MJSAT

Malaysian Journal of Science and Advanced Technology

journal homepage: https://mjsat.com.my/

The Spatial and Temporal Variability Physicochemical Seawater Parameter in Dangli Island of Langkawi, Malaysia

Nurul Hidayah Rosmee[1], Jamil Tajam*[1], Mohd Azlan Mohd Ishak[2] Sabiha Hanim Saleh[2], Aileen Tan Shau Hwai[3], Khairul Naim Abd. Aziz[1], and Md Nizam Ismail[4]

[1]*Marine Research Station (MARES), Faculty of Applied Sciences, Universiti Teknologi MARA, Arau Campus, 02600 Arau, Perlis, Malaysia.*

[2]*School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.*

[3]*Centre for Marine and Coastal Studies, Universiti Sains Malaysia, Penang, Malaysia.*

[4]*Fisheries Research Institute, 11960, Batu Maung, Pulau Pinang, Malaysia.*

KEYWORDS

Physico-chemical parameter
Seawater
Seasonal,
Dangli Island

ARTICLE HISTORY

Received 22 November 2025
Available online 21 August 2026

ABSTRACT

Marine environments that are subject to seasonal changes are increasingly exposed to various factors, such as water pollution, climate change, coastal development and human impacts. Therefore, this study examined seasonal changes in the main physicochemical parameters of seawater around Dangli Island, Langkawi, Malaysia to better understand the environmental conditions that affect the local marine ecosystem. This study examined seasonal variations in the main physicochemical parameters of seawater such as salinity, temperature, conductivity, pH, dissolved oxygen (DO), Total Ammoniacal Nitrogen (TAN) and Orthophosphate (PO_4^{3-}) between twelve monitoring stations D1–D12 around Dangli Island during the Southwest and Northwest Monsoons. The results showed a significant difference between the Southwest Monsoon (SWM) season which exhibited higher salinity up to 31.16 ppt, temperature up to 30.62°C and conductivity, while the Northwest Monsoon (NEM) was recorded with cooler temperatures as low as 28.73°C and a slight increase in dissolved oxygen in some areas. This phenomenon causes the ocean to absorb CO_2 and control ocean acidification. Warmer waters during NEM can reduce CO_2 solubility, while cooler, oxygenrich SWM conditions increase CO_2 uptake, potentially increasing acidification. By studying and understanding how these seasonal conditions affect ocean chemistry, it can help assess the long-term impacts of climate change on the marine environment of Dangli Island and allow us to prepare early conservation strategies for the future. These factors can be influenced by seasonal variations and upwelling phenomenon. Two-way ANOVA results demonstrated all physico-chemical parameter have no significant difference between sampling stations ($p > 0.05$). In addion, there have high significant differences between monsoon seasons ($p < 0.05$) except for conductivity and DO level. The variations in the physicochemical properties of seawater around Dangli Island has reveals the influences of the by rainfall, river discharges, and upwelling phenomenon on stratification shifts that shows the differences in the distribution of seawater physico-chemical parameters.

1. INTRODUCTION

Seawater physicochemical parameter refers to the physical and chemical characteristics of seawater that together control its quality, behavior, and ecological functioning. This is very important in determining air quality, habitat suitability and the level of potential stress on marine organisms in an area such as Dangli Island. Seawater physicochemical parameter consists of parameters such as temperature, salinity, pH,

*Corresponding author:
E-mail address: Jamil bin Tajam < jamiltajam@uitm.edu.my >.
https://doi.org/10.56532/mjsat.v6iS1.803

dissolved oxygen (DO) and nutrient levels such as total ammoniacal-nitrogen and orthophosphate are important indicators of water quality and ecosystem health. These parameters influence marine biodiversity, coral reef resilience, and the productivity of coastal ecosystems.

In tropical coastal regions, such as those in Malaysia, physicochemical properties are strongly influenced by seasonal monsoons, freshwater inflows, land runoff, and anthropogenic activities. The cause of the decrease in marine life such as seashells, mussels and other carbonate marine animals must have related to the changes in the physicochemical seawater conditions in Dangli, and they were searched and identified in the area. The geographical conditions of Dangli Island, which is open in the northern sea of the Strait of Malacca, have been exposed to various seawater flows, mostly from the Indian Ocean, which allows for changes in conditions in seawater parameters. These parameters affect biological processes, chemical reactions, and overall functioning of the coastal ecosystem [1].

Temperature has an effect on the solubility of gases, the stratification of the water column, and the metabolic rate of marine organisms. In turn, the balance between the inflow of fresh and salt water into the ocean is represented by salinity, which is often influenced by evaporation, precipitation, and river discharge. Rising atmospheric CO2 levels are causing the global problem of ocean acidification, which is directly related to pH, which is a measure of how high or low the pH of a saltwater body is [2]. Aerobic life depends on the level of dissolved oxygen (DO), and variations in it can indicate pollution, algal bloom, or eutrophication. Conductivity is used to measure the ionic strength of water and usually correlates with salinity, providing insights into the mixing of freshwater and seawater [3].

