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Spatial and Temporal Variability of Physico-chemical Parameters in Songsong Island, Kedah, Malaysia.

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ABSTRACT

Marine ecosystems are distinctive environments and habitats that are increasingly under threat from multiple pressures, including global warming, coastal development, pollution, and other human-induced impacts. Therefore, this study examines the seasonal variations in key physico-chemical parameters of seawater around Songsong Island, Kedah, Malaysia to better understand the environmental conditions influencing the local marine ecosystem. Data was collected from 12 stations during both the Southwest (SWM) and Northeast Monsoon (NEM) periods to address a knowledge gap in seasonal variability across the island. Seawater physico-chemical parameters measured included pH, salinity, temperature, conductivity, dissolved oxygen (DO), Total Ammoniacal-Nitrogen (TAN), and orthophosphate (PO_4^{3-}). Findings revealed moderate spatial and seasonal variability. Seawater pH decreased during the NEM (average pH 7.91 ± 0.033) compared to the SWM (7.96 ± 0.022). Besides, salinity increased slightly in the NEM (30.63–31.54 ppt) compared to the SWM (29.50–30.82 ppt). Thus, conductivity also increased during NEM (51.75 ± 3.84 mS/cm) compared to SWM (52.01 ± 0.44 mS/cm). Moreover, seawater temperature was higher during the SWM (30.57–31.01°C), while DO levels remained healthy across both seasons. Notably, TAN concentrations were much higher in the NEM (1.02 ± 0.317 mg/L) than in the SWM (0.04 ± 0.017 mg/L), possibly due to reduced dilution and anthropogenic inputs. Conversely, PO_4^{3-} levels were greater during the SWM with an (0.190 ± 0.0881 mg/L) compared to the NEM (0.050 mg/L ± 0.003 mg/L), with a much greater variability. Two-way ANOVA analyses confirmed that there is no significant difference between sampling stations while there are significant differences between monsoon seasons ($p < 0.05$) except for conductivity, highlighting spatial heterogeneity and seasonal influences. These results underline the impact of monsoonal dynamics, river discharge, rainfall and human activities on seawater characteristics. The study provides a valuable baseline for environmental monitoring and supports conservation and management strategies for coastal ecosystems around Songsong Island.

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INTRODUCTION

Physico-chemical parameters are critical indicators used to assess the quality and ecological integrity of marine environments (Marigo, 2014). These parameters encompass a range of measurable physical and chemical conditions of seawater, including temperature, pH, salinity, dissolved oxygen (DO), turbidity, and nutrient concentrations (such as nitrate, nitrite, ammonium, and phosphate). Each plays a unique and interconnected role in maintaining marine ecosystem functionality (Huang et al., 2020). Temperature, for example, influences the metabolic rates of aquatic organisms, seasonal species distribution, and the onset of spawning cycles (Beachum et al., 2019). A rise in sea surface temperature has been directly linked to coral bleaching events and altered fish migration routes (Hoegh-Guldberg et al., 2019). pH levels, which determine the acidity or alkalinity of seawater, have a significant impact on calcifying organisms like corals and shellfish, as ongoing ocean acidification driven by increased atmospheric CO_2 threatens their ability to build and maintain calcium carbonate structures (González-Gaya et al., 2023). Salinity, another crucial parameter, affects water density, osmoregulation in marine species, and circulation patterns that drive nutrient and oxygen distribution across marine basins.

Dissolved oxygen (DO) is vital for sustaining aerobic marine life; its depletion often indicates pollution, eutrophication, or restricted water circulation, leading to hypoxic conditions or 'dead zones' (Dreiss et al., 2024). Similarly, turbidity reflects the clarity of the water and is influenced by suspended solids from land runoff, erosion, or phytoplankton blooms. High turbidity can reduce sunlight penetration, which negatively impacts photosynthetic organisms like seagrasses and coral symbionts, leading to decreased productivity and biodiversity. Nutrient levels, especially when elevated due to anthropogenic inputs such as agricultural runoff or untreated sewage discharge, can cause nutrient enrichment or eutrophication, which leads to harmful algal blooms (HABs) and oxygen depletion in coastal zones (Brenckman et al., 2025).

Globally, monitoring these parameters has provided valuable insights into environmental changes and stressors. In the Great Barrier Reef, for instance, long-term water quality monitoring programs have revealed clear correlations between coastal nutrient runoff and reef degradation, prompting stricter land-use regulations (UNEP, 2021). In the Caribbean Sea, regional collaborations have emphasized the importance of temperature and pH monitoring to protect coral reef ecosystems from bleaching and acidification threats. Regionally in Southeast Asia, particularly in Malaysia, the seasonal monsoon cycles greatly influence these parameters, leading to variations in water quality between the Northeast and SWM periods.

Understanding the dynamics of physico-chemical parameters is essential not only for maintaining the ecological balance of marine systems but also for safeguarding the socio-economic benefits derived from them, such as fisheries, tourism, and coastal protection. These parameters serve as early warning indicators for marine pollution, climate change impacts, and biodiversity loss. As such, systematic and site-specific monitoring, especially in under-researched areas like Songsong Island, is necessary for guiding evidence-based conservation and sustainable management practices. By establishing physico-chemical baselines and tracking changes over time, researchers and policymakers can implement timely interventions to preserve marine biodiversity, ensure food security, and enhance ecosystem resilience in the face of global environmental change.

