ENVIRONMENTAL MONITORING ON THE SURFACE OF THE ANDAMAN SEA OVER THE SOUTHWESTERN COAST OF THAILAND: A CASE STUDY OF SPATIAL AND TEMPORAL VARIABILITY OF CHLOROPHYLL-A

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ABSTRACT

Chlorophyll-a is a pigment or substance used in photosynthesis that is found within the cell of phytoplankton, small unicellular algae that floats in water and is blown by waves, wind, and tide. Phytoplankton is essential for the aquatic ecosystem. This research studies the spatial and temporal variability of chlorophyll-a using data from the Aqua satellite in the MODIS system from 2018 to 2022, then analyzes the data with the SeaWiFS Data Analysis System (SeaDAS) program. The results show that chlorophyll-a on the surface of the Andaman Sea varies during the year according to monsoon activity. It has a high value during the northeast monsoon (November to March), and its maximum value is in January. On average, chlorophyll-a in June 2021 had a minimum value of 0.1994 mg/m^3, and chlorophyll-a in January 2022 had a maximum value of 0.8591 mg/m^3. The relationship between chlorophyll-a and sea surface temperature during the northeast monsoon, including wind stream at different times, shows the increase and decrease of chlorophyll-a, which may be consistent with upwelling and downwelling at the eastern coast of the Andaman Sea.

***Key-words**: Remote Sensing, Chlorophyll-a, Andaman Sea, Digital Image Processing, MODIS-Aqua*

1. INTRODUCTION

Open sea is divided vertically, light being an essential factor that separates it into the photic zone and aphotic zone. The photic zone has full sunlight and is located in the same zone as the continental shelf; photosynthesis can occur within this zone at a depth of approximately 200 m. The aphotic zone is deeper than the photic zone and cannot receive sunlight, so there is no photosynthesis and there are fewer organisms (Difference Between, 2023). It may be further divided according to marine organisms into five zones: 1) the epipelagic zone, which begins at the surface and reaches a depth of 200 m, and which can be compared to the photic zone as it obtains enough sunlight for photosynthesis; 2) the mesopelagic zone, with a depth of 200 to 1,000 m; 3) the bathypelagic zone, with a depth of 1,000 to 4,000 m; 4) the abyssalpelagic zone, with a depth of 4,000 to 6,000 m; and 5) the hadalpelagic zone, which is deeper than 6,000 m and always found at oceanic trenches (NOAA, 2023).

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The Andaman Sea is part of the continental shelf of the Indian Ocean. It is a submerged coast with a marginal sea surrounded by land, an island, and a peninsula. It also has an open part connected to the open sea at the surface and may have oceanic ridges. It is a semi-closed basin located to the east of the Bay of Bengal. There are different depths of seabed in the Andaman Sea (Marine Knowledge Hub, 2023); they can be divided into two zones according to sea contouring, which causes there to be diverse types and quantities of coral reefs. The seabed at the coastline of Ranong, western Phang Nga, and western Phuket has a high slope and an average depth of approximately 1,000 m. The Andaman Basin, the deepest part of the Thai Sea, reaches approximately 3,000 m, while the seabed at the coastline of southern Phang Nga, eastern Phuket, Krabi, and Trang have a slight slope, and the continental shelf has a depth of less than 300 m (Biodiversity CHM Thailand, 2023).

Phytoplankton is a small organism that floats in water and within its cell has pigment such as chlorophyll-a, a substance used for photosynthesis. Therefore, it is essential for the aquatic ecosystem. Phytoplankton is categorized by type of chlorophyll; chlorophyll-a is categorized as Cyanophyta (Laosuwan et al., 2022). Chlorophyll-a is a primary photosynthetic pigment that can capture sunlight by itself, while other chlorophyll are secondary photosynthetic pigments (accessory pigments) that capture the light's energy and pass it to chlorophyll-a (Zhao et al., 2023).