Furthermore, water nutrient such as orthophosphate and total ammonia-nitrogen are essential for the daily processes of primary productivity but can be harmful in high concentrations. These substances are often present from land-based sources, including as aquaculture effluents, sewage discharges and agricultural runoff. High concentrations can result in the phenomenon of eutrophication, a condition in which nutrients are excessively enriched, which depletes oxygen and damages habitats [4]. Therefore, it is important to monitor the physicochemical properties of coastal waters to determine the level of pollution, understand environmental changes and practice efficient coastal zone management. To identify changes in water composition quality and ecosystem health, it is important to assess these indicators across multiple temporal scales due to the dynamics of the seasonally driven Southeast Asian monsoon system, such as the Northeast and Southwest Malaysian Monsoons. [5].

2. METHODS

2.1 Study Area

Dangli Island of Langkawi will be selected as the sampling site in this study (Fig 1). This area was chosen because it has a unique marine ecosystem with a lot of abundance marine life and coral reef site area. Dangli Island is a small, uninhabited rocky islet located about 3–4 km (around 2 miles) off the northern coast of Langkawi. Despite its small size, Dangli is well known for its coral reefs, and marine biodiversity, making it a popular spot for snorkeling, scuba-diving, eco-tourism and research areas.

The NEM season occurs from January to March every year in our country making it exposed to water from the Indian Ocean through the Andaman Sea. Therefore, the region in the North Straits of Malacca (NSOM) which is near Dangli Island will have a high level of bio-productivity due to any physical mechanism that can provide nutrients to the water's surface. There were 12 sampling stations with 3 replicates, and the coordinates were recorded by using Global Positioning System (GPS) and Google Earth software (Table 1).

Table 1. The number of station and the coordinate of Dangli Island.

Station	Latitude	Longitude
D1	6° 26' 46.6008" N	99° 46' 06.2004" E
D2	6° 26' 28.4820" N	99° 46' 24.7908" E
D3	6° 26' 10.6404" N	99° 46' 43.0248" E
D4	6° 27' 09.9000" N	99° 46' 37.4520" E
D5	6° 26' 51.7128" N	99° 46' 56.1432" E
D6	6° 26' 33.6120" N	99° 47' 13.7976" E
D7	6° 27' 33.0588" N	99° 47' 08.7612" E
D8	6° 27' 14.4072" N	99° 47' 27.5712" E
D9	6° 26' 56.8176" N	99° 47' 44.8872" E
D10	6° 27' 55.8072" N	99° 47' 39.5412" E
D11	6° 27' 37.7532" N	99° 47' 57.5592" E
D12	6° 27' 20.2248" N	99° 48' 15.2928" E

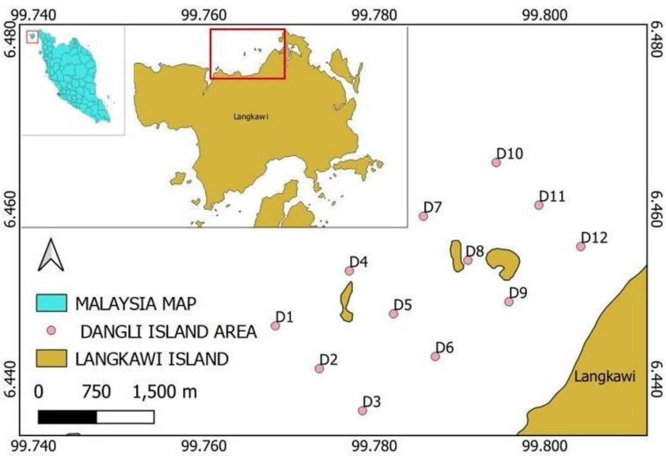


Fig. 1. The map of sampling points area for Dangli Island

2.2 Sample Collection and Preservation

Field measurements were carried out during South-West Monsoon (Jun to August) and North-East Monsoon Seasons (December to February). The physical parameters (salinity, conductivity, temperature, pH and Dissolved Oxygen) will be obtained in-situ. A combination of in-situ instrumentation and laboratory-based analysis was used to accurately assess the temporal and geographic variability of physico-chemical parameters in the waters around Dangli Island, Langkawi (Figure 1). Various important parameters such as temperature, salinity, pH, dissolved oxygen (DO) and conductivity were measured simultaneously using multi-parameter seawater quality devices, such as CTD (Figure 2), DO meters and pH meters, which are mainly used for field measurements.

These sondes were calibrated prior to each field deployment following the manufacturer's guidelines to ensure data accuracy. Multiple sites covering varying seawater depths were used for the measurements. Seawater depth data were recorded using a CTD instrument (Conductivity, Temperature and Depth sensor). This instrument provided high-resolution vertical data that was important for understanding the stability, mixing and stratification of the seawater column. Water samples were taken using Niskin bottles at predetermined depths for seawater nutrient analysis. They were then filtered with an instant filter and stored in acid-washed plastic bottles. Then, the samples had to be brought to the laboratory for further examination within a day. So, the samples were placed and stored in an ice box to maintain the quality and composition of the seawater.