METHODOLOGY

Study area

Songsong Island is located off the northwestern coast of Peninsular Malaysia in the state of Kedah. The island lies within the Strait of Malacca and is influenced by a tropical monsoon climate, characterized by the northeast and southwest monsoon seasons. Seasonal variations in rainfall and riverine inputs also influence the physico-chemical properties of seawater in this area. Seawater sampling was conducted at twelve (12) stations (Figure 1) distributed around Songsong Island to represent the spatial variability of the

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surrounding marine environment. The geographical coordinates of each sampling station are provided in Table 1. Samples were collected during 1 cycle of the Southwest monsoon and Northeast monsoon. Each checkpoint was taken at 3 different depths which were the upper surface layer, middle and water in the seabed layer to ensure that the replicates taken are more accurate and more suitable for calculating the overall average. The surrounding waters are relatively shallow, with depths generally within 3 to 10 meters, and are subject to semi-diurnal tidal fluctuations. This area was chosen because it has a unique marine ecosystem such as coral reefs and other marine life. Songsong Island supports diverse marine ecosystems, including coastal and nearshore habitats that are potentially affected by anthropogenic activities such as tourism, fishing, and coastal development. These factors make the area suitable for investigating seasonal variations in seawater physico-chemical parameters and their implications for local marine environmental conditions.

Table 1. The geographical coordinates of each sampling station.

Station	Latitude	Longitude
S1	5°49′09.12″ N	100°17′44.93″ E
S2	5°48′51.98″ N	100°18′00.94″ E
S3	5°48′32.38″ N	100°18′21.16″ E
S4	5°48′44.64″ N	100°17′12.04″ E
S5	5°48′27.78″ N	100°17′29.18″ E
S6	5°48′08.94″ N	100°17′48.18″ E
S7	5°48′23.35″ N	100°16′42.75″ E
S8	5°48′06.21″ N	100°17′00.73″ E
S9	5°47′47.10″ N	100°17′19.00″ E
S10	5°47′23.74″ N	100°16′48.33″ E
S11	5°47′41.92″ N	100°16′30.03″ E
S12	5°47′59.79″ N	100°16′12.51″ E

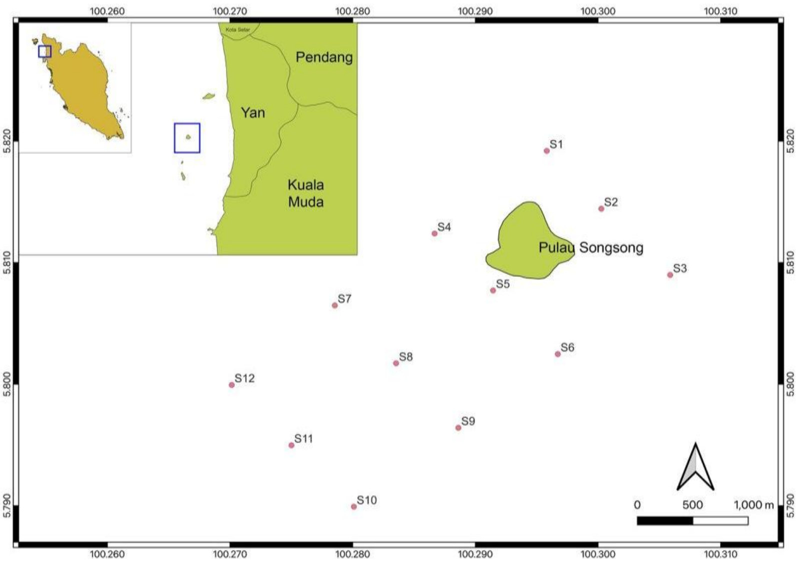

Fig. 1. The map of the sampling points area.

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Sample collection and preservation

Sample collection and preservation were conducted following the methods previously published by Dickson et al. (2007). The project has been done during the South-West Monsoon (Jun to August) and North-East Monsoon Seasons (December to February). The physical parameters (salinity, conductivity, temperature, pH and Dissolved Oxygen) were obtained in situ by using AML Oceanographic Plus X CTD in Fig. 2 for each station. Standard methods are used to calibrate the CTD prior to physical parameter measurements being taken in the field. Meanwhile, for seawater nutrients, water samples are collected from Niskin bottles into polyethylene bottles. Each checkpoint was taken at three different depths which were the upper surface layer, middle and bottom layer. Water samples were filtered on-site or as soon as possible after collection and stored at 4°C in an ice box or refrigerator. All samples were analyzed within 24–48 hours of sampling to ensure data quality.

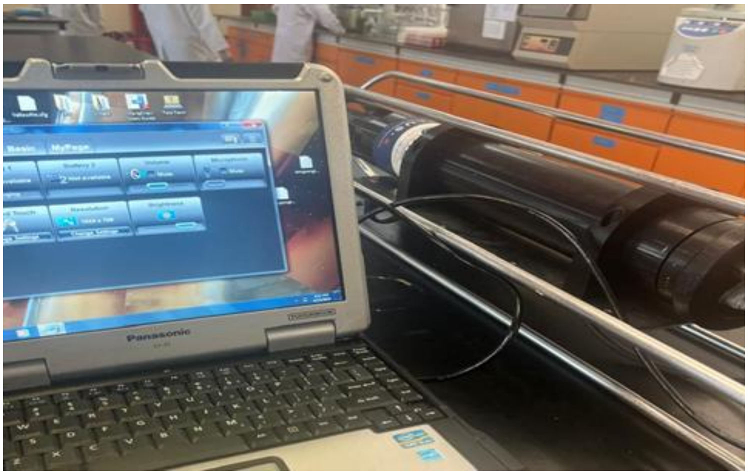

Fig. 2. The extraction information from the CTD into the laptop.