Remote sensing technology using satellites is considered an effective method for monitoring phenomenal changes in the atmosphere, land, and ocean (Gomasathit et al., 2015; Rotjanakusol & Laosuwan, 2018; Itsarawisut & Laosuwan, 2022; Itsarawisut et al., 2022; Ounrit et al., 2022). This technology uses electromagnetic waves to acquire information without making physical contact with objects (Uttaruk & Laosuwan, 2019; Rotjanakusol & Laosuwan, 2020; Uttaruk et al., 2022; Laosuwan et al., 2023). It can record data in a wide range and repeat it in the same area in each orbit of the satellite, so environmental changes can be monitored in different periods (Laosuwan & Uttaruk, 2017; Rotjanakusol & Laosuwan, 2019a; Rotjanakusol & Laosuwan, 2019b; Auntarin et al., 2021; Jomsrekrayom et al., 2021; Celik et al., 2022; Kanjanasiranont et al., 2022; Turton et al., 2022; Chen et al., 2023; Phoophiwfa et al., 2023). For this reason, this technology has been used for studying chlorophyll-a at the surface of the sea, such as in the studies by Lins et al. (2017), Silveira et al. (2020), Aranha et al. (2022), and Wang et al. (2022).

Phytoplankton is a significant manufacturer of food chains in water supply and has been used as a sea fertility index. Open sea has few plankton as it lacks nutrients, which causes low fertility, while the coastline or upwelling area has rich nutrients and plenty of phytoplankton, indicating the fertility and amount of aquatic animal resources in that area (Buranapratheprat & Meesook, 2013). The goal of this research is to study the spatial and temporal variability of chlorophyll-a by using data from the Aqua satellite in the MODIS system from 2018 to 2022.

2. MATERIALS AND METHODS

2.1. Study Area

The Andaman Sea (**Fig. 1**) is located to the east of the Bay of Bengal, a part of the Indian Ocean.

The north is close to the Irrawaddy Estuary, while the east is bounded by the coastlines of Myanmar, Thailand, and Malaysia. On the west side lie the Andaman Islands and Nicobar Islands. The southern end is at Sumatra Island and the Strait of Malacca. The territory's latitude extends from 6° to 14°N, and its longitude from 93° to 99°E. The length of the Andaman Sea from north to south is approximately 1,200 km, and the width is 650 km.

The sea has an approximate area of 797,700 km^2 and an average depth of 870 m, the deepest point being 3,777 m. It is influenced by the northeast monsoon from November to December and the southwest monsoon from May to September.

Fig. 1. The study area.

2.2. Operation

This study analyzes three sets of data:

1) Wind stream data (**Fig. 2**) from Remote Sensing Systems, which can be downloaded from www.remss.com/measurements/wind.

2) Level-2 product measured by a MODIS sensor installed on the Aqua satellite. It can be downloaded from Ocean Color (http://oceancolor.gsfc.nasa.gov) (**Fig. 3**). Level-2 MODIS Aqua data has a pixel size equal to 1,000 m. Data processing was conducted with SeaDAS.