2.3 Analytical methods

Sample collection and preservation will be conducted following the methods previously published by (Dickson et al., 2007). The amounts of important nutrients, such as nitrate, total ammoniacal nitrogen (TAN), and orthophosphate (PO_4^{3-}), were measured using water quality APHA techniques. A UV- visible spectrophotometer was used for these tests, which were conducted in accordance with the American Public Health Association's standard operating procedures (APHA, 2017). In particular, the cadmium reduction method was used for nitrate determination, the phenate method for ammonium, and the ascorbic acid method for orthophosphate. Blanks and standards were prepared and run alongside samples to ensure the reliability and reproducibility of the data. Overall, the field work and analysis through laboratory experiments can provide more accurate and comprehensive physico-chemical environment monitoring data on Dangli Island. This supports the objective of examining the pattern of changes in the physico-chemical quality of seawater through spatial and temporal variation factors.

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

2.4 Statistical analysis

In this study, the analysis of (Two-Way ANOVA), were 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. It is particularly useful when researchers want to determine not only the individual (main) effects of each factor but also whether the effect of one factor depends on the level of the other (interaction effect).

For example, in environmental studies, a two-way ANOVA can be used to examine how seasonal variation (Southwest vs. Northeast Monsoon) and sampling location (different stations). In short, two-Way ANOVA analysis is applied to the data. In all statistical analyses, a value of ($p < 0.05$) was considered to signify a significant difference. All statistical analyses are performed with SPSS 12.0 for Windows Release 12.0 and Microsoft Office Excel 2020 Data Analysis.

3. RESULT AND DISCUSSION

The results of the study on the physico-chemical parameters in seawater in the Dangli Island area have been analyzed and arranged in tables (Tables 2). It is shown that parameters such as salinity, temperature, pH, conductivity, dissolved oxygen, orthophosphate distribution and TAN distribution have been measured. All these parameters are very important because they affect the biodiversity and ecosystem of marine life. Temperature affects the rate at which gases dissolve, the rate at which life forms metabolism, and the density of seawater.

Two-way ANOVA results demonstrated all physico-chemical parameters have no significant difference between sampling stations ($p > 0.05$). 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 that all parameters show a significant difference between the monsoon seasonals ($p < 0.05$) except for conductivity and DO value. Table 2 below shows the average and standard deviation data for physico-chemical during SWM and NEM of Dangli.

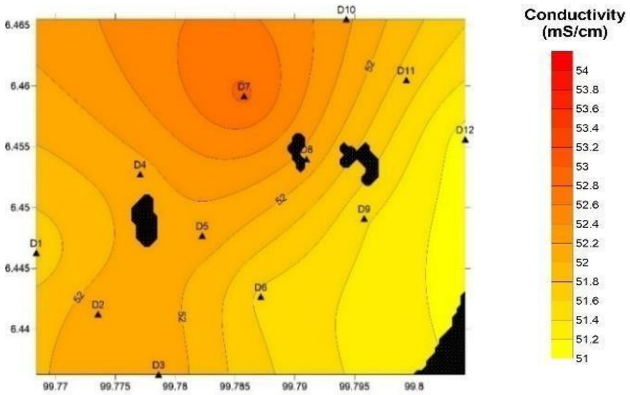
Table 2. The average and standard deviation data for physico-chemical during SWM and NEM of Dangli Island.

Parameter	SWM		NEM	
	Range	Mean ± STD	Range	Mean ± STD
Physical				
Con(mS/cm)	49.00-52.24	51.56 ± 0.92	49.73-52.67	52.01 ± 0.90
DO (mg/L)	6.79-8.37	7.88 ± 0.58	7.91-8.22	8.03 ± 0.10
pH	8.04-8.13	8.09 ± 0.03	8.09-8.23	8.16 ± 0.04
Salinity (ppt)	29.61-31.16	30.15 ± 0.65	30.84-31.80	31.57 ± 0.41
Temp (°C)	30.33-30.62	30.50 ± 0.10	28.74-29.92	29.04 ± 0.31
Chemical				
TAN (mg/L)	0.000-0.161	0.10 ± 0.07	0.279-2.060	1.24 ± 0.62
PO_4^{3-}(mg/L)	0.000-0.911	0.15± 0.25	0.000-2.445	0.90 ± 0.88