Analytical methods

In the laboratory, water quality of American Public Health Association (APHA) methods was employed to determine the concentrations of key nutrients including Total Ammoniacal-Nitrogen (TAN), and orthophosphate (PO_4^{3-}) (Hashim et al., 2023). These analyses followed standard procedures outlined by the American Public Health Association (APHA, 2017) and were carried out using a UV-Visible spectrophotometer. Blanks and standards were prepared and run alongside samples to ensure the reliability and reproducibility of the data. Together, these field and laboratory techniques allowed for comprehensive and precise monitoring of the physico-chemical environment in Songsong Island, supporting the overall objectives of understanding spatial and temporal water quality trends.

Statistical analysis

In this study, the analysis of (Two-Way ANOVA) was used. The mean ± standard deviation was used in this work to represent the data analysis outcomes. The two-way ANOVA (Analysis of Variance) is a statistical test used to evaluate the effects of two independent variables (factors) on one continuous dependent variable, as well as any interaction between the two factors. In all statistical analyses, a value of $p < 0.05$ was considered a significant difference. All statistical analyses are performed with SPSS 12.0 for Windows Release 12.0 and Microsoft Office Excel 2020 Data Analysis.

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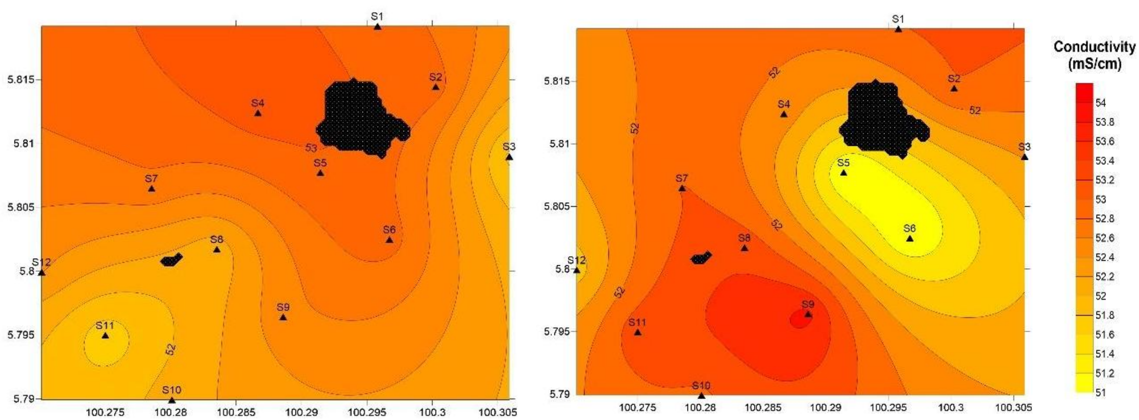
RESULTS AND DISCUSSION

The results of the study on the physico-chemical parameters in seawater in the Songsong Island area have been analyzed and arranged in Tables 4.1 and 4.2. It is shown that parameters such as salinity, temperature, pH, conductivity, dissolved oxygen, TAN and PO_4^{3-} concentration have been measured. All of these parameters are very important because they affect the biodiversity and ecosystem of marine life (Levesque, 2019). Temperature affects the rate at which gases dissolve, the rate at which life forms metabolize, and the density of seawater. The dataset presents clear seasonal differences in the physico-chemical parameters of seawater during the Southwest Monsoon (SWM) and Northeast Monsoon (NEM), with statistical analysis indicating there is no significant difference ($p > 0.05$) between sampling stations, while there are significant differences between monsoon seasons ($p < 0.05$) except for conductivity.

Table 2. The range and mean data of physico-chemical parameters during the SWM and NEM.

Parameter	SWM		NEM	
	Range	Mean ±STD	Range	Mean ± STD
Physical				
Conductivity (mS/cm)	51.94-53.28	51.75 ± 3.48	51.01-52.65	52.01 ± 0.44
DO (mg/L)	7.30-8.02	7.75 ± 0.23	7.17-8.00	7.66 ± 0.23
pH	7.93-8.00	7.96 ± 0.02	7.86-7.95	7.91 ± 0.03
Salinity (ppt)	29.54-31.13	30.72 ± 0.42	30.63-31.54	31.20 ± 0.30
Temp (°C)	30.53-30.99	30.80 ± 0.16	28.96-29.51	29.17 ± 0.17
Chemical				
TAN (mg/L)	0.018-0.078	0.04 ± 0.02	0.687-1.813	1.02 ± 0.31
PO_4^{3-} (mg/L)	0.078-0.356	0.19 ± 0.08	0.052-0.059	0.050 ± 0.003

Based on Table 2, conductivity during the SWM ranged from 51.94 to 53.28 mS/cm, with a mean of 51.75 ± 3.48 mS/cm, indicating dilution effects likely due to increased freshwater input from rainfall or river discharge during the SWM season. In contrast, during the NEM, conductivity was significantly lower, ranging from 51.01 to 52.65 mS/cm with a mean of 52.01 ± 0.44 suggesting higher ionic content in the water. This shows a clear seasonal variation in seawater conductivity around Songsong Island. During the SWM (Fig. 3(a)), conductivity values range from approximately 51-53 mS/cm, with lower conductivity detected near the southern stations such as S1 and S2, likely influenced by increased freshwater input from rainfall and runoff in this monsoon period. This dilution effect reduces the concentration of ions in seawater, resulting in lower conductivity, which is consistent with the observed lower salinity values during this season (Tan et al., 2023).



