			
Mean Surface Wind Speed			
Daily Evaporation			
Monthly 24 Hour Mean MSL Pressure			

2.2 Hydrological Data Analysis

In-situ measurements were conducted during both low and high tides for dry (June–July 2015) and wet (November–December 2015) periods, based on historical monthly rainfall data. Saifullah et al. (2014) identified three distinct annual seasons in Malaysia—wet (September–December), intermediate (January–April), and dry (May–August)—which align well with these sampling periods. Four rivers within three forest areas were selected for physicochemical assessment: Sungai Tiram Laut in Kuala Trong, Sungai Jarum Mas and Sungai Tinggi in Sungai Kerang, and Sungai Sepetang near Kuala Sepetang (Figure 2). Stratified sampling was used to designate sampling points along these rivers, with 5 to 8 points per river spaced 1–3 km apart, depending on the river's length.

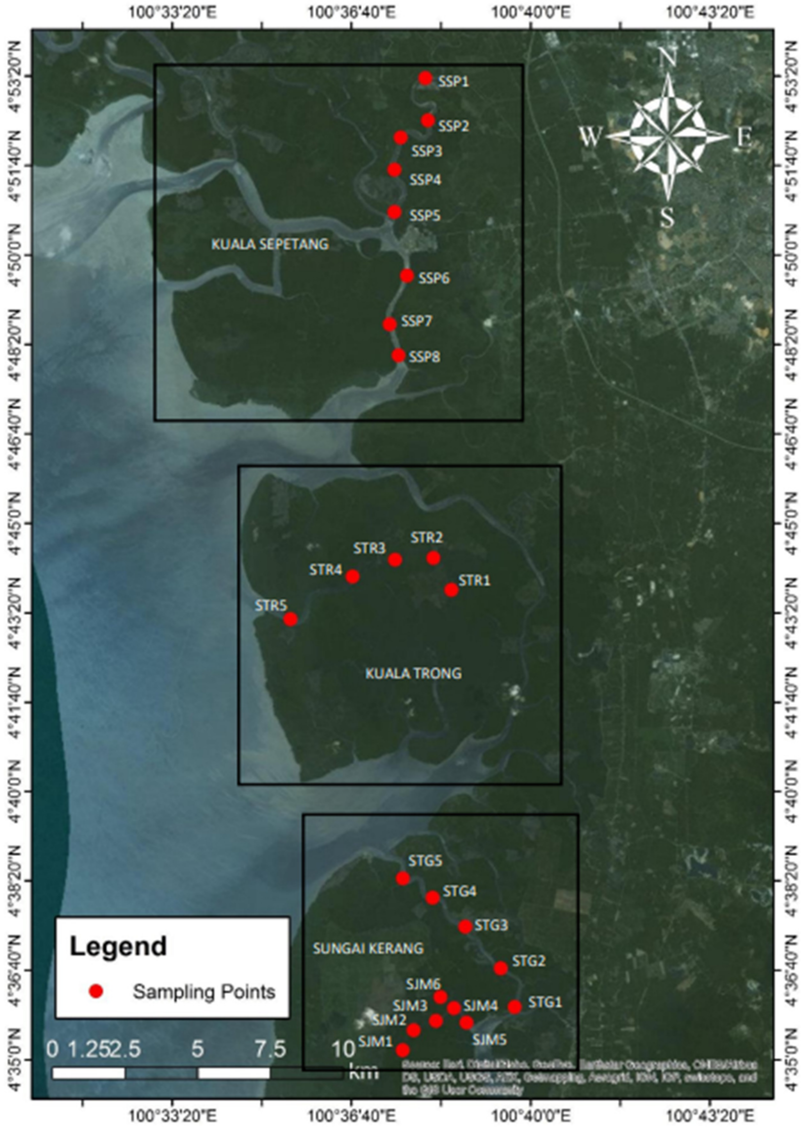

Figure 2. Sampling points (n=24) in three areas of Matang Mangrove Forest Reserve

The in-situ measurements assessed seven physicochemical parameters—Dissolved Oxygen (DO), Salinity, Temperature, Total Dissolved Solids (TDS), pH, Turbidity, and Electric Conductivity (EC) as well as river physiography, including width, depth, and velocity. Total Suspended Solids (TSS) was measured ex-situ. Water samples were collected in triplicate from each sampling point, with measurements taken between 7–10 a.m. for low tide and 12–3 p.m. for high tide in both seasons (June, July, November, and December).

Table 1 lists the physicochemical parameters and equipment used. Depth was measured with a HawkEye® Handheld Digital Depth Sounder, river width with a NIKON ProStaff 550 Rangefinder, and velocity with a SEBA Velocity Current Meter. In-situ water quality parameters were measured using portable sensors: turbidity with a HACH 2100P Portable Turbidity Meter, pH and Dissolved Oxygen with a HANNA Instruments 9829 Meter, and Salinity, Total Dissolved Solids (TDS), Temperature, and Electric Conductivity (EC) with a YSI 300 EC Meter. Water samples were collected in 1-liter polyethylene bottles, kept cool to preserve chemical properties, and analyzed for TSS within 48 hours. Laboratory analysis followed the Standard Methods for the Examination of Water and Wastewater (APHA, 2012) in the Forest Hydrology Lab, Universiti Putra Malaysia.

2.2 Statistical Analysis

All physicochemical parameters data were statistically analyzed with Descriptive Analysis to summarize the data and to measure the central tendency and dispersion of data. One Way Analysis of Variance (ANOVA) and Post Hoc test of Duncan Multiple Range Test (DMRT) were used to determine any significant differences between rivers, seasons, tides, and sampling stations. Pearson correlation analysis was performed to determine the relationship between physicochemical parameters and river physiography. All statistical tests were performed using SPSS version 22.0. Rainfall and climate were analyzed with Mann-Kendall test to determine their data trend throughout the 25-years period obtained as it is widely used to analyze environmental data, particularly for hydrometeorology time series data analysis such as river discharge, rainfall, and temperature (Nayan et al., 2012).

Table 2. The physicochemical parameters, equipment and their accuracy in sampling at Matang Mangrove Forest Reserve

Data	Parameters	Equipment	Accuracy
Physicochemical parameters	Turbidity	Hach 2100P Portable Turbidimeter	±0.01 NTU
	Electric Conductivity (EC)	YSI300 EC Meter	±1µS/cm
	Temperature	HANNA Instruments 9829 multiparameter water quality meter	±0.15°C
	Salinity		±2%
	Dissolved Oxygen (DO)		±1.5%
	pH		±0.02
	Total Suspended solids (TSS)	Gravimetric Method	±5 mg/L
River Characteristics	River Width	NIKON ProStaff 550 Rangefinder	±1 to 250 m
	River Velocity	SEBA Velocity Current Meter	+0.01s
	River Depth	HawkEye® Handheld Digital Depth Sounder	±1 to 250 m

3. Results and Discussion

3.1 Rainfall Trend and Frequency (1989–2014)

The results of daily rainfall from 1989 to 2014, except for several stations which contained the shorter period of data, showed that the average of total annual rainfall in the stations in MMFR ranged from 1746.40 mm to 3984.02 mm (Table 3). The lowest total annual rainfall recorded was 1071.5 mm at RF4507037 (Hidden Stream) in 2003, while the highest total annual rainfall recorded was 5244 mm at RF4807016 station (Bukit Larut) in 1999. Generally, the rainfall pattern declined from 2000 to 2003 but increased from 2007 to 2010. It declined again in 2011-2014. The trend of annual rainfall in MMFR showed diverse patterns, where four stations showed an upward trend, and the rest showed downward trends as shown in Table 3. Meanwhile, of all eight rainfall stations, two stations showed significant differences ($p < 0.05$).