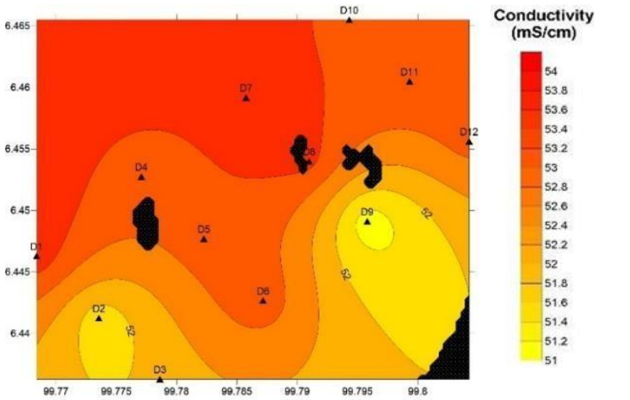
3.1 *Conductivity distribution*

The analysis revealed distinct seasonal variability in all physical parameters. Conductivity increased slightly from an average of 51.56 ± 0.92 mS/cm in the SWM to 52.01 ± 0.90 mS/cm in the NEM. This increase in data suggests that there is less freshwater inflow and rainfall during the NEM, which increases ionic concentrations in the saline water. This result is supported by previous studies showing that limited dilution during the dry monsoon season further increases seawater conductivity [6][7].

Referring to Figure 3, the conductivity data informs the current situation of seawater salinity and the total ionic content present in the seawater composition in the area. Conductivity values at all stations are generally lower during SWM in Figure 3(a), ranging from 51.0 to 52.2 mS/cm. This is because increased river discharge and more rainfall, which dilute freshwater and lower conductivity distinguish SWM. The SWM area with the highest conductivity is station D7 and the lowest area is around station 12.



(a)



(b)

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

In contrast, the northern area at Station D7 in particular is shown to have a very high conductivity range during NEM, increasing above 54.0 mS/cm in several places and decreasing towards the southeast, near Stations D9 and D12. The warmer and drier NEM in Figure 3(b) increases salinity and conductivity to a greater extent due to high evaporation during dried and hot weather and less freshwater uptake that concentrates dissolved salts [3][8]. Around Station D9, the process of leaching from rainwater or freshwater runoff showed the lowest conductivity. Furthermore, since conductivity affects species distribution, nitrogen cycling, and metabolic activity in the water column, this finding has ecological significance. Thus, marine life can be stressed by prolonged exposure to fluctuating conductivity levels, especially in sensitive environments such as seagrass meadows and coral reefs [9]. However, statistical studies showed that there was no significant difference in conductivity parameters between the monsoon period and the Dangli Island season ($p = 2.96 \times 10^{-1}$, $p > 0.05$). The discovery and disclosure of this conductivity distribution pattern somewhat facilitate basic monitoring initiatives in underrepresented areas, such as Dangli Island.

3.2 *Dissolve Oxygen (DO) Distribution*

Next, dissolved oxygen (DO) values were not significantly different and were only uniform between monsoon seasons ($p = 0.36$, $p > 0.05$). Their values were higher and more stable during NEM (8.03 ± 0.10 mg/L) compared to SWM (7.88 ± 0.58 mg/L). The better aeration and stable DO profile is a result of the effect of low temperature in NEM increasing oxygen solubility [4]. Values above 7.0 mg/L mainly indicate healthy oxygenation conditions suitable for marine life [10].

Figure 4(a) records DO concentration values during the Southwest Monsoon season varying between 7.0 and 8.4 mg/L. The areas near stations D10 and D11, in the northeastern region, mainly have higher values, with DO exceeding 8.2 mg/L. A region of moderate oxygen levels is seen extending in the center (7.4–7.8 mg/L), and lower DO levels (<7.3 mg/L) appear in the southern and southwestern parts near D2 and D3. The increase in low temperatures during the rains, photosynthetic activity, water mixing processes and possible nutrient availability may influence and impact these data changes. In contrast, the DO distribution appears more homogeneous and lower overall during the NEM in Figure 4(b), with values mostly between 6.9 and 8.2 mg/L. Localized DO peaks are found around station D5, but the eastern part near station D12 still maintains relatively high oxygen levels (>8.0 mg/L). Less turbulent mixing and greater organic matter decomposition may account for the lower DO concentrations in most of the central and western zones, indicating reduced oxygen depletion or lower re-aeration rates during this season. Overall, this trend suggests that SWM carries higher and more spatially variable dissolved oxygen levels while NEM offers more consistent but slightly lower oxygen conditions. This is consistent with findings in monsoon-influenced coastal waters, where seasonal circulation and biological activity significantly influence oxygen dynamics [1].

3.2 *pH Level Distribution*

In addition, the pH data showed a significant difference ($p = 3.71 \times 10^{-6}$, $p < 0.05$) with NEM (8.16 ± 0.04) being higher than SWM (8.09 ± 0.03). The reason for this small increase could be due to better photosynthetic activity or reduced CO_2 accumulation due to better mixing and circulation [12]. Although both values are within acceptable ecological limits, even small changes in pH can have a significant impact on calcifying species such as corals and mollusks over time [13].