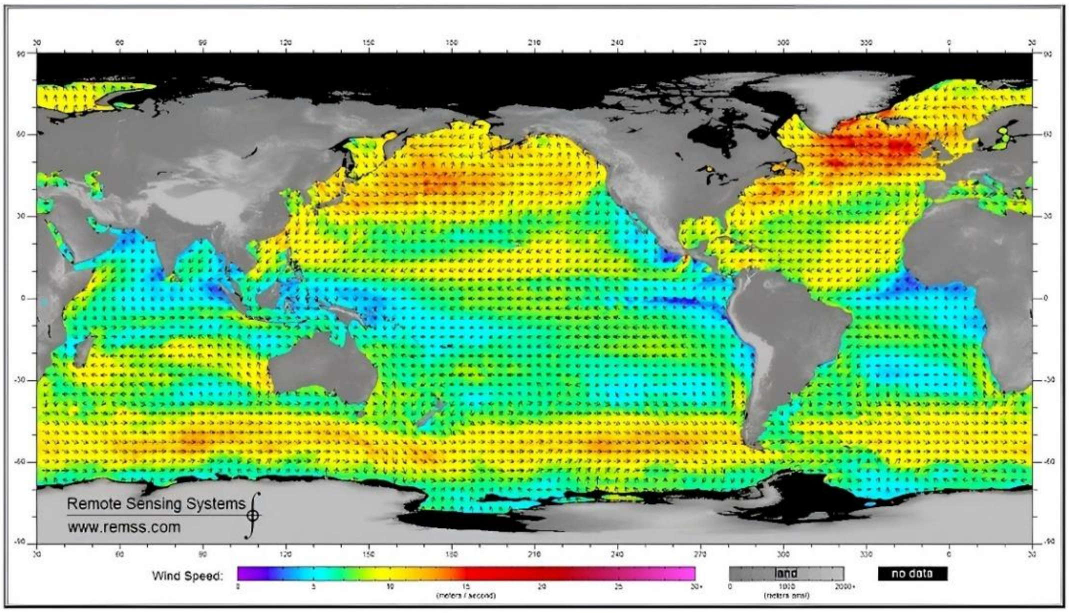

Fig. 2. Wind stream data.