The S value from Mann Kendall test (Table 3) at RF4507036 (Ladang Allagor) shows an increase, 12, which was not statistically significant ($p < 0.05$), whereas the S value in RF4507037 (Hidden Stream) shows a decrease, -8, that was not statistically significant ($p < 0.05$). The S value in RF4707033 (Bukit Gantang) shows a decrease, -14, which was not statistically significant ($p < 0.05$). Then, the S value in RF4707034 (Ladang Temerloh) shows an increase, 18, which was not statistically significant ($p < 0.05$). The S value in RF4707035 (Ladang Taiping) shows a decrease, -22, which was not statistically significant ($p < 0.05$). Then, the S value in RF4806032 (SK Matang) shows an increase, 94, which was statistically significant ($p < 0.05$). The S value in RF4807016 (Bukit Larut) shows an increase, 57, which was not statistically significant ($p < 0.05$). The S value in RF4806026 (Ladang Gula) shows an increase, 106, which was statistically significant ($p < 0.05$).

Table 3. The Mann-Kendall test for 25 years rainfall (1989–2014) from DID stations in Matang Mangrove Forest Reserve

Year / Station	RF450736	RF4507037	RF4707033	RF4707034	RF4707035	RF4806032	RF4807016	RF4904026
1989	3171.00	2340.50	3024.90	2920.00	2837.90	1521.60	3624.00	1635.90
1990	2738.50	1914.50	2760.00	2967.00	3083.20	1149.70	3673.50	1961.50
1991	4000.00	2119.50	2932.40	2821.50	3209.00	594.00	2604.00	2396.50
1992	2923.00	1347.00	2247.80	2105.00	2401.00	507.80	3031.50	1590.50
1993	4038.50	1010.50	3303.60	2779.00	2952.50	1157.30	4715.00	1956.00
1994	3327.50	NA	2451.40	3033.50	3518.50	1622.60	3298.50	1899.50
1995	3836.50	NA	2600.10	2571.00	3424.00	1483.40	4186.00	1993.50
1996	3486.00	NA	2432.00	4112.00	2739.00	1060.00	4146.00	NA
1997	2898.00	NA	1901.00	3249.50	2831.00	1416.00	3016.00	1343.50
1998	2596.00	NA	2095.00	2339.00	3128.50	3099.50	3497.00	NA
1999	3726.00	NA	2566.00	2502.00	2906.50	3705.20	5244.50	2232.00
2000	3221.50	NA	2582.50	3245.00	3382.00	4439.50	5237.50	2110.50
2001	2539.00	NA	1929.50	3113.00	3401.00	3195.00	4245.10	2174.00
2002	2885.50	NA	1366.00	3238.00	3032.00	4042.50	3728.50	1822.00
2003	3119.00	NA	1071.50	2644.00	3225.50	3711.00	3581.70	2563.50
2004	3238.00	NA	1710.50	3030.00	2852.00	4336.20	3872.70	2575.10
2005	2541.00	NA	1676.00	2410.00	1988.00	4410.50	NA	2039.50
2006	3181.00	NA	3189.50	3242.00	2707.50	4704.00	NA	2508.50
2007	2997.00	NA	2784.00	2880.00	2591.00	2675.00	NA	2624.00
2008	3901.00	NA	4037.00	3405.00	3459.00	2938.50	NA	2605.50
2009	4289.00	NA	3896.00	3830.00	3094.00	3080.50	4830.50	2723.50
2010	4334.00	NA	3095.50	2587.00	2826.00	2481.50	3793.00	2164.50
2011	4067.50	NA	3230.00	3204.00	3485.00	3196.00	4892.00	2556.00
2012	1600.00	NA	1348.00	1433.50	1600.00	823.50	5017.50	NA
2013	NA	NA	NA	NA	NA	NA	3939.50	NA
2014	NA	NA	NA	NA	NA	NA	3474.50	NA
N	24	5	24	24	24	24	26	24
Min	1600.00	1010.50	1071.50	1433.50	1600.00	507.80	2604.00	1343.50
Max	4334.00	2340.50	4037.00	4112.00	3518.50	4704.00	5244.50	2723.50
Avg.	3277.27	1746.40	2509.60	2902.54	2944.75	2556.28	3984.02	2165.50
Std. dev.	660.11	552.60	775.28	552.75	468.01	1364.11	745.085	385.933
S-value	12	-8	-14	18	-22	94	57	106
Z-value	0.043	-0.800	-0.051	0.065	-0.080	0.341	0.247	0.505
P-value	0.788	0.083	0.643	0.677	0.607	0.020	0.116	0.001
Trend	↑	↓	↓	↑	↓	↑	↑	↑
Sig.	NS	NS	NS	NS	NS	S	NS	S

NA: data is not available/missing data; S: significant; NS: not significant; ↑: upward trend; ↓: downward trend

The rainfall values in MMFR were in line with the range of rainfall distribution reported by Roslan and Nik Mohd Shah (2013), which is from 2000 to 2800 mm per year. As MMFR is characterized by the warm humid climate of Malaysia, the rainfall distribution was almost the same as other part of Malaysia, which is 2000–2500 mm per year (DID, 2014). However, the rainfall distribution in MMFR could be relatively higher due to its location in western of Peninsular Malaysia that faces the Malacca straits which is influenced by the monsoon. The highest rainfall in Taiping area results from the regional monsoon rain and the mountainous terrain in Taiping (e.g. Bukit Larut, Gunung Bubu). Indeed, the MMFR is also located proximate to Taiping (DID, 2015). Typical annual rainfall for Taiping ranged from 2500 to 5000 mm per year (Station RF4807016 in Table 3), which was comparatively higher compared to other areas.

The analysis of rainfall and climate in MMFR area analyzed the historical conditions of MMFR for the past 25 years. In tropical countries such as Malaysia, rainfall is the most important cyclic phenomenon as it brings important changes in the hydrological characteristics of the coastal marine environments such as mangrove areas (Prabu et al., 2008).

In addition, Eslami-Andargoli et al. (2009) stated that mainly landward expansion promotes the higher rainfall and the resulting lower salinity, which may be the factors contributing to the mangrove encroachment into the upper inter-tidal marsh. The study also proved that there is a significant relationship between rainfall pattern and the landward expansion of mangroves in Moreton Bay's subtropical estuaries. Therefore, it is also suggested that changes in the mangrove land use are related to climate variability.

In addition, the rainfall trend for stations in MMFR for the 25-years period (1989–2014) illustrated that the total annual rainfall is slightly diverse between stations. Among all eight stations, the lowest and most consistent total annual rainfall was in RF4904026 (Ladang Gula) (Figure 3), whereas the highest annual rainfall was at RF4807016 (Bukit Larut). The year 1992 was the driest year as all stations recorded the lowest annual rainfall average throughout the 25-years period. By contrast, the wettest period at all stations occurred between the years 1999–2000. According to Oceanic Niño Index (ONI), 1991-1992 possessed a strong El-Nino, which corresponded to the driest year. On the other hand, the years 1999-2000 were noted by strong La-Nina years (GGWS, 2017).

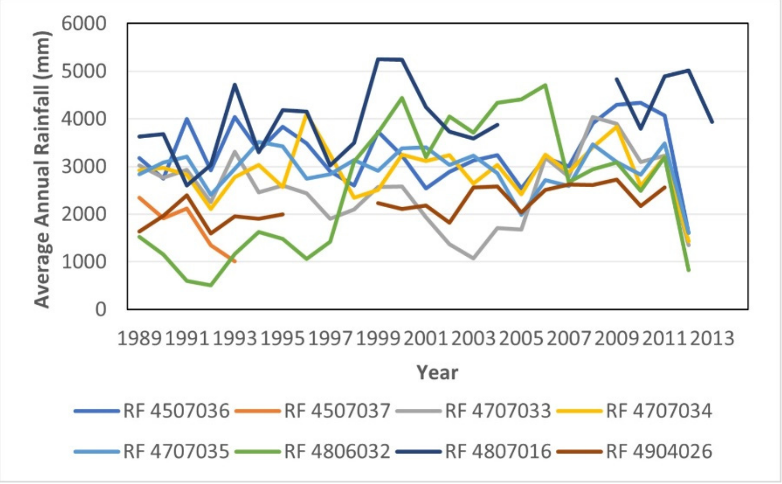

Figure 3. Rainfall trend for DID stations in Matang Mangrove Forest Reserve (1989–2014)

3.2 Physicochemical Parameters between Rivers

Dissolved Oxygen (DO) in Sungai Tiram Laut ranged from 0.54 to 10.42 mg/L, with both minimum and maximum values recorded during low tide in the dry season (Table 4). Water temperature varied between 27.30 and 32.10 °C, with the lowest temperature observed at low tide in the dry season (02/06/2015) and the highest at high tide in the wet season (10/12/2015). pH values ranged from 6.22 to 8.62, with the minimum pH recorded at low tide in the dry season (02/07/2015) and the maximum during low tide in the wet season (10/11/2015). In comparison, pH levels in Kuala Sepetang were more alkaline, likely influenced by nearby human activities such as aquaculture and industry (REF).