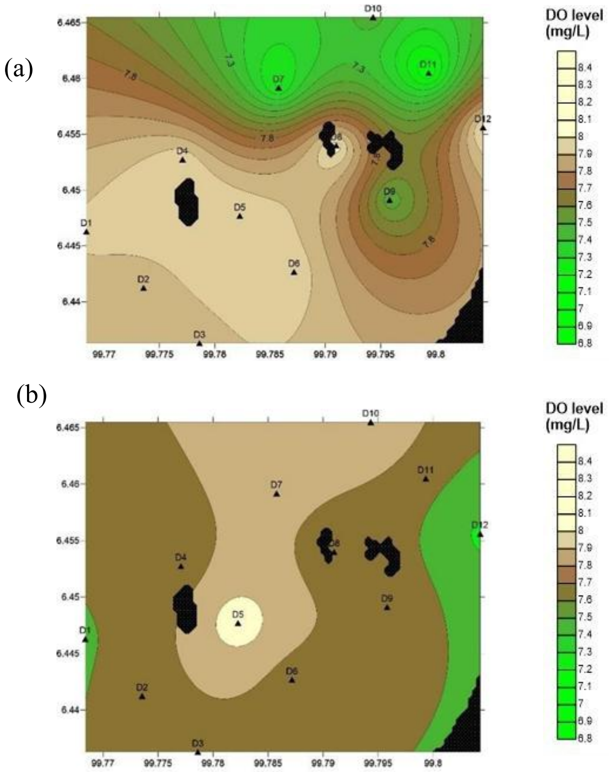


Fig. 4. Contour map of DO level during (a) SWM and (b) NEM

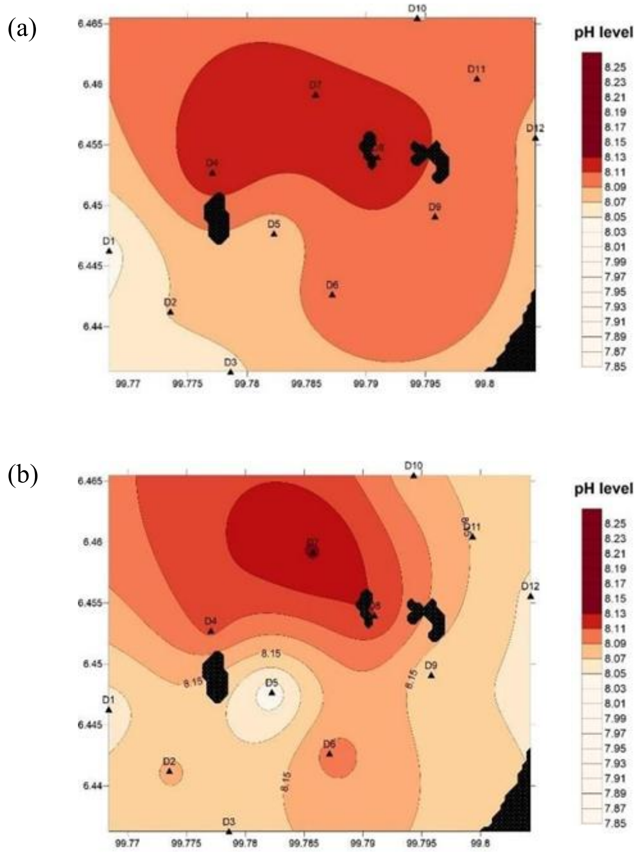


Fig. 5. Contour map of pH level during (a) SWM and (b) NEM

During the SWM in Figure 5(a), the pH values were generally higher between approximately 7.93 and 8.25. The northern and central parts of the study area, near stations D6, D7, and D11, had the highest pH levels. This indicated an increase in pH during the SWM, which may be due to enhanced phytoplankton photosynthetic activity, which decreased CO_2 levels and increased pH.

In the southern and western regions, the pH data readings are relatively low, such as near station D2, but the variance is generally small. In contrast, pH levels are generally lower and more fluctuating during NEM in Figure 5(b), ranging from 7.85 to 8.23. Acidification effects or possibly higher CO_2 dissolution due to improved vertical mixing or river input are indicated when values fall below 8.00, with the lowest pH zones found near stations D2 and D5. Meanwhile, higher pH values are concentrated near station D11 in the North-Eastern region. This seasonal variation suggests that pH values tend to be higher during SWM, while during NEM, lower pH values may be more variable and more stable, possibly due to variations in biological activity and soil runoff. This seasonal pattern is consistent with findings in tropical coastal ecosystems, where the monsoon cycle has a significant impact on water chemistry.