(a) (b)

Fig. 3. Contour map of Conductivity during (a) SWM and (b) NEM

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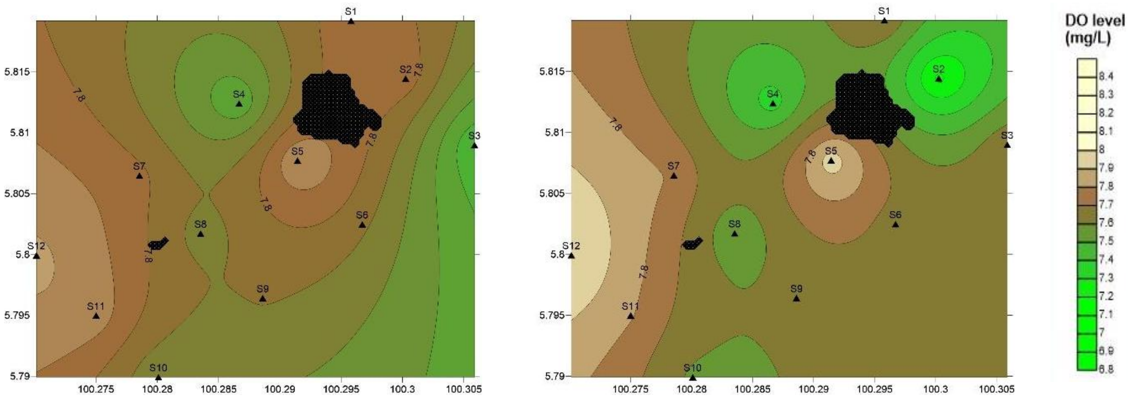
In contrast, the NEM in Fig. 3(b) exhibits generally higher conductivity values up to around 54.0 mS/cm especially concentrated near stations S8 and S9. This pattern is associated with drier atmospheric conditions and reduced freshwater influx, allowing seawater to retain more dissolved salts and ions, thus increasing conductivity (Mondal et al., 2010). The spatial gradient from higher to lower conductivity zones suggests limited mixing in nearshore waters and highlights areas of greater marine ionic concentration during this period. According to statistical analysis (two-way ANOVA), there are no significant differences between monsoon season ($p = 0.806$, $p > 0.05$), which are both controlled by seasonal monsoon-driven hydrological processes such as rainfall, evaporation, and freshwater discharge. Conductivity can therefore serve as a reliable proxy for assessing coastal salinity dynamics, particularly in small island ecosystems where seasonal freshwater fluxes are pronounced.

Besides, Dissolved Oxygen (DO) levels that were shown in Table 2 were notably higher during the NEM compared to SWM. During the SWM (Fig. 4(a)), DO levels across most stations range between 7.30 and 8.02 mg/L, with slightly lower concentrations observed in central zones, especially near stations S4 and S6. This reduced DO may be linked to higher seawater temperatures during this season (above 30°C), which decreases oxygen solubility and increases microbial respiration rates, resulting in lower available oxygen in the water column (Ahmad et al., 2023). In contrast, the NEM Fig. 4 (b) exhibits higher and more stable DO concentrations, particularly around station S2, reaching up to 8.4 mg/L. The DO-rich zones in this season can be attributed to cooler temperatures, which enhance oxygen solubility, and potentially greater vertical mixing due to wind activity, allowing oxygen-rich surface water to mix into deeper layers (Tan et al., 2022).



(a) (b)

Fig. 4. Contour map of DO during (a) SWM and (b) NEM

The maps also show that DO distribution tends to form localized zones, indicating that station-specific biological activity (phytoplankton photosynthesis or organic matter decay) may also influence oxygen availability. The observed pattern aligns with the statistically significant seasonal variation in DO with ($p= 4.27\times10^{-4}$, $p < 0.05$) Fig. 4 confirming that seasonality plays a major role in shaping the oxygen dynamics around Songsong Island.