Electric Conductivity (EC) in Sungai Tiram Laut ranged from 20.23 to 49.65 µS/cm, with both extremes recorded at high tide during the dry season (02/07/2015). Total Dissolved Solids (TDS) and Salinity ranged from 16.97 to 31.14 g/L and 16.00 to 31.02 ppt, respectively, with minimum TDS observed at low tide during the dry season (02/06/2015) and maximum at high tide in the dry season. Turbidity varied between 2.29 and 51.40 NTU, with the minimum at high tide during the dry season (02/06/2015) and maximum at low tide in the dry season (02/07/2015). Total Suspended Solids (TSS) ranged from 0.20 to 26.10 mg/L, with minimum values recorded at high tide in the wet season (10/12/2015) and maximum at low tide in the dry season (02/06/2015).

For Sungai Jarum Mas, DO levels were higher than Sungai Tiram Laut, ranging from 0.15 to 13.26 mg/L, with the lowest and highest levels both recorded at low tide in the dry season (03/07/2015). The water temperature ranged from 26.70 to 32.90 °C, similar to Sungai Tiram Laut, with the lowest temperature at low tide during the wet season (11/11/2015) and highest at high tide in the wet season (11/12/2015). pH levels in Sungai Jarum Mas were also slightly higher, from 6.65 to 8.81, with both lowest and highest values recorded during low tide in the dry season (03/06/2015). EC ranged from 12.11 to 46.14 µS/cm, lower than in Sungai Tiram Laut, with the lowest recorded at high tide in the wet season (11/12/2015) and highest at high tide in the dry season (03/07/2015). TDS levels were between 6.71 and 28.93 g/L, and salinity from 5.80 to 28.30 ppt, with the minimum values observed at low tide during the dry season (03/07/2015) and maximum values at high tide in the wet season (11/12/2015). Turbidity was higher than in Sungai Tiram Laut, ranging from 7.56 to 126.00 NTU, with both minimum and maximum values at high tide in the wet season (11/12/2015). TSS ranged from 0.20 to 16.00 mg/L, with the lowest recorded at low tide in the dry season (03/06/2015) and the highest at low tide in the wet season (11/12/2015).

In Sungai Tinggi, DO ranged from 0.16 to 9.96 mg/L, lower than in Sungai Tiram Laut and Sungai Jarum Mas, with the minimum observed at low tide during the dry season (04/07/2015) and the maximum at high tide in the dry season (04/06/2015). The water temperature ranged from 28.80 to 32.20 °C, comparable to Sungai Tiram Laut and Sungai Jarum Mas, with the lowest at low tide in the dry season (04/06/2015) and highest at low tide in the wet season (12/11/2015). pH ranged from 6.70 to 8.80, with minimum and maximum values recorded during low and high tide in the wet season, respectively. EC ranged from 21.48 to 51.60 µS/cm, with the minimum at low tide during the wet season (12/11/2015) and maximum at high tide in the dry season (04/06/2015). TDS and salinity ranged from 13.68 to 32.20 g/L and 11.50 to 32.33 ppt, respectively, with the minimum values at low tide in the wet season (12/12/2015) and maximum at high tide in the dry season (04/07/2015). Turbidity levels varied between 6.09 and 348.00 NTU, with the minimum recorded at high tide in the wet season (12/11/2015) and maximum at high tide in the dry season (04/07/2015). TSS ranged from 0.20 to 41.70 mg/L, higher than in Sungai Tiram Laut and Sungai Jarum Mas.

Sungai Sepetang had the lowest DO levels, ranging from 0.33 to 8.60 mg/L, with minimum levels at low tide during the dry season (14/11/2015) and maximum at high tide during the wet season (09/12/2015). Water temperature varied from 27.50 to 32.20 °C, with the lowest observed at both low and high tide during the wet season and the highest at high tide during the dry season. The pH ranged from 6.21 to 8.90, with the most acidic and alkaline values both recorded at low tide in the wet season (09/12/2015). EC ranged from 0.50 to 468.10 µS/cm, with minimum and maximum values recorded at high tide during the wet season (14/11/2015). TDS varied from 0.06 to 57.30 g/L, with the lowest at low tide in the wet season (14/11/2015) and highest at high tide in the wet season (09/12/2015). Abnormal results were noted in Sungai Sepetang, possibly influenced by human activities like aquaculture and urban runoff. Salinity ranged from 0.10 to 23.73 ppt, with the minimum at both low and high tide in the wet season and maximum at high tide in the dry season. Turbidity ranged from 3.56 to 819.00 NTU, with the minimum at low tide in the wet season and maximum at high tide in the wet season. TSS ranged from 0.10 to 39.50 mg/L.

According to Ibrahim (2015), land uses such as aquaculture, agriculture, and urbanization influence EC and TDS in the mangroves. Wastewater from shrimp ponds near the riverbank, as well as urban stormwater runoff, also affect water quality, as reported by Jusoff (2013). Agricultural runoff containing fertilizers and pesticides can further impact physicochemical parameters, as observed by Lotfinasabasl et al. (2013) in the Alibaug Mangrove, India. In summary, the highest and lowest concentrations of physicochemical parameters in MMFR are linked to both natural tidal conditions and human activities. Mangrove water quality is closely related to surrounding land use management, such as aquaculture, oil palm plantations, and mangrove harvesting (Valiela et al., 2020). Lower DO levels during low tide in the dry season may result from shallow river conditions, while industrial waste and dumping may contribute to low pH values (Lewis, 2005). Higher EC, TDS, and salinity during high tide suggest seawater intrusion and runoff from adjacent land uses (Stringer, 2010; Bong and Lee, 2008).

3.3 Correlation between Physicochemical Parameters

Table 4 presents the intercorrelations of eight physicochemical parameters. At $p < 0.01$, salinity was intermediately and strongly correlated with DO and TDS (r = 0.560 and 0.990, respectively), and positively correlated with TSS and Temperature (r = 0.452 and 0.315, respectively). Apart from that, DO was positively intermediately correlated with TDS (r = 0.542) and positively correlated with Temperature (r = 0.430). Turbidity and TDS were positively intermediately correlated with TSS (r = 0.684 and 0.444, respectively).

Table 4. The descriptive statistical analysis of physicochemical parameters in Matang Mangrove Forest Reserve