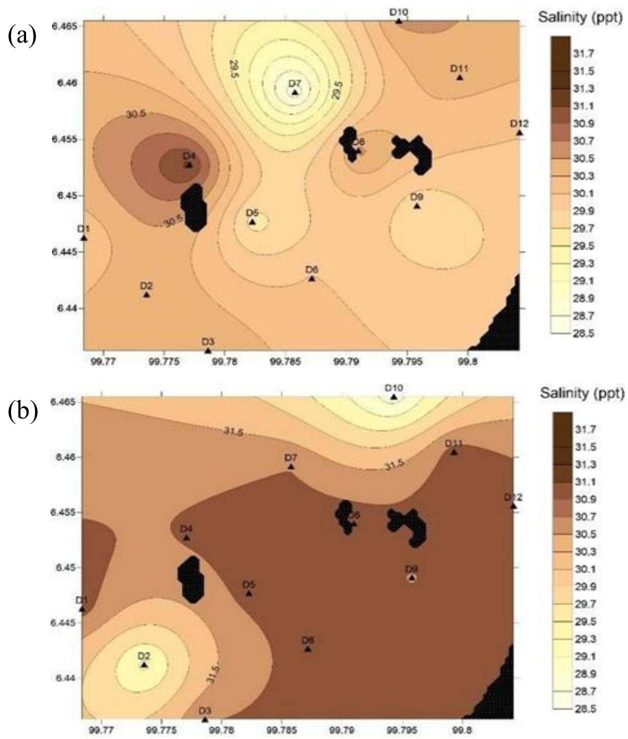


Fig. 6. Contour map of salinity during (a) SWM and (b) NEM

3.3 Salinity Distribution

With a clear increase during NEM, with an average of 31.57 ± 0.41 ppt, salinity had a significant difference (p = 1.89 x 10-8, p < 0.05), compared to 30.15 ± 0.65 ppt in SWM. This data can be attributed to warmer weather, reduced freshwater inflow and higher evaporation during the dry NEM season. In contrast, SWM, which is usually associated with heavy rainfall, dilutes seawater and lowers salinity levels [14][15].

During SWM, salinity levels showed non-uniform data, which is ranging from 28.5 ppt to 31.6 ppt. Local mixing and freshwater inflow may have caused the lowest salinity levels at Station D7. In addition, in Figure 6(a) at stations D4 and D9 show slightly lower salinity zones, indicating the potential impact of rivers or runoff from adjacent coastal areas. In contrast, during NEM in Figure 6(b), the salinity distribution is more uniform and constant, with values typically exceeding 30.5 ppt and the highest salinity measured at Station D11 (>31.5 ppt). This more constant distribution during NEM is consistent with increased seasonal evaporation rates and drier weather, which increase salinity levels [3]. The difference between the two seasons highlights how monsoon processes affect the salinity distribution in coastal waterways.

The SWM season is often associated with the rainy season due to the higher rainfall in the Dangli Island area, which dilutes freshwater and causes a more pronounced horizontal salinity gradient. During the NEM season, the opposite is true, with warmer and drier weather, which increases evaporation and increases salinity levels [8]. Since many marine animals are sensitive to salinity changes, which can affect osmoregulation, species distribution and reproductive cycles, these salinity changes are ecologically important [9]. These results highlight the need to monitor seasonal salinity as an important physicochemical parameter, especially in near- coastal ecosystems where climate variability and human activities coexist. These physicochemical trend processes need to be understanding, so coastal vulnerability assessments can be easily addressed to conserve natural resources in the future.

3.4 Temperature distribution

Furthermore, the temperature patterns revealed a notable seasonal contrast. The SWM recorded warmer temperatures (30.50 ± 0.10°C), while the NEM showed significantly cooler values (29.04 ± 0.31°C). The NEM brings colder air masses from the upwelling process, reducing sea surface temperature especially along Malaysia's northwest coast. This seasonal thermal difference plays a major role in influencing solubility, species metabolism, and nutrient cycling.

As we can see from the Figure 7(a) during the SWM, the temperature distribution shows a statistically significant different between monsoon seasonal which is (p= 1.89 x 10-8, p< 0.05) with higher temperatures (above 31.5°C) concentrated in the southwest region (near stations D2 and D3). The temperature gradually decreases moving eastward in Figure 7(a). In contrast, the NEM in Figure 7(b) shows a more uniform and low temperature distribution, with the highest temperature (around 30.5–31.0°C) centered near station D8, and gradually decreasing outwards.