Furthermore, as shown in Table 4.1, pH values differed between the two monsoon periods, with slightly higher values recorded during the SWM (7.96 ± 0.02) compared to the NEM (7.91 ± 0.03). Although the observed variation is small, it may reflect seasonal influences such as changes in biological activity, photosynthetic processes, and freshwater input, all of which can modify seawater carbonate chemistry. A slight decrease in pH during the NEM in Fig. 5(b) is likely associated with cooler water temperatures and an increased contribution of dissolved CO_2. Statistical analysis of pH indicated that this variation has a

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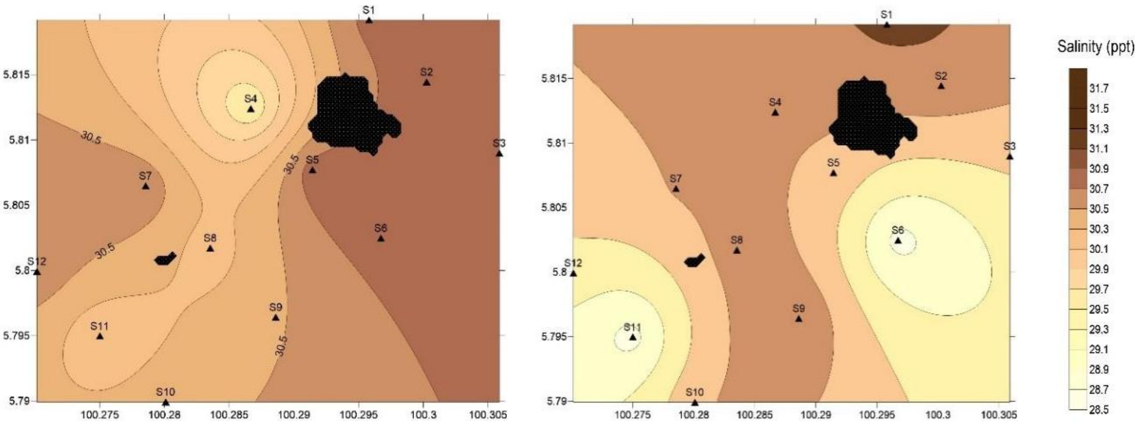
significant difference (p= 5.86x10^{-4}, p < 0.05). Nevertheless, even minor fluctuations in seawater pH can have ecological implications, particularly for calcifying organisms such as corals and mollusks, as reduced pH conditions may interfere with calcification processes, including shell and skeletal formation.

Next, based on Fig. 6, the salinity distribution shows a statistically significant difference between monsoon seasonal (p= 1.32 × 10-2 < 0.05) and an increase from SWM (29.54–31.13 ppt; mean 30.72 ± 0.42 ppt) to NEM (30.63–31.54 ppt; mean 31.20 ± 0.30 ppt), likely influenced by reduced freshwater input or increased saline intrusion during the drier NEM. According to Wong & Li (2020), rainfall can significantly influence salinity levels in seawater, particularly in coastal and estuarine environments, where the balance between freshwater and seawater is more sensitive.



(a) (b)

Fig. 6. Contour map of salinity during (a) SWM and (b) NEM

Moreover, Zainudin et al. (2022) stated that the influx of large volumes of freshwater will dilute the concentration of dissolved salts, leading to a decrease in salinity, especially in the surface water layer. During NEM seasons, the reduction in freshwater input, combined with increased evaporation, can lead to higher salinity values due to the concentration of salts in the remaining seawater. This statement was supported by Tan et al. (2023) who stated that SWM, often associated with heavier rainfall in the western coastal zones, tends to lower salinity values in nearshore waters, while the NEM, which brings less rainfall to the west coast, may allow salinity to rise slightly due to reduced freshwater dilution.

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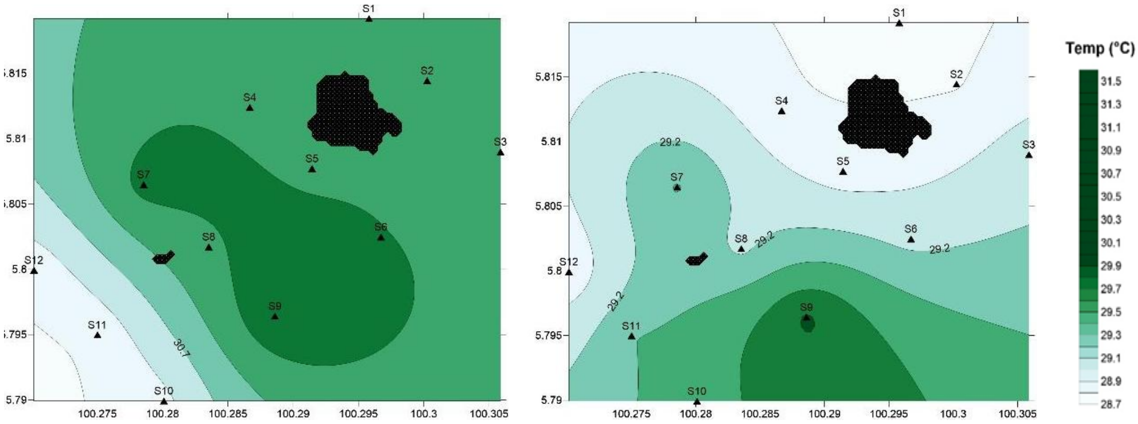
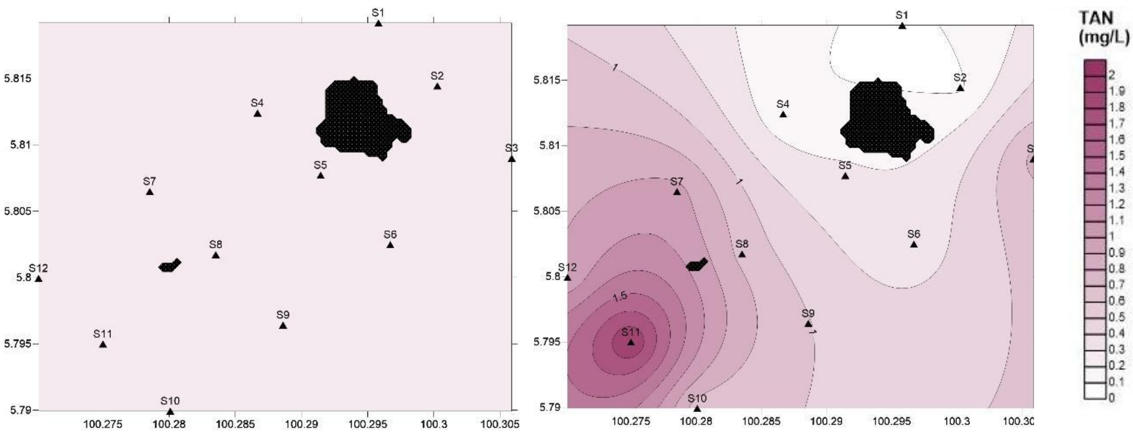