Site/ Season		DO (mg/L)		TEMP (°C)		pH		EC (uS/cm)		TDS (g/L)		SAL (mg/L)		TUR (NTU)		TSS (mg/L)	
		L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
STR	Min	0.54	3.3	27.3	28.2	6.22	6.72	27.65	20.23	16.97	20.13	16.00	19.20	2.75	2.29	3.2	1.90
(n=30)	Max	10.42	8.00	30.7	31.8	7.33	7.83	48.81	49.65	29.55	31.14	28.42	31.02	51.40	43.70	26.1	8.40
DRY	Mean	5.52	5.85	29.2	30.16	6.74	7.08	39.79	42.39	24.20	26.20	23.45	25.50	13.57	13.23	6.73	4.65
	SD.	330	1.46	1.12	1.06	0.36	0.34	7.49	8.32	4.15	3.09	4.57	3.22	11.00	10.84	5.32	1.56
(n=30)																	
WET	Min	0.77	1.30	27.80	28.20	7.31	7.10	29.96	31.93	18.78	19.71	17.40	18.50	4.90	5.42	0.30	0.20
	Max	6.10	7.86	31.60	32.10	8.62	8.61	39.66	42.39	23.32	24.28	22.60	23.50	32.20	33.20	7.10	6.50
	Mean	3.76	4.20	29.86	29.55	8.08	8.03	36.02	36.60	21.63	21.92	20.74	21.01	11.31	10.82	3.00	2.40
	SD	1.90	2.04	1.18	1.11	0.52	0.63	2.91	2.94	1.35	1.33	1.42	1.40	7.08	7.71	2.31	1.72
SJM	Min	1.05	1.58	27.30	29.00	6.65	6.80	32.05	32.09	20.82	18.98	19.90	17.90	11.20	11.30	0.20	0.80
(n=36)	Max	12.36	9.02	30.00	32.00	9.81	7.54	44.58	46.14	28.77	28.93	28.30	28.25	44.50	42.80	11.10	9.99
DRY	Mean	6.11	5.69	28.71	30.39	7.64	7.16	39.63	40.91	24.25	21.10	23.94	23.82	17.96	21.22	3.53	5.03
	SD	3.03	2.31	0.79	0.90	1.00	0.27	4.13	4.70	2.46	2.84	3.03	3.27	6.31	7.86	2.58	2.32
(n=36)	Min	1.21	1.25	26.70	27.00	7.40	7.00	26.90	12.11	16.67	6.71	15.60	5.80	10.10	7.56	0.70	0.40
WET	Max	6.11	7.11	32.10	32.90	9.00	8.79	35.29	39.86	20.84	20.15	20.00	19.20	74.60	126.0	16.00	10.60
	Mean	3.69	3.87	29.29	29.17	8.37	8.07	30.55	28.71	18.36	17.10	17.34	16.13	36.52	43.57	7.33	5.04
	SD.	1.32	2.16	1.91	1.27	0.46	0.67	2.62	5.85	1.07	3.51	1.10	3.48	24.91	38.43	5.01	2.86
STG	Min	0.16	1.81	28.80	29.90	7.05	6.90	37.78	35.41	22.42	22.74	21.90	22.20	27.10	29.00	0.90	0.20
(n=30)	Max	7.76	9.96	30.80	31.60	8.01	7.74	48.68	51.60	28.51	32.20	30.75	32.33	345.0	348.0	30.00	41.70
DRY	Mean	4.75	5.14	30.04	30.75	7.46	7.20	44.13	44.31	26.09	27.72	26.07	27.38	113.7	108.8	13.38	12.60
	SD	2.67	3.00	0.57	0.66	0.30	0.25	3.56	4.68	1.92	3.49	2.59	3.83	79.41	91.43	8.09	12.16
(n=30)	Min	1.69	2.78	29.00	29.10	6.70	6.77	21.48	24.36	13.68	14.87	11.50	13.80	8.30	6.09	0.30	0.20
WET	Max	6.68	7.37	32.20	31.10	8.72	8.80	39.27	40.21	32.69	31.40	22.00	22.60	25.70	35.50	4.70	5.30
	Mean	4.32	4.50	30.65	30.10	7.79	8.23	32.30	34.17	20.23	20.99	17.98	19.31	14.21	14.61	3.01	2.28
	SD	1.80	1.57	1.18	0.58	0.55	0.49	4.96	4.66	4.76	3.62	2.88	2.58	4.98	8.54	1.13	1.78
SSP	Min	0.33	2.43	28.10	29.10	6.78	6.94	2.50	0.62	0.09	0.36	0.20	0.30	18.70	20.60	0.10	0.10
(n=48)	Max	4.97	8.11	30.20	32.20	8.07	7.63	410.7	38.32	23.78	22.03	23.02	23.73	168.0	188.6	18.80	23.70
DRY	Mean	3.08	4.99	29.31	30.63	7.18	7.11	54.29	19.99	12.68	12.19	12.44	11.54	45.22	53.17	4.33	3.88
	SD	1.35	1.77	0.60	1.59	0.40	0.15	95.54	11.65	8.01	6.87	7.52	7.09	31.78	41.65	4.19	4.30
(n=48)	Min	0.79	0.78	27.50	27.50	6.21	6.50	0.64	0.50	0.06	0.07	0.10	0.10	3.56	29.90	0.30	0.40
WET	Max	7.41	8.60	31.60	31.60	8.90	8.00	427.0	468.1	9.77	57.30	8.90	6.50	177.0	819.0	20.60	39.50
	Mean	2.62	2.93	28.76	28.76	7.81	7.42	65.19	62.26	3.17	7.60	2.77	2.50	83.90	157.2	3.61	6.35
	SD	1.59	2.11	1.38	0.85	0.62	0.39	122.5	133.6	3.20	13.99	2.87	2.47	57.74	188.9	4.07	9.45

Notes: STR=Sg. Tiram Laut; SJM=Sg. Jarum Mas, STG=Sg. Tinggi, SSP=Sg. Sepetang, L=low tide; H= high tide, SD=Standard Deviation

Table 5. Pearson correlation coefficient (r) between water quality parameters

	Salinity	pH	EC	DO	Turbidity	TDS	TSS	Temperature
Salinity	1							
pH	0.077	1						
EC	-0.009	-0.003	1					
DO	0.560**	0.145*	0.021	1				
Turbidity	0.111	0.047	0.005	0.043	1			
TDS	0.990**	0.062	-0.046	0.542**	0.114	1		
TSS	0.452**	0.087	0.019	0.273**	0.684**	0.444**	1	
Temperature	0.315**	0.000	-0.028	0.430**	0.189**	0.291**	0.283**	1

Notes: ** = $p < 0.01$ * = $p < 0.05$

In the mangrove ecosystem, salinity is one of the most important parameters in defining the conditions of the water suitability for aquatic life (Friedl et al., 2004). As a matter of fact, the reason why salinity was correlated with DO, TDS, TSS, and Temperature was because all the parameters were required for the survival of aquatic species. DO correlation with TDS is common because mangroves possess high organic matter. The discharge of organic matter will eventually cause a lack of oxygen in water (McNeil and Closs, 2007). This occurs by means off suspended materials which either originated from the discharged organic matters or soil particles caused by erosion. Such particles absorb heat in sunlight, thus raising water temperature and decreasing dissolved oxygen.

3.4 Correlation of Physicochemical Parameters with River Physiographic

As shown in Table 6, salinity has a positive intermediate relationship ($p < 0.01$) with river depth (r = 0.479). pH has a positively intermediate relationship ($p < 0.01$) with river width (r = 0.403). Besides that, TDS (r = 0.449) and Temperature (r = 0.337) have a positively intermediate relationship ($p < 0.01$) with river depth.

According to Wahid (2007), river depth in mangrove area is influenced by three major factors: (1) the river discharge at the head, (2) the tidal input at the mouth, and (3) the topography of the area. These three factors were supported by Rahman et al. (2013). Essentially, that could be the reason of the intermediate correlation of salinity with river depth. The soil type and soil acidity level of the area likely affected the pH values (Saeed, 2014). Apart from soils, mangrove litter decomposition may have also contributed to the pH values (Lacerda et al., 1995; Saravanakumar et al., 2008).

Table 6. Pearson correlation coefficient (r) between physicochemical parameters with river physiographic parameters

	Salinity	pH	EC	DO	Turbidity	TDS	TSS	Temperature
Width	-0.256**	0.403**	0.029	-0.030	0.260	-0.167	0.105	0.176*
Depth	0.479**	-0.005	-0.058	0.183*	-0.247**	0.449**	-0.010	0.337**
Velocity	-0.204*	-0.122	-0.092	-0.118	0.066	-0.218*	-0.069	-0.018

Notes: ** = $p < 0.01$ * = $p < 0.05$

3.5 Seasonal Variation of Physicochemical Parameters

ANOVA were carried out to compare the mean for statistical significant based on seasonal variation. The parameters that showed a significant difference between the dry and wet seasons were DO, pH, TDS, Salinity, Temperature, and TSS (Table 7). Table 8 illustrates the significant differences seasonally in each four rivers of MMFR. Overall, all parameters showed significant differences except for Turbidity in Sungai Tiram Laut; Temperature in Sungai Tiram Laut, Sungai Jarum Mas, and Sungai Tinggi; DO in Sungai Tinggi; and EC and TSS in Sungai Sepetang.