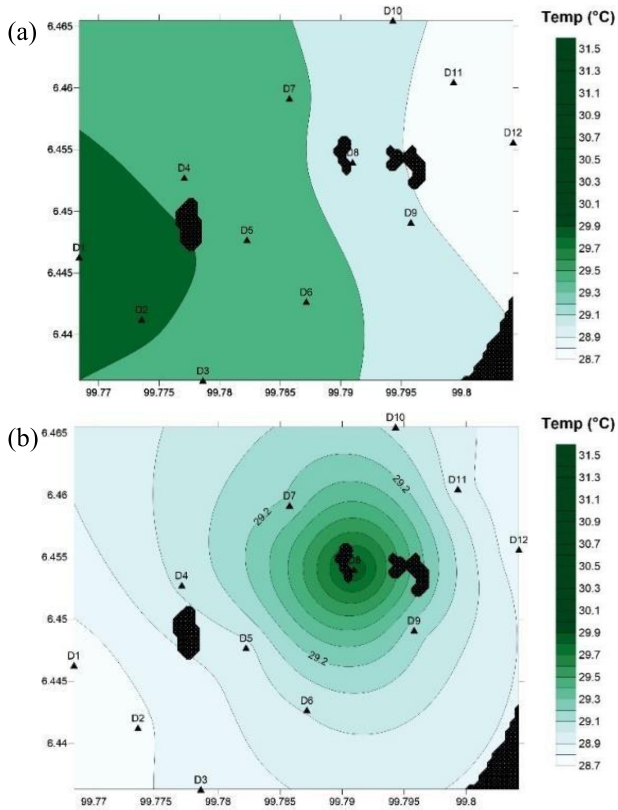


Fig. 7. Contour map of Temperature during (a) SWM and (b) NEM

The overall temperature during the NEM appears lower than that of the SWM, with the line contours indicating low temperature conditions throughout the region as low as 28.7°C. This difference suggests that surface seawater is warmer and more spatially variable during the SWM season, most likely due to stronger solar heating and limited mixing. Meanwhile, the lower seawater temperature and more uniform temperature during the Northeast Monsoon may be due to increased mixing processes and seawater upwelling that brings cold seawater from the bottom to the surface. This seasonal difference is consistent with the documented regional climate influence in tropical marine environments [16].

3.5 Orthophosphate distribution

In addition, orthophosphate exhibited the most pronounced contrast between seasons and between chemical parameters. During SWM, orthophosphate levels were low (0.10 ± 0.07 mg/L, range: 0.000–0.161mg/L), while during NEM, they increased sharply (1.24 ± 0.62 mg/L, range: 0.279– 2.060 mg/L). The distribution of orthophosphate showed a statistically significant difference between monsoon seasons (p = 2.99 x 10-2, p < 0.05). This may be due to the process of water runoff, reduced leaching, and anthropogenic sources such as agricultural activities resulting in large nutrient inputs during NEM. The risk of eutrophication and reduced water quality is often due to high orthophosphate levels [17][18].

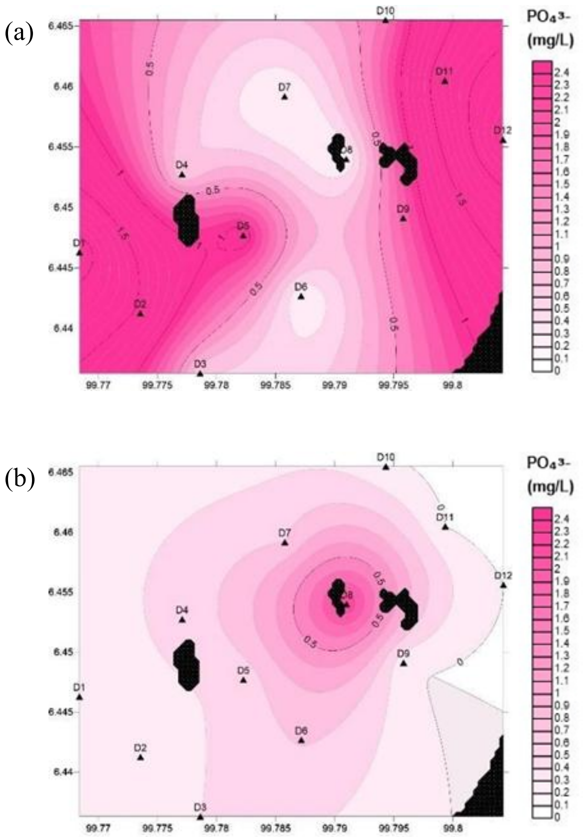


Fig. 8. Contour map of orthophosphate during (a) SWM and (b) NEM

During the SWM, as shown in Figure 8(a), the orthophosphate data showed much lower values. Most sites had concentrations below 0.2 mg/L. At Stations D9 to D12, indicating either rapid digestion by phytoplankton or low anthropogenic input and recording the lowest value of almost 0 mg/L. Around Stations D1 to D6, moderate orthophosphate levels were observed, indicating potential nutrient input from organic matter decomposition or soil runoff. In contrast, in Figure 8(b), orthophosphate concentrations increased around Stations D7, D8, and D11 significantly and peaked at 2.0 mg/L, especially during NEM. The observed increase in nutrient loading could be due to aquaculture waste, or possibly because of less dilution from less rainfall and reduced water movement.

The impact of anthropogenic and hydrological influences on nutrient movement in coastal environments is demonstrated by this seasonal discrepancy. SWM may increase leaching and promote nutrient distribution due to high rainfall and increased freshwater inflow. Conversely, NEM with drier conditions and limited water exchange may facilitate the accumulation of nutrients such as orthophosphate, especially in semi-enclosed areas or near human settlements [3][19]. High levels of orthophosphate may cause eutrophication, which in turn may lead to algal blooms and hypoxic conditions that are detrimental to fisheries and marine biodiversity [20]. During NEM, sudden increases may indicate the need for better wastewater management and nutrient load control, especially near populated coastal areas in Langkawi. Therefore, understanding this spatiotemporal should be explored to help formulate targeted strategies for marine conservation and water quality management.