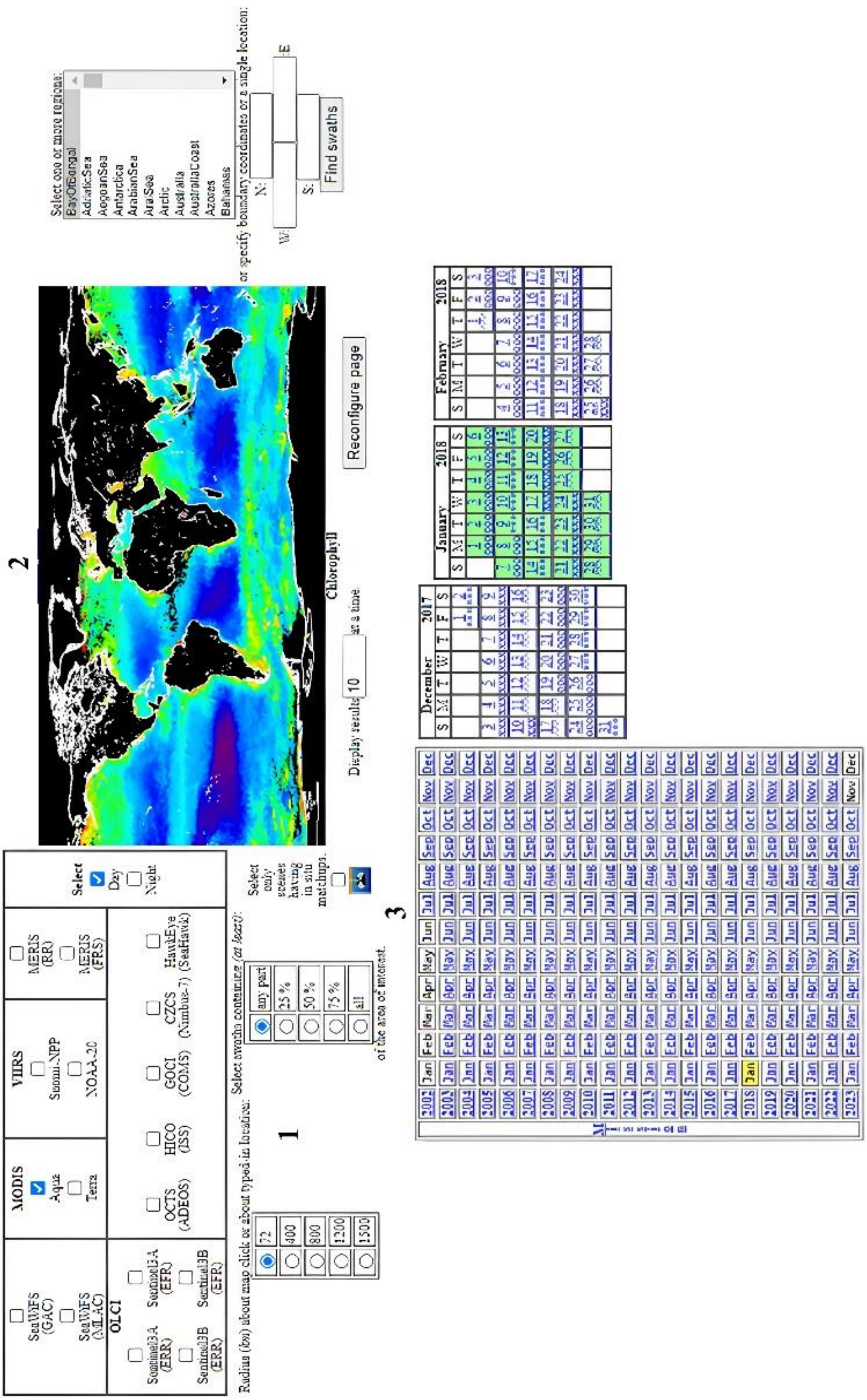

Fig. 3. MODIS Aqua Level-2 product.

3) Sea surface temperature data (**Fig. 4**) from EARTHDATA, which can be downloaded from https://giovanni.gsfc.nasa.gov/giovanni/.

Level-2 MODIS Aqua data was gathered from daily and monthly data each year, then calculated for the average annual data. Wind stream and sea surface temperature were analyzed with the average amount of chlorophyll-a at the sea surface to determine the spatial and temporal variability of chlorophyll-a.

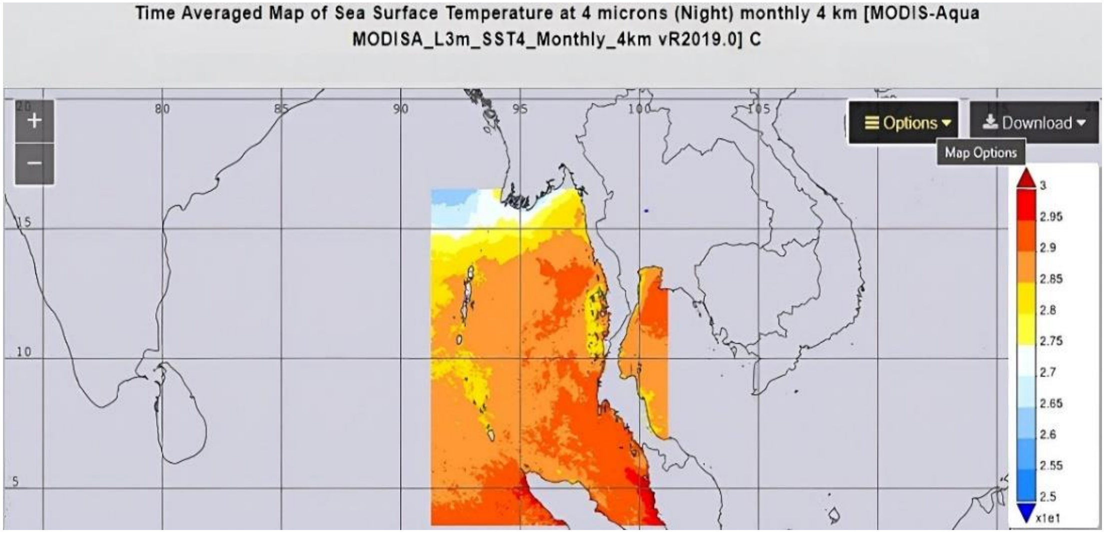

Fig. 4. Sea surface temperature.

3. RESULTS AND DISCUSSION

3.1. Analysis results of chlorophyll-a

The analysis results of the expansion of chlorophyll-a by monthly average at the surface of the Andaman Sea from 2018 to 2022 is shown in **Table 1**.