The higher the DO, the better the water quality (Brönmark and Hansson, 2005). The DO reading in the dry season (June and July 2015) was higher than the wet season (November and December 2015) for all four rivers (Figure 4(a)). Elevated DO levels are indicative of healthier mangrove ecosystems, as they are influenced significantly by tidal fluctuations and rainfall patterns (Sasekumar et al., 1994; Nurhidayu et al., 2020).

In the dry season, lowest DO was recorded in Sungai Sepetang (mean: 4.04 ± 0.23 mgL-1) and the highest was recorded in Sungai Jarum Mas (mean: 5.69 ± 0.45 mgL-1), while in the wet season, the lowest reading was recorded in Sungai Sepetang (mean: 2.78 ± 0.27 mgL-1) on and the highest was recorded in Sungai Tinggi (mean: 4.41 ± 0.31 mgL-1).

Higher DO concentration found during the dry season contradicts with most studies of seasonal variation of physicochemical parameters, as the DO reported by Vijaya Kumar and Kumara (2013) was 1.94 to 6.71 mgL-1 and the DO reported by Saifullah *et al.* (2014) was 3.25 to 11.78 mgL-1. The contradiction herein exisits possibly because river water is shallow in the dry season with less decomposition compared to the wet season which results in higher DO levels (Jusof *et al.*, 2013). Besides that, the variation is also related to the different rivers with different river physiography which supports different kinds of aquatic life. The increasing trend of DO across all stations suggests a positive improvement in water quality, aligning with findings by Nayan et al. (2012), which reported a year-on-year increase in DO in the coastal zones of Perak.

The decrease in water temperature and respiratory activities of aquatic creatures and vegetation, as well as the aerobic process by microorganisms, will result in increased oxygen content (Nasir *et al.,* 2012). Vijaya Kumar and Kumara (2013) stated that higher concentration of DO were recorded in Kundapura Mangrove Forest, Karnataka, India during the monsoon (wet) season and relatively low during the summer (dry) season due to the influence of rainfall. Water temperature had a higher reading in the dry season as compared to the wet season for all the rivers except for Sungai Tiram Laut (Figure 4(b)). The difference was slight and did not exceed 1 °C. In dry season, the lowest temperature was recorded in Sungai Jarum Mas (mean: 29.55 ± 0.14 °C) and the highest was recorded in Sungai Tinggi (mean: 30.40 ± 0.11 °C). In the wet season, the lowest temperature was recorded in Sungai Sepetang (mean: 28.76 ± 0.16 °C) and the highest was in Sungai Tinggi (mean: 30.38 ± 0.16 °C).

Water temperature is influenced by canopy cover (Gandaseca, 2016), river width (Shuhaimi-Othman *et al*., 2007), and time of sampling (Rahman *et al.*, 2013). Sungai Tinggi is a wider river lacking canopy cover. In relation to the time of sampling, most of the readings that recorded higher temperature were taken in the afternoon. Higher temperature during dry season could be attributed to high solar radiation (Prabhu *et al.*, 2008), whereas low temperature during wet season is a function of a strong sea breeze and precipitation (Satheeshkumar and Khan, 2011). Important biologically, temperature plays an important role in the metabolic activities of the organism (Sirajudeen and Mubashir, 2013).

The pH was high in the wet season as compared to the dry season for all rivers (Figure 4(c)). pH during the dry season was the lowest in Sungai Tiram Laut (mean: 6.9 ± 0.06) and highest in Sungai Jarum Mas (mean: 7.4 ± 0.11). During the wet season, the lowest pH was recorded in Sungai Sepetang (mean: 7.6 ± 0.07) and the highest was recorded in Sungai Jarum Mas (mean: 8.2 ± 0.09).

During the wet season, the pH values were relatively higher due to river discharge from rainfall which resulted in alkaline river water (Rita and Ramanathan, 2008). Gandaseca *et al.* (2014) states in mangrove ecosystem, water with a high and low pH might be unsafe to aquatic life, suggesting a neutral pH (6.91–7.51) is best for fish and other aquatic life as found in his study in Sarawak.

EC in the dry season was higher than the wet season in all rivers except for Sungai Sepetang (Figure 4(d)). Higher values in the dry season may be due to the decrease of freshwater flow and high evaporation rate which may significantly increase the concentration of dissolved conducting minerals (Rahman *et al.*, 2013). In the dry season, the lowest readings were recorded in Sungai Sepetang (mean: 37.14 ± 7.74 µS/cm) and the highest was recorded in Sungai Tinggi (mean: 44.22 ± 0.75 µS/cm). During the wet season, the lowest EC reading was in Sungai Jarum Mas (mean: 29.63 ± 0.71 µS/cm), while the highest was in Sungai Sepetang (mean: 63.73 + 18.48 µS/cm), as compared to previous research by Seca et al. (2011) suggested that EC levels in mangrove areas typically range from 0.805 to 96.1 µS/cm.

This condition might be because Kuala Sepetang is a part of Matang Mangrove with the most concentrated development compared to other areas which are located upstream. The higher EC could be from the sewage discharges associated with manufacturing industries. Chong (2006) believed that the variation of EC in Sungai Sepetang is due to dissolved nutrients and other dissolved ions from industry effluents. The variations in EC values could also stem from the freshwater influx that mixes with saline waters during flood and ebb flows (Mishra *et al.,* 2008). EC readings varied indicating a higher presence of ionic particles.

TDS values were higher during the dry season as compared to the wet season for all the rivers (Figure 4€). In the dry season, the lowest values were recorded in Sungai Sepetang (mean: 12.44 ± 1.07 gL-1) and the highest was recorded in Sungai Tinggi (26.91 ± 0.49 gL-1), while for the wet season (09/12/2015), the lowest was also recorded in Sungai Sepetang (mean: 5.39 ± 1.24 gL-1) and the highest was recorded in Sungai Tiram Laut (mean: 21.78 ± 0.24 gL-1).

Rahman *et al.* (2013) showed that TDS ranged from 22.2 to 24.4 gL-1 in the summer season, while in this study it ranged 40.0 to 53.3 gL-1 in the rainy season at Passur River in Sundarban mangrove in Bangladesh. This contrasts with the results from the current study which could be because their study site was in an arid prone area. The results revealed that there is a distinct variation in TDS for different seasons. Theoretically, TDS concentration is related directly to EC (Gandaseca *et al.*, 2016). All four rivers in Matang recorded low concentrations of TDS in water bodies due to the low conductivity.

In general, the salinity in Matang Mangrove was higher during the dry season as compared to the wet season (Figure 4(f)). The variation could be influenced by diferential river discharge between both seasons. For the dry season, Sungai Sepetang recorded the lowest values (mean: 11.99 ± 1.05 ppt), while Sungai Tinggi recorded the highest (mean: 26.73 ± 0.59 ppt). During the wet season, Sungai Sepetang also recorded the lowest value (mean: 2.64 ± 0.39 ppt), while Sungai Tiram Laut recorded the highest (mean: 20.88 ± 0.26 ppt).

The low salinity in Sungai Sepetang compared to other rivers indicates that it was the most impacted by human activities such as plantation, aquaculture, and tourism. Salinity levels across the three areas showed minimal variation, with lower salinity observed near Kuala Sepetang, likely due to adjacent human settlements and industrial activities (Figure 5). Although Muda and Mustafa (2003) reported salinity levels in MMFR ranging from 11 to 32 ppt, the readings of 0.01-0.41 ppt obtained from river water are acceptable, considering they did not extend into coastal zones.

A study in Sundarban Mangrove by Rahman *et al.* (2013) showed that the salinity was 1 to 20 ppt throughout the whole year with the maximum salinity observed in summer. Salinity in a mangrove forest is affected by the mixing of seawater and freshwater flow, with rainfall acting as a diluting agent in the mangrove water. Sungai Tinggi had the highest salinity among all rivers, may be due to the low incidence of human activities in the Sungai Kerang area (Rhyma *et al.*, 2015).