(a) (b)

Fig. 7. Contour map of temperature during (a) SWM and (b) NEM

In addition, coastal tropical temperatures during NEM would range from 28°C to 30°C. Meanwhile, the SWM values are reported within a realistic tropical range of 30.53°C to 30.99°C, consistent with warmer sea surface temperatures during this season. From Fig. 7(a) above, the temperature during the SWM is lower than the temperature during the northwest monsoon season. This is because the process of upwelling that happens in the seawater during NEM. Extreme upwelling events can cause near-surface temperatures to drop dramatically within a short period (Wirasatriya et al., 2023.) The temperature is strongly validated by a highly significant difference between monsoon seasons ($p = 4.92 \times 10^{-11}$, $p > 0.05$).

In Table 2, the TAN concentrations during the NEM were significantly elevated (0.687–1.813 mg/L, mean 1.02 ± 0.31 mg/L) compared to the SWM (0.018–0.078 mg/L, mean 0.04 ± 0.02 mg/L). This increase suggests higher nutrient loading during the NEM, potentially due to runoff, upwelling, or anthropogenic sources such as agricultural or urban discharge. During the SWM shown in Fig. 8 (a), TAN concentrations remain very low and uniform, with minimal spatial variation observed across all stations. This pattern is likely due to higher rainfall and water mixing, which dilute nutrient concentrations and enhance dispersion, thereby limiting ammonia accumulation in coastal waters (Zainudin et al., 2022).



(a) (b)

Fig. 8. Contour map of TAN during (a) SWM and (b) NEM

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Conversely, the NEM Fig. 8(b) reveals significantly elevated TAN levels, particularly around station S11, where concentrations exceed 1.813 mg/L. The map shows a strong concentration gradient, indicating localized nutrient accumulation possibly linked to limited freshwater inflow, reduced vertical mixing, and retention of organic matter, which leads to enhanced ammonification processes. The lower rainfall during the NEM reduces flushing of coastal waters, allowing ammonia derived from organic decay, sewage, or land runoff to accumulate in the water column (Tan et al., 2023). This seasonal difference in TAN distribution aligns with the statistical findings in Table 4.1, where TAN shows a significant seasonal variation ($p = 2.91 \times 10^{-4}$, $p < 0.05$). High TAN levels during the dry season may also lead to an upwelling event at the Northern Strait of Malacca. The presence of a seasonal cyclonic eddy during the NEM also contributes to upwelling, enhancing nutrient availability and supporting higher primary productivity (Mandal et al., 2021).

Lastly, PO_4^{3-} concentration levels exhibited the opposite trend (Table 4.1). During the SWM, concentrations were higher (0.19 ± 0.08 mg/L) compared to the NEM (0.050 ± 0.001 mg/L) with a significant difference (p= 4.79 x10-7, $p < 0.05$), suggesting a seasonal difference in nutrient cycling. The distribution of PO_4^{3-} in the waters surrounding Songsong Island exhibits notable seasonal variation, as illustrated in Fig. 9. During the SWM (Fig. 9(a)), PO_4^{3-} concentrations were more spatially varied, with elevated levels particularly observed around Station S12. This pattern may be attributed to increased terrestrial runoff, organic matter input, and potentially limited flushing mechanisms, all of which are common during the heavy rainfall period of the SWM (Hashim et al., 2022). Elevated PO_4^{3-} levels in coastal waters are often linked to decomposition of organic matter, wastewater discharge, and anthropogenic nutrient loading, which can trigger localised eutrophication and deteriorate water quality (Ismail et al., 2023).