As recorded in **Table 1**, the average amount of chlorophyll-a at the surface of the Andaman Sea in 2018 had a maximum value in October of 0.6948 mg/m^3, a minimum value in April equal to 0.2802 mg/m^3, and an annual average value of 0.4055 mg/m^3. In 2019, the average amount of chlorophyll-a at the surface of the Andaman Sea had a maximum value in December of 0.6214 mg/m^3, a minimum value in May of 0.2709 mg/m^3, and an annual average value of 0.4174 mg/m^3.

In 2020, the average amount of chlorophyll-a at the surface of the Andaman Sea had a maximum value in November of 0.6483 mg/m^3, a minimum value in May of 0.2847 mg/m^3, and an annual average value of 0.4274 mg/m^3. In 2021, the average amount of chlorophyll-a at the surface of the Andaman Sea had a maximum value in November of 0.6380 mg/m^3, a minimum value in June of 0.1994 mg/m^3, and an annual average value of 0.4208 mg/m^3. In 2022, the average amount of chlorophyll-a at the surface of the Andaman Sea had a maximum value in January of 0.8591 mg/m^3, a minimum value in June of 0.2419 mg/m^3, and an annual average value of 0.4932 mg/m^3. The result of chlorophyll-a expansion by monthly average at the surface of the Andaman Sea was calculated for the annual average in each month, as shown in **Fig. 5** and **Fig. 6**.

Table 1.

Analysis results of the expansion of chlorophyll-a by monthly average.

2018		**2019**	
Month	Average amount of chlorophyll-a (mg/m^3)	Month	Average amount of chlorophyll-a (mg/m^3)
Jan	0.5319	Jan	0.5432
Feb	0.5936	Feb	0.5610
Mar	0.4180	Mar	0.4418
Apr	0.2802	Apr	0.3100
May	0.3353	May	0.2709
Jun	0.3828	Jun	0.3412
Jul	0.2833	Jul	0.3162
Aug	0.2818	Aug	0.3997
Sep	0.3950	Sep	0.3533
Oct	0.6948	Oct	0.4105
Nov	0.3281	Nov	0.4394
Dec	0.3411	Dec	0.6214
2020		**2021**	
Month	Average amount of chlorophyll-a (mg/m^3)	Month	Average amount of chlorophyll-a (mg/m^3)
Jan	0.5469	Jan	0.5427
Feb	0.5070	Feb	0.5391
Mar	0.3838	Mar	0.5094
Apr	0.3535	Apr	0.3646
May	0.2847	May	0.4090
Jun	0.3908	Jun	0.1994
Jul	0.3367	Jul	0.3059
Aug	0.3716	Aug	0.2565
Sep	0.3855	Sep	0.4398
Oct	0.3601	Oct	0.4428
Nov	0.6483	Nov	0.6380
Dec	0.5593	Dec	0.4026
2022			
Month	Average amount of chlorophyll-a (mg/m^3)		
Jan	0.8591		
Feb	0.7684		
Mar	0.5246		
Apr	0.5518		
May	0.4409		
Jun	0.2419		
Jul	0.3529		
Aug	0.3506		
Sep	0.3536		
Oct	0.5183		
Nov	0.4186		
Dec	0.5374		