Sungai Tiram Laut and Sungai Tinggi recorded higher turbidity in dry season than wet season, while Sungai Jarum Mas and Sungai Sepetang recorded higher turbidity during the wet season. Sungai Tiram Laut (mean: 13.40 ± 1.99 NTU) recorded the lowest value during the dry season, 88 while the highest was in Sungai Tinggi (mean: 111.26 ± 15.60 NTU) (Figure 4(g)). Sungai Tiram Laut (mean: 11.07 ± 1.35 NTU) recorded the lowest value during the wet season, while the highest was in Sungai Sepetang (mean: 120.56 ± 17.80 NTU).

The large difference of turbidity between the wet and dry seasons in Sungai Tinggi was probably caused by rainwater flushing during the wet season, which increased water turbidity (Chong *et al.*, 2006). The results reflected Toriman *et al.* (2013) who found that turbidity averaged from 5.44 to 7.78 in dry season and 6.65 to 10.67 NTU in the wet season, which were similar to Sungai Tiram Laut. Apart from that, Sungai Sepetang recorded the highest turbidity in the wet season partially due to the high concentration of human settlements or fishing villages such as in Bagan Sangga Besar (Chong *et al.*, 1999; Chong, 2006).

TSS was higher during the dry season for Sungai Tiram Laut and Sungai Tinggi (Figure 4(h)) while it was higher during the wet season for Sungai Jarum Mas and Sungai Sepetang. The relatively higher TSS in Sungai Tinggi compared to other rivers may be due to the less freshwater flow, bank erosion, and forest litter (Gilman *et al.*, 2008; Wang *et al.* 2010; Winterwerp *et al.*, 2013).

TSS was lowest in Sungai Sepetang (mean: 4.11 ± 0.61 mgL-1) and highest in Sungai Tinggi (mean: 12.99 ± 1.85 mgL-1) during the dry season, while lowest in Sungai Tinggi (mean: 2.65 ± 0.27 mgL-1) and highest in Sungai Jarum Mas (mean: 6.19 ± 0.66 mgL-1) during the wet season. However, the ranges of the TSS in the rivers for both the dry and wet seasons were below the limit of the moderate class of Water Quality Index Classification of DOE (2001) which is 50 mgL-1. 89

The seasonal variation of physicochemical parameters in Matang Mangrove highlighted some notable findings. The concentration of Turbidity and TSS in Sungai Tinggi was recorded higher during the dry season due to the intensive shrimp farming during the period (June and July 2015). Similar findings were reported by Seca et al. (2014) in the Awat Awat Mangrove region of Borneo, where TSS levels ranged from 0.03 to 61.50 mg/L. The turbidity levels mirrored those of TSS, with 2SP16 station showing the lowest turbidity (23.98 NTU) and 2SP01 station reflecting the highest (58.54 NTU) (Figure 8). This elevated TSS and turbidity suggests poor environmental conditions (Azinoor et al., 2010). The other parameters in Sungai Tiram Laut and Sungai Jarum Mas recorded values that aligned with the direct trend.

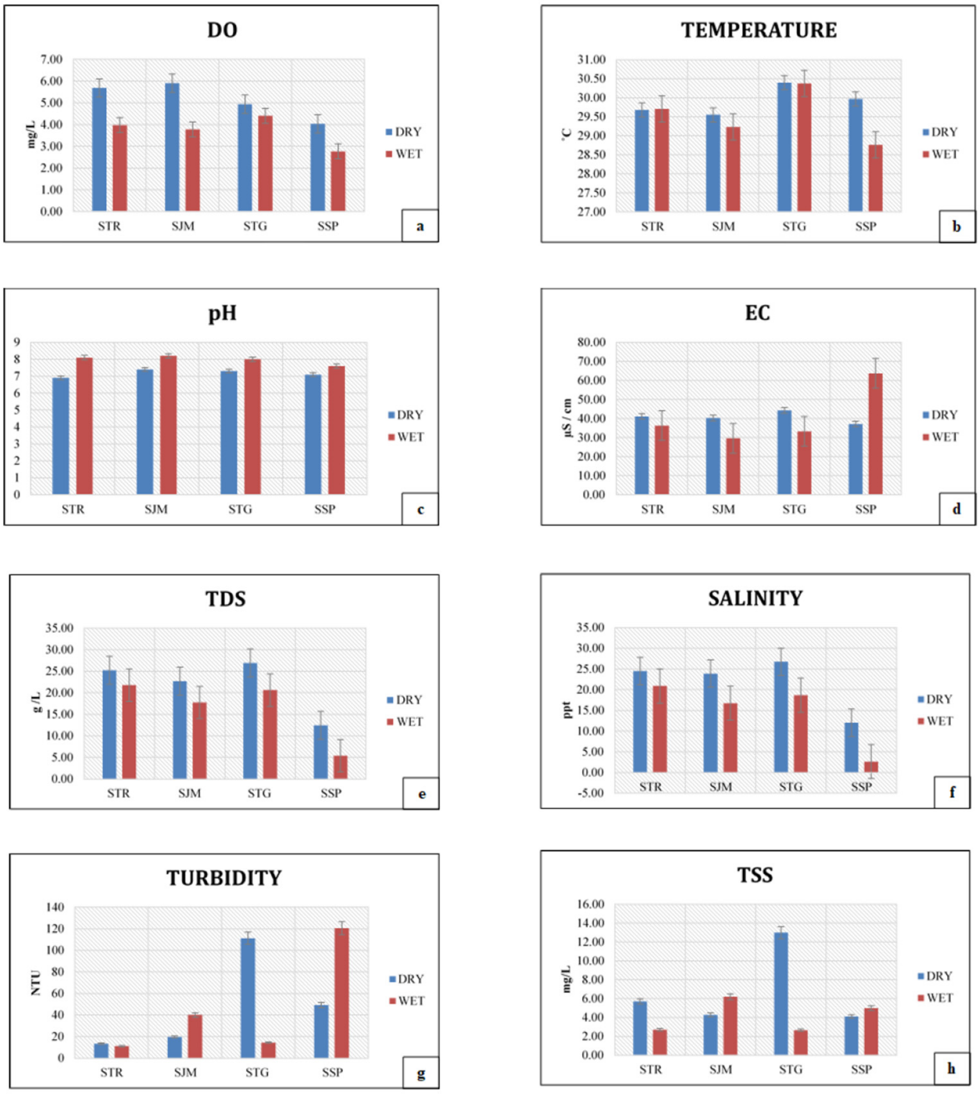

Figure 4. The seasonal variation of water physiochemical parameters with Standard Error for four rivers in Matang Mangrove ((a)DO - *Dissolved* Oxygen; (b) Temperature; (c) pH; (d) EC – Electric Conductivity; (e) TDS - Total *Dissolved* Solid; (f) Salinity; (g) Turbidity; (h) TSS – Total Suspended Solids; STR – Sg. Tiram Laut; SJM – Sg. Jarum Mas; STG – Sg. Tinggi; SSP – Sg. Sepetang)

Figure 5. Settlement at Kuala Sepetang and Sungai Kerang, Matang Mangrove Forest Reserve

3.2 Tidal Variation of Physicochemical Parameters of Selected Rivers of Matang Mangrove Forest Reserve

ANOVA was carried out to compare the mean for statistical significane based on tidal variation. In general, the parameters exhobiting significant difference in low and high tide were: DO, pH, Turbidity and Temperature (Table 5). The ANOVA results for tidal variation of physicochemical parameters in Matang Mangrove rivers is shown in Table 8 and only some parameters showed significant differences between the tides. In Sungai Tiram Laut, only TSS showed a significant difference between low and high tides, whereas in Sungai Jarum Mas, pH and Temperature showed significant differences. In Sungai Tinggi, none of the parameters showed significant differences, while in Sungai Sepetang, four parameters show significant differences which were DO, pH, Turbidity, and Temperature.

It is apparent that tidal transition leads to the variation in physical and chemical parameters (Krumme *et al.*, 2012). As a matter of fact, in Matang Mangrove, the tide was normally inundating mangroves via creeks and surface overflow (Mohamad Lokman *et al.*, 2005). The incoming tide enters and fills the creeks first before overflowing their banks and then inundating the middle and back mangrove forest. By surface flow, the incoming tide overflows the front mangroves bordering the sea or rivers, before inundating the middle and back mangrove. The gradual change in the flow direction in the mangrove forest implies that the flow does not move simply back and forth alternately at flood and ebb tides but forms a horizontal water circulation encompassing the entire swamp. This velocity distribution and its tidal variation likely play an important role in the water quality, soil transportation, and the maintenance of the mangrove ecosystem (Kobashi and Mazda, 2005).