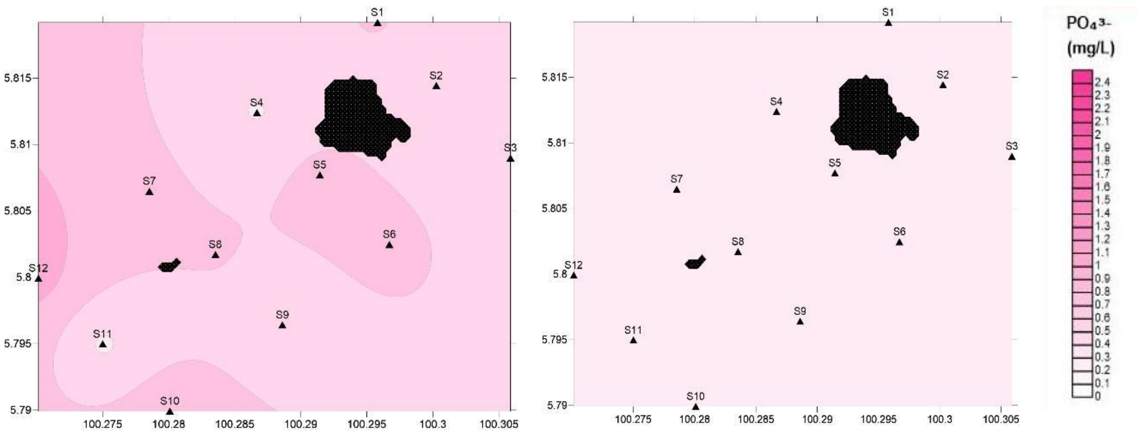

Fig. 9. Contour map of PO_4^{3-} during (a) SWM and (b) NEM

In contrast, during the NEM in Fig. 9 (b), PO_4^{3-} levels appeared to be more uniform and generally lower across all stations. This may result from enhanced water circulation and mixing, which promote dilution and dispersion of nutrients (Azmi et al., 2021). The reduced concentrations during this period suggest lesser nutrient accumulation and improved water quality, aligning with typical seasonal hydrodynamic patterns observed in tropical marine environments. These findings underscore the seasonal influence on phosphate dynamics and highlight the need for continuous monitoring, especially during periods prone to nutrient enrichment.

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CONCLUSION

In conclusion, this study has achieved the first objective of examining the change pattern of physicochemical properties in the coral reef ecosystem of Songsong Island. Clearly, this study provides a deeper understanding of the nature of each physicochemical chemistry. The process of fluctuation of physicochemical parameters of seawater is closely related to the upwelling process due to seasonal monsoon factors. The upwelling process during NEM really affects the study area and changes the water parameters. Two-way ANOVA analyses confirmed that there is no significant difference between sampling stations, while there are significant differences between monsoon seasons ($p < 0.05$) except for conductivity. Therefore, this study recommends that seawater quality monitoring be carried out continuously covering both monsoon seasons to understand the seasonal variations for each parameter such as salinity, conductivity, temperature, DO, TAN, phosphate, alkalinity, pH, fugacity, aragonite and calcite. These parameters need to be monitored consistently because long-term monitoring will provide trends for easy understanding of seawater quality conditions as well as dynamic climate changes that will occur in Songsong Island in the future.

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AUTHOR’S CONTRIBUTION

Nurul Hidayah Bt Rosmee carried out the research, wrote and revised the article. Dr Jamil Tajam Mohd Azlan Bin Mohd Ishak, Sabiha Hanim Bt Saleh, Aileen Tan Shau Hwai, Khairul Naim Bin Abd. Aziz and Md Nizam Bin Ismail conceptualised the central research idea and provided the theoretical framework. They also designed the research, supervised research progress, anchored the review, revisions and approved the article submission.

CONFLICT OF INTEREST STATEMENTS

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare absence of conflicting interests with the funders. The authors declare that there are no personal or financial conflicts of interest that could have influenced the research reported in this paper. All affiliations, funding sources, and other potential conflicts have been fully disclosed and managed in accordance with institutional guidelines to ensure objectivity and transparency in the research process.

REFERENCES

Ahmad, M. H., Ismail, W. R., & Lim, S. Y. (2023). Monsoonal variation of marine water quality in Peninsular Malaysia. *Journal of Environmental Marine Science*, 15(1), 45–59. https://doi.org/10.1016/j.jems.2023.01.004

Beachum, C. E., Michel, M. J., & Knouft, J. H. (2019). Metabolic rates from Bluntnose minnow (*Pimephales notatus*) populations at lower latitudes are more sensitive to changes in temperature than populations at higher latitudes. March 1–10. https://doi.org/10.1111/eff.12507

https://doi.org/10.24191/scl.v20i2.10571

Brenckman, C. M., Jayalakshmamma, M. P., Pennock, W. H., Ashraf, F., & Borgaonkar, A. D. (2025). A Review of Harmful Algal Blooms: Causes, Effects , Monitoring , and Prevention Methods. 1–26.

Department of Environment Malaysia (DOE). (2019). Malaysia Marine Water Quality Criteria and Standard (MMWQS). Putrajaya: Ministry of Natural Resources and Environment.

Department of Environment Malaysia (DOE). (2019). Malaysia Marine Water Quality Criteria and Standard (MMWQS). Putrajaya: Ministry of Natural Resources and Environment.