3.6 Total Ammoniacal-Nitrogen distribution

Lastly, based on figure 9, the concentration of TAN also increased significantly from 0.000-0.911mg/L in SWM to 0.000-2.445 mg/L in NEM. The distribution of TAN showed a statistically significant difference between monsoon seasons ($p = 9.05 \times 10\text{-}5$, $p < 0.05$). The upwelling process that occurs in seawater may cause high and wide variations during NEM showing episodic nutrient loading. TAN is essential for phytoplankton growth, but excessive levels can cause harmful algal blooms and oxygen depletion [21][14].

With values exceeding 2.0 mg/L, TAN levels appear to be more concentrated in the western area especially near stations D1 to D4 during SWM in Figure 9(a). The contour gradient shows that the concentration decreases progressively as one moves eastward, indicating possible anthropogenic input or land-based runoff from the western part. The significant difference in TAN levels is potentially due to less mixing of water at this time of year, which allows accumulation in certain areas. During the NEM season in Figure 9(b), the TAN distribution is more diffuse and diffuse with concentrations varying between 0.3 and 2.0 mg/L. High concentrations are seen in the central and northeastern zones near stations D7 and D11, this may be due to biological activity and increased nutrient cycling caused by the upwelling process where water from the lower column rises to the upper surface. Greater water mixing and a more uniform distribution of TAN throughout the area are suggested by the smoother and more concentric contour lines, which are typical of NEM.

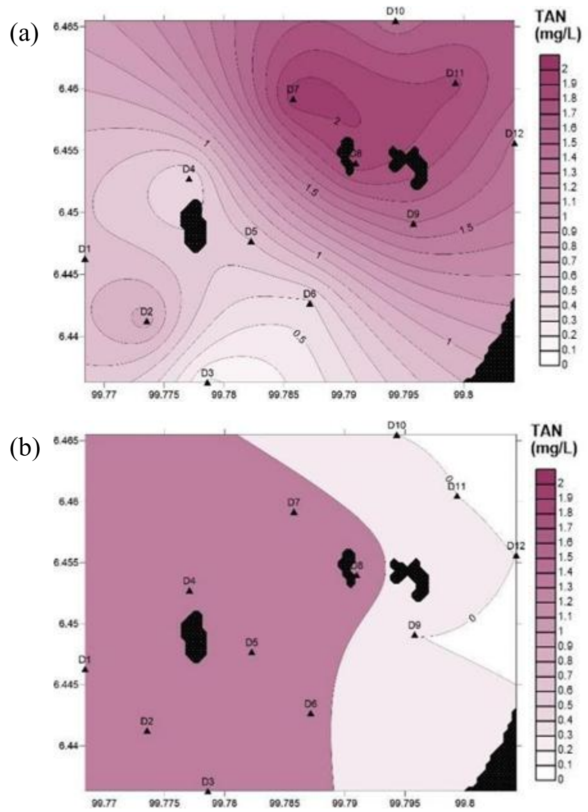


Fig. 9. Contour map of Total Ammoniacal-Nitrogen during (a) SWM and (b) NEM

These wider distribution and moderate levels during the NEM are probably caused by increased vertical mixing and circulation from the upwelling process during the monsoon season, whereas these seasonal variations in TAN concentration imply that nutrient enrichment is more localized and elevated during the SWM, possibly connected to surface runoff and decreased dilution. This pattern is consistent with research showing that nutrient variability in tropical coastal systems is driven by the monsoon [22].

4. CONCLUSION

According to the study, monsoon seasons have a substantial impact on physico-chemical parameters like temperature, pH, salinity, and nutrients ($p < 0.05$), while conductivity and DO do not alter significantly ($p > 0.05$). In addition, Two-way ANOVA results demonstrated all physico-chemical parameter have no significant difference between sampling stations ($p > 0.05$). Thus, these parameter plays a crucial role in defining seawater quality and marine ecosystems around Dangli Island. The NEM brings oxygen-rich waters with higher nutrient levels because of upwelling process during the monsoon season, while the SWM produces more diluted conditions with lower oxygen solubility but higher productivity. These seasonal changes affect species survival, indicate climate-related impacts like ocean warming and help detect pollution sources. Therefore, this study recommends that seawater quality monitoring be carried out continuously covering both monsoon seasons by collaboration between research institutions and government agencies and local stakeholders in order 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 the Dangli island in the future.

ACKNOWLEDGEMENT

The author expresses gratitude for the financial support provided by the grant FRGS/1/2022/WAB02/UITM/02/1. Special thanks are due to Faculty of Applied Science of UiTM Perlis, UiTM Marine Research Station (MARES) and the facilities provided. Sincere appreciation is extended to the academic and non-academic staff for their invaluable contributions to this research and publication.

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