For the first parameter analyzed, DO had higher readings during high tide as compared to low tide for all rivers except for Sungai Jarum Mas (Figure 6(a)). The lowest DO during low tide was recorded in Sungai Sepetang (mean: 2.85 ± 0.21 mgL-1), and the highest was recorded in Sungai Jarum Mas (mean: 4.90 ± 0.36 mgL-1). Similarly, during high tide, the lowest DO was also recorded in Sungai Sepetang (mean: 3.96 ± 0.28 mgL-1), but the highest DO was recorded Sungai Tiram Laut (mean: 5.03 ± 0.32 mgL-1). Higher DO in high tide water is influenced by the tidal transition and mixing of high oxygen level of offshore water into inshore water (Pawar and Kulkarni, 2007). Besides that, it is also due to the oxygen exchange within the mangroves root system (Jitthaisong *et al.*, 2012).

For the second parameter analyzed, all rivers recorded lower water temperature concentrations during low tide relative to high tide (Figure 6(b)). For low tide conditions, Sungai Jarum Mas (mean: 29.00 ± 0.23 °C) recorded the lowest, while the highest was in Sungai Tinggi (mean: 30.35 ± 0.16 °C). However, for high tide conditions, Sungai Sepetang (mean: 29.70 ± 0.18 °C) recorded the lowest value, while the highest was also in Sungai Tinggi (mean: 30.43 ± 0.11 °C).

The water temperature in the rivers in MMFR are suggested to be influenced by the tidal transition where the readings were acquired whether it was during the rising or falling limb of low or high tides (Urish *et al.*, 2009). If the readings were taken during the rising limb of tide, the water was likely to be hotter as it originated from the sea as during that time, seawater intrudes the mangrove area (Hoguane *et al.*, 1999). However, during the falling limb of tide, the water would be cooler as seawater would start to flow back to the sea. That was why the water temperatures recorded higher during high tide as compared to low tide.

For the third parameter analyzed, pH was higher in low tide as compared to the high tide for Sungai Jarum Mas and Sungai Sepetang, while it was higher in high tide in Sungai Tiram Laut and Sungai Tinggi (Figure 6(c)). During low tide, pH was lowest in Sungai Tiram Laut (mean: 7.41 ± 0.08) and highest in Sungai Jarum Mas (mean: 8.01 ± 0.12). Conversely, during high tide, the lowest pH was recorded in Sungai Sepetang (mean: 7.27 ± 0.04) and the highest was recorded in Sungai Tinggi (mean: 7.72 ± 0.07).

The pH in MMFR was influenced by the flow of water from tidal transition. The pH values were recorded almost the same to the pH values in most studies. Among that is a study by Ramanathan *et al.* (1999) that reported the average pH was 7.0-7.5 in mangrove water. They also suggested that the pH value may increase due to mixing of estuaries water. On the other hand, Edzwald and Haarhoof (2011) found that pH of seawater is mainly in the range of 8.1–8.3, which supports the pH values in this study.

For the fourth parameter analyzed, EC in low tide was higher than high tide for all four rivers in MMFR (Figure 6(d)). During low tide, the lowest EC was recorded in Sungai Jarum Mas (mean: 35.09 + 0.56 µS/cm) and the highest was recorded in Sungai Sepetang (mean: 59.74 + 15.73 µS/cm), while during high tide, the lowest reading was also recorded in Sungai Jarum Mas (mean: 34.81 + 0.88 µS/cm) and the highest was recorded in Sungai Sepetang (mean: 41.13 + 10.48 µS/cm).

The extreme value of EC as demonstrated in Sungai Sepetang was due to the intense farming and tourism activities (Chong, 2006). In addition, the high level of EC proves the presence of dissolved salts (from agriculture) in high levels in the water bodies as found in this study. However, this tidal variation of EC was contrasted with the findings by Gandaseca *et al.* (2014) in Awat-Awat Mangrove, Borneo where low level of EC (2.72-3.70 µS/cm) was found due to the discharge of high organic matter contents which included both dissolved and suspended material.

For the fifth parameter analyzed, TDS values were higher during the high tides as compared to the low tide for all the rivers except for Sungai Jarum Mas (Figure 6e). During low tide, the lowest values was recorded in Sungai Sepetang (mean: 7.93 ± 0.81 gL-1) and the highest was recorded in Sungai Tinggi (23.16 ± 0.61 gL-1), while for the high tide, the lowest was also recorded in Sungai Sepetang (9.90 ± 1.51 gL-1) and the highest was also recorded in Sungai Tinggi (24.36 ± 0.65 gL-1).

Higher TDS content is attributed to the presence of organic salts in high volumes (Sathe *et al.*, 2002) or the inflow of effluent from sewage plants or industry (Rita and Ramanathan, 2008). These factors contributed to the variation of TDS concentration during both tides in this study. In fact, some areas of MMFR were affected by the various activities (i.e. shrimp farming, factory, and settlement) which contributed to the low level of dissolved solids compared to suspended solids.

For the sixth parameter analyzed, Salinity was higher during low tide as compared to the high tide in Sungai Jarum Mas and Sungai Sepetang, while it was higher during high tide than during low tide in Sungai Tiram Laut and Sungai Tinggi (Figure 6(f)). For the low tide, Sungai Sepetang recorded the lowest salinity values (mean: 7.61 ± 0.75 ppt), while Sungai Tiram Laut recorded the highest (mean: 22.10 ± 0.55 ppt). For the high tide, Sungai Sepetang also recorded the lowest value (mean: 7.02 ± 0.69 ppt), while Sungai Tinggi recorded the highest (mean: 23.35 ± 0.59 ppt).

The low salinity in Sungai Sepetang compared to other rivers provided evidence that it was influenced by the irrigation from Taiping River in town. Kuala Sepetang was the part of MMFR which was located closest to Taiping town or urbanized area. Other than that, the existence of industrial area near to the mangrove area, even some of the factories (rubber and oil palm) were close to the water bodies, making the salinity concentration of the river fluctuate constantly. Zingde *et al.* (1994) found that the changing in salinity concentration between different tides which was correlated with the circulation pattern of offshore water of high salinity with coastal water in their area, Mahim estuary, India. The research study by Pawar (2013) in Navi Mumbai, west coast of India also found similar findings, where the salinity ranged from 14.85 to 33.10 ppt due to same classical estuarine circulation pattern (high salinity offshore water with coastal water (Figure 5(f)).

For the seventh parameter analyzed, Turbidity was higher in low tide than high tide in Sungai Tiram Laut and Sungai Tinggi, while it was higher in high tide than low tide in Sungai Jarum Mas and Sungai Sepetang (Figure 5(g)). During low tide, the lowest readings were recorded in Sungai Tiram Laut (mean: 12.44 ± 1.65 NTU) and the highest was recorded in Sungai Sepetang (mean: 64.56 ± 6.46 NTU). During the high tide, the lowest Turbidity was also in Sungai Tiram Laut (mean: 12.03 ± 1.69 NTU) and the highest was also in Sungai Sepetang (mean: 105.19 ± 16.64 NTU).

A possible explanation for the highest concentration of turbidity in Sungai Sepetang might be due to the industrial effluents and fertilizers and feed from shrimp farming brought by the tidal from the surrounding factories (Chong, 2006). In the same way, Islam *et al.* (2004) found that the excessive use of feed and fertilizers in shrimp culture in Sundarban Mangrove, Bangladesh caused considerable amount of nutrient input and consequently, raised the turbidity (77.67–439.00 NTU). Yisa and Jimoh (2010) discovered that high concentration of turbidity is attributed by waves and turbulence caused by winds and tides which facilitate the mixing of sediment with surface water river and streamflow.