Dreiss, A., Reza, A., Anna, A., Seyedeh, H., Pourreza, F., Syeda, A., Ali, S., Malabanan, V., Qian, L., Laura, Z., Ryan, L. L., Lora, J. W., & Testa, J. M. (2024). Controls on Oxygen Variability and Depletion in the Patuxent River Estuary. Estuaries and Coasts, 47(8), 2306–2323. https://doi.org/10.1007/s12237-024-01390-3

González-Gaya, B., Martínez-Varela, A., Roscales, J. L., & Echeveste, P. (2023). Emerging pollutants and their interactions with marine biogeochemical cycles. Marine Pollution Bulletin, 189, 115927. https://doi.org/10.1016/j.marpolbul.2023.115927

Hashim, A. R., Kamaruddin, S. A., Abd.Aziz, K. N., Tajam, J., Buyong, F., Che-Zulkifli, C. I., Abdullah, A. L., Azis, T. M. F., & Anscelly, A. (2023). Assessment of The Current Spatial-Temporal Variations of Total Dissolved Solids On the Surface Waters of Kuala Perlis, Perlis. Journal of Academia, 11(1), 47–63. https://myjms.mohe.gov.my/index.php/joa/article/view/20842

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., ... & Knowlton, N. (2019). Coral reefs under rapid climate change and ocean acidification. Science, 318(5857), 1737–1742. https://doi.org/10.1126/science.1152509

Huang, W., Kao, K., Lin, Y., Chen, C. A., & Liu, J. T. (2020). Estuarine , Coastal and Shelf Science Daily to weekly impacts of mixing and biological activity on carbonate dynamics in a large river-dominated shelf. Estuarine, Coastal and Shelf Science, 245(June), 106914. https://doi.org/10.1016/j.ecss.2020.106914

Ismail, W. R., Ahmad, M. H., & Zaki, M. (2020). Marine water quality monitoring and assessment in Malaysia: A review. Malaysian Journal of Environmental Management, 21(2), 33–49.

Jalil, M. A., Zainal, N. A., & Yusuf, M. N. (2021). Seasonal variability of nutrient loading and salinity in estuarine waters of Kedah, Malaysia. Asian Journal of Environmental Management, 5(2), 22–34.

Kamaruzzaman, B. Y., Ong, M. C., & Jalal, K. C. A. (2020). Physicochemical characteristics of Malaysian coastal waters in relation to seasonal variation. Malaysian Journal of Science, 39(2), 45–52. https://doi.org/10.22452/mjs.vol39no2.5

Levesque, J. C. (2019). Spatio-temporal patterns of the oceanic conditions and nearshore marine community in the Mid-Atlantic Bight. https://doi.org/10.7717/peerj.7927

Lim, W. Y., Mohamed, C. A. R., & Zainudin, M. F. (2022). Seasonal variability of water quality in Terengganu coastal waters, Malaysia. Environmental Monitoring and Assessment, 194, 369. https://doi.org/10.1007/s10661-022-10151-5

Malik, R. A., Hashim, M., & Tan, C. L. (2021). Meteorological drivers of ocean surface temperature in Malaysia. Marine Climate Research, 9(3), 118–130.

Marigo, I. (2014). Environmental Risk Assessment, Marine. 2, 398–401. https://doi.org/10.1016/B978-0-12-386454-3.00556-X

https://doi.org/10.24191/scl.v20i2.10571

Mondal, N. C., Singh, V. P., Singh, V. S., & Saxena, V. K. (2010). Determining the interaction between groundwater and saline water through groundwater major ions chemistry. Journal of Hydrology, 388(1–2), 100–111. https://doi.org/10.1016/j.jhydrol.2010.04.032

Rahim, S. A., Hashim, M., & Tan, C. L. (2022). Spatio-temporal trends of marine pollution in Peninsular Malaysia using integrated monitoring and remote sensing. Marine Pollution Bulletin, 183, 114054. https://doi.org/10.1016/j.marpolbul.2022.114054

Roslee, R., Tan, K. S., & Omar, W. A. (2023). Physico-chemical patterns in the Langkawi archipelago during contrasting monsoon seasons. Journal of Marine and Coastal Research, 12(1), 66–78.

Said, S. N., Hashim, N. O., & Ahmad, W. R. (2020). Coral reef water quality and tourism impact in Pulau Payar Marine Park. Journal of Aquatic Science and Conservation, 8(3), 45–57.

Salleh, S. F., Lim, W. L., & Yusof, N. (2021). Institutional collaboration for sustainable coastal water quality management in Malaysia. Ocean and Coastal Governance, 5(1), 72–88.

Tan, K. S., Jalaludin, A. A., & Roslee, R. (2022). Seasonal dynamics of nutrients and ammonia in Malaysian coastal zones. Environmental Pollution and Monitoring, 38(4), 98–110.

Tan, K. S., Roslee, R., & Jalaludin, A. A. (2023). Monsoonal influence on coastal salinity and nutrient dynamics in Malaysian nearshore waters. Journal of Ocean and Coastal Monitoring, 17(1), 55–68. https://doi.org/10.1016/j.jocm.2023.03.006

U.S. Environmental Protection Agency (EPA). (2024). Water Quality Criteria for Dissolved Oxygen in Coastal Waters. https://www.epa.gov

United Nations Environment Programme (UNEP). (2021). State of the Ocean and Coastal Areas 2021. Nairobi, Kenya: UNEP.

Wirasatriya, the, I. N., Of, S., Alor, T. H. E., & Island, A. (n.d.). *EXTREME UPWELLING EVENTS IN THE SEAS OF THE ALOR KECIL*. *36*(1), 28–37.

Zainudin, Z., Mohd Sopian, N. A., & Rani, N. A. (2021). Monsoon impacts on dissolved oxygen and salinity in Malaysian coastal waters. Marine Environmental Assessment, 29(2), 112–124.

https://doi.org/10.24191/scl.v20i2.10571