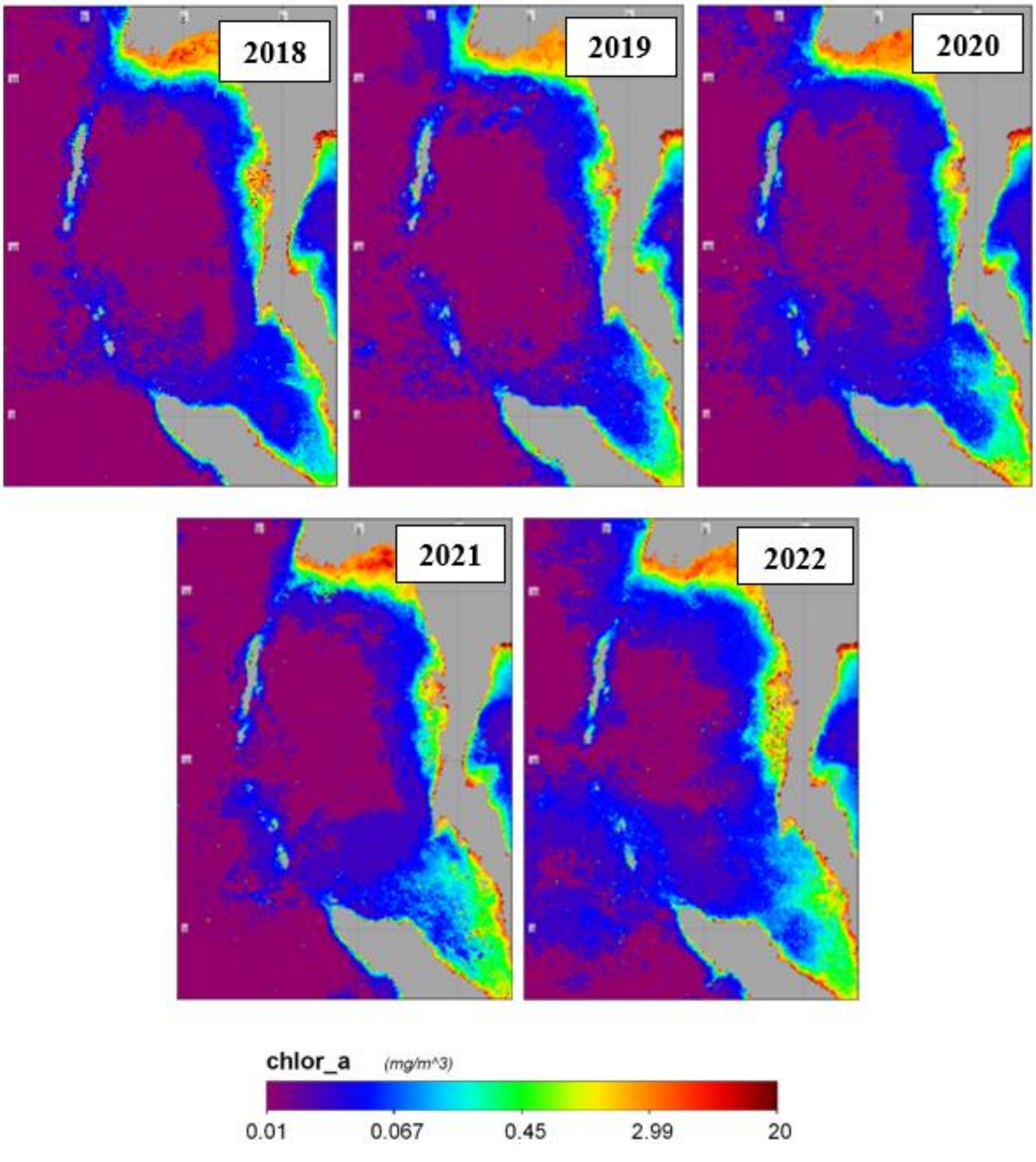

Fig. 5. The annual average distribution of chlorophyll-a in the Andaman Sea.

Fig. 5 and **Fig. 6** show that the average amount of chlorophyll-a at the surface of the Andaman Sea from 2018 to 2022 had a maximum value in January of 0.6845 mg/m^3. The value decreased in March, and the minimum value in August was 0.3566 mg/m^3. It started to rise again in October, the average steadily increasing. During those five years, chlorophyll-a at the surface of the Andaman Sea had a high value from December to March, which was influenced by the northeast monsoon, and a low value from April to September, which was influenced by the southwest monsoon. Chlorophyll-a will increase or decrease depending on season, weather condition, density, and the expansion of phytoplankton in each area.