For the eighth parameter analyzed, TSS was higher during the low tide in Sungai Tiram Laut, Sungai Jarum Mas, and Sungai Tinggi, while it was higher in the high tide for Sungai Sepetang (Figure 6(h)). TSS was lowest in Sungai Sepetang (mean: 3.97 ± 0.60 mgL-1), and highest in Sungai Tinggi (mean: 9.20 ± 0.84 mgL-1) during the low tide. Conversely, TSS was lowest in Sungai Tiram Laut (mean: 3.53 ± 0.30 mgL-1) and highest in Sungai Tinggi (mean: 7.44 ± 1.27 mgL-1) during the high tide.

Higher content of TSS could be contributed by the minerals and organic matter transported from the sea during tide transition as suggested by Gandaseca *et al.* (2011). The relatively higher TSS in Sungai Tinggi possibly due to less freshwater flow, bank erosion, and forest litter (Rahman *et al.*, 2013; Giri *et al.*, 2015). Besides, there is also land erosion due to fallen trees on riverbanks of the rivers, particularly in Sungai Tinggi, which influenced the high concentration of TSS during both low and high tides. Then, high variation in the TSS is also an indication of the change in the process parameter in the industrial units. Sathe *et al.* (2002) reported the similar increase in TSS in Waldhuni nalla of Thane creek, Mumbai, India.

Overall, the physicochemical parameters in MMFR portrayed remarkable tidal variation, particularly in some parameters. For instance, Turbidity and TSS showed distinct variation between low and high tides. However, there are contradictions of results found at Sungai Sepetang compared to other rivers, where both Turbidity and TSS were recorded higher in high tide which could be due to intensive land use and human activities in Kuala Sepetang area. The concentration of effluent and organic matter was greater during high tide which is reflected in the study. Although there was much research about the physicochemical parameters in mangrove, few of them focused on the tidal variation (i.e. Nurhidayu et al., 2020).

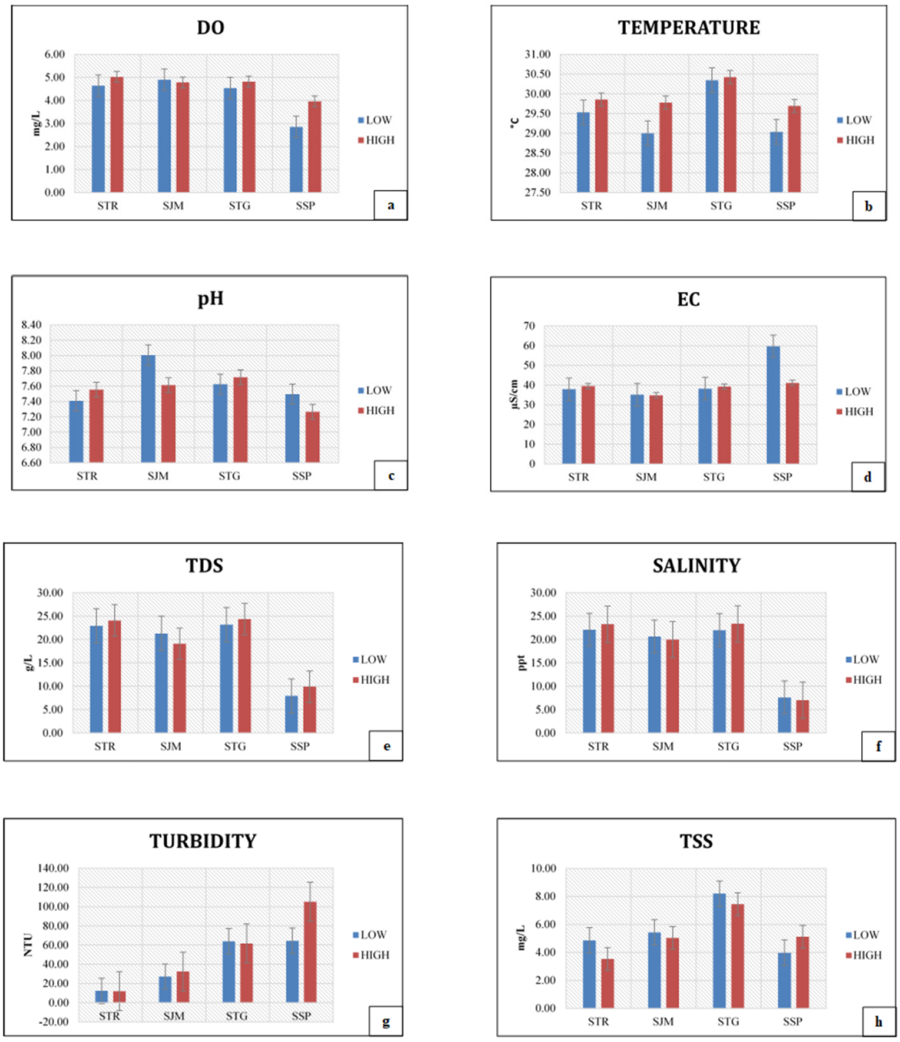

Figure 6. The seasonal variation of water physiochemical parameters with Standard Error for four rivers in Matang Mangrove ((a)DO - *Dissolved* Oxygen; (b) Temperature; (c) pH; (d) EC – Electric Conductivity; (e) TDS - Total *Dissolved* Solid; (f) Salinity; (g) Turbidity; (h) TSS – Total Suspended Solids; STR – Sg. Tiram Laut; SJM – Sg. Jarum Mas; STG – Sg. Tinggi; SSP – Sg. Sepetang)

Table 7. The ANOVA analysis of seasonal variation and tidal variation of physicochemical parameters for all rivers of Matang Mangrove Forest Reserve

Parameter	All rivers (Tidal)	All rivers (Seasonal)
EC	0.254	0.560
DO	0.015*	0.000*
pH	0.028*	0.000*
Turbidity	0.031*	0.214
TDS	0.208	0.000*
Salinity	0.833	0.000*
Temperature	0.000*	0.000*
TSS	0.762	0.000*

Note: *significant at 0.05

Table 8. The tidal variation of physicochemical parameters in four rivers in Matang Mangrove

Parameter	STR	SJM	STG	SSP
EC	0.18	0.81	0.43	0.21
DO	0.39	0.78	0.50	0.00*
pH	0.29	0.00*	0.38	0.00*
Turbidity	0.81	0.23	0.87	0.01*
TDS	0.06	0.32	0.17	0.16
Salinity	0.07	0.39	0.16	0.58
Temperature	0.13	0.00	0.62	0.00*
TSS	0.03*	0.52	0.65	0.19

Note: *significant at 0.05

4. Conclusion

Seasonal variation of physicochemical parameters in mangrove rivers highlighted several findings. It indicated that the different seasons influenced the variation of physicochemical parameters especially salinity, TSS, and TDS. Besides, high levels of TSS and turbidity were observed during wet period particularly in areas with highly concentrated human activities, such as Kuala Sepetang and Sungai Kerang. This finding indicated the flush of effluent through rain into the mangrove system, thus supporting the inference of the role of rainfall in regulating the water quality through pollutants sequestration. TSS is strongly correlated with turbidity, with higher TSS levels typically indicating increased turbidity. The evidence from seasonal variation analysis suggested that the intense pollution from land use changes and human activities deteriorates river water quality in the mangrove forest. Additional variations in the measurements of the physicochemical parameters as daily tidal transition occurs. Tidal transition involves the entry and exit of seawater into mangrove rivers, hence, influences the rate of saltwater intrusion. As a result, there are variations in concentrations of organic matter, sediment, and salinity. Moreover, narrower and shallower rivers had higher saltwater intrusion into mangrove as the seawater was relatively intense. Effects of intensive land use change and human activities can be shown through the tidal variation of the physicochemical parameters. While these findings offer valuable insights, a more in-depth and comprehensive study is recommended to gain a clearer understanding of the water quality conditions. To achieve a better assessment, it is essential to conduct further research directly within the Matang Mangrove Forest Reserve area. Continuous monitoring and detailed analysis of water quality will enhance our understanding of the hydrological dynamics and water quality status in this vital ecosystem. Such research will further contribute to the effective management and conservation of the mangroves, ensuring their health and resilience in the face of environmental changes.

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