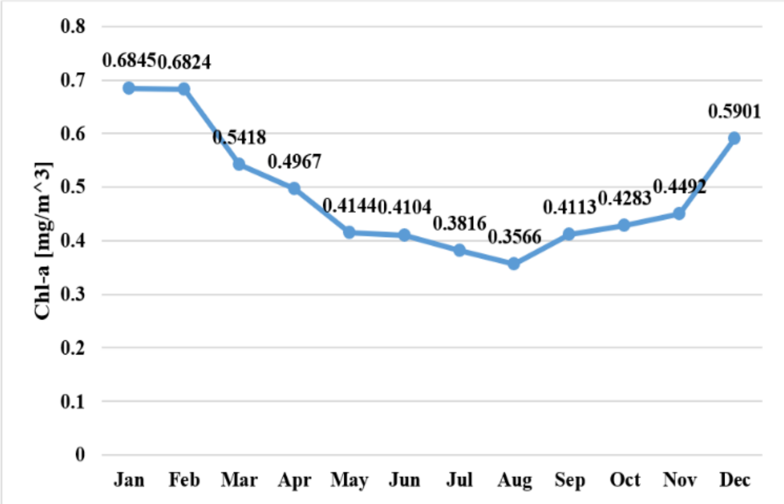

Fig. 6. Average amount of chlorophyll-a at the surface of the Andaman Sea from 2018 to 2022.

3.2. Analysis of the quantity and expansion of chlorophyll-a at the surface of the Andaman Sea with wind stream and surface temperature

Wind streams flow through the surface of the Andaman Sea in a different manner each month, but it is possible to track their directions. In this study, the directions of wind streams were downloaded from Remote Sensing Systems. For the analysis of the quantity and expansion of chlorophyll-a at the surface of the Andaman Sea with wind stream and surface temperature, an example wind stream chart from 2022 is shown in **Fig. 7**.

This study found that the quantity of chlorophyll-a at the sea surface varies according to season and monsoon activity. From November to March (the northeast monsoon), chlorophyll-a at the sea surface was higher than from May to September (the southwest monsoon), with a maximum value in January of 0.6845 mg/m^3 and a minimum value in August of 0.3566 mg/m^3. The increase and decrease of chlorophyll-a according to season were similar in each year. From the data of Level-2 product measured by a MODIS sensor installed on the Aqua satellite, chlorophyll-a at the surface of the Andaman Sea changed in line with wind stream. In addition, it had a high value during the northeast monsoon and a low value during the southwest monsoon. It was seen on the eastern coast of the Andaman Sea, consistent with Buranapratheprat and Meesook's study (2013).

The study "Temporal Variations of Sea Surface Chlorophyll-a in the Andaman Sea Based on Aqua MODIS Image Processing" found that chlorophyll-a at the surface of the Andaman Sea varies during the year according to monsoon activity; it has a high value during the northeast monsoon, its maximum value occurring in January, and a low value during the southwest monsoon. It is consistent with the study by Tan et al. (2006) that is referenced by Buranapratheprat and Meesook (2013). The study "Seasonal Variability of SeaWiFS Chlorophyll-a in the Malacca Straits in Relation to Asian monsoon" also found that chlorophyll-a at the surface of the Andaman Sea varies during the year according to monsoon activity. Chlorophyll-a at the surface of the northern part of the Malacca Strait starts to increase in November and has a maximum value in January (during the northeast monsoon), and it decreases in March and has a minimum value in August (during the southwest monsoon); it starts to increase again from November onward. In this study, chlorophyll-a from Level-2 product measured by a MODIS sensor installed on the Aqua satellite falls within the range that has been measured at the Andaman Sea (Buranapratheprat & Meesook, 2013).

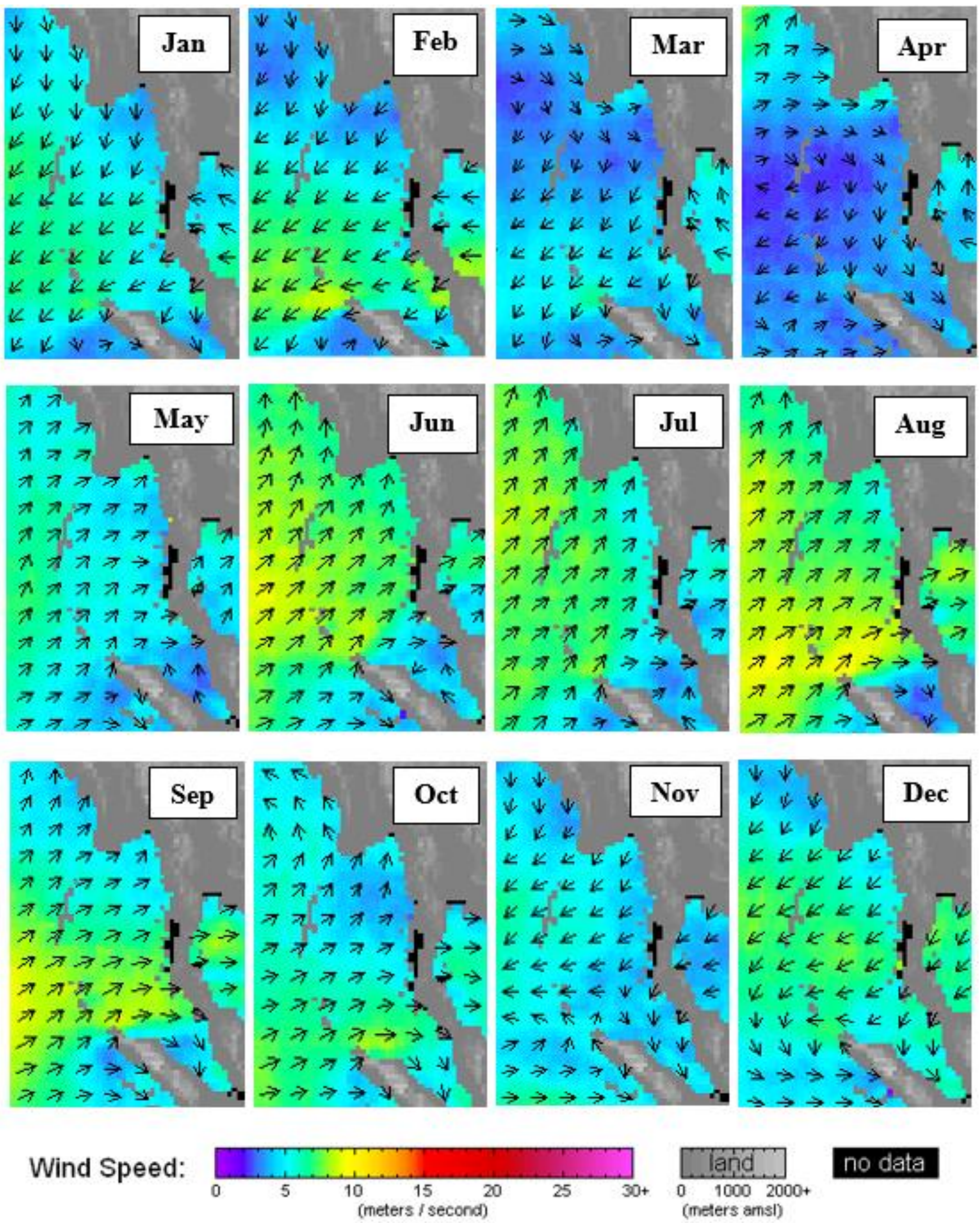

Fig. 7. Average amount of chlorophyll-a at the surface of the Andaman Sea in 2022.

The consistency of the result demonstrates the reliability of the chlorophyll-a data from this study. The increase of chlorophyll-a at the sea surface during the northeast monsoon may occur from upwelling at the eastern coast of the Andaman Sea—that is, the surface of the water has moved from the coastline according to the direction of the wind at a certain time (**Fig. 4**), then the lower layer of the water, which has a low temperature, flows upward to replace the upper layer of water and bring all nutrients to the sea surface. Then plankton can use these nutrients to grow and increase, causing chlorophyll-a at the surface of the coastline to have a high value (Knauss, 1997; Buranapratheprat & Meesook, 2013). The sample of chlorophyll-a increased at the eastern coast of the Andaman Sea in January 2022, which is consistent with the temperature of the sea surface, and it had less value in the same area (**Fig. 8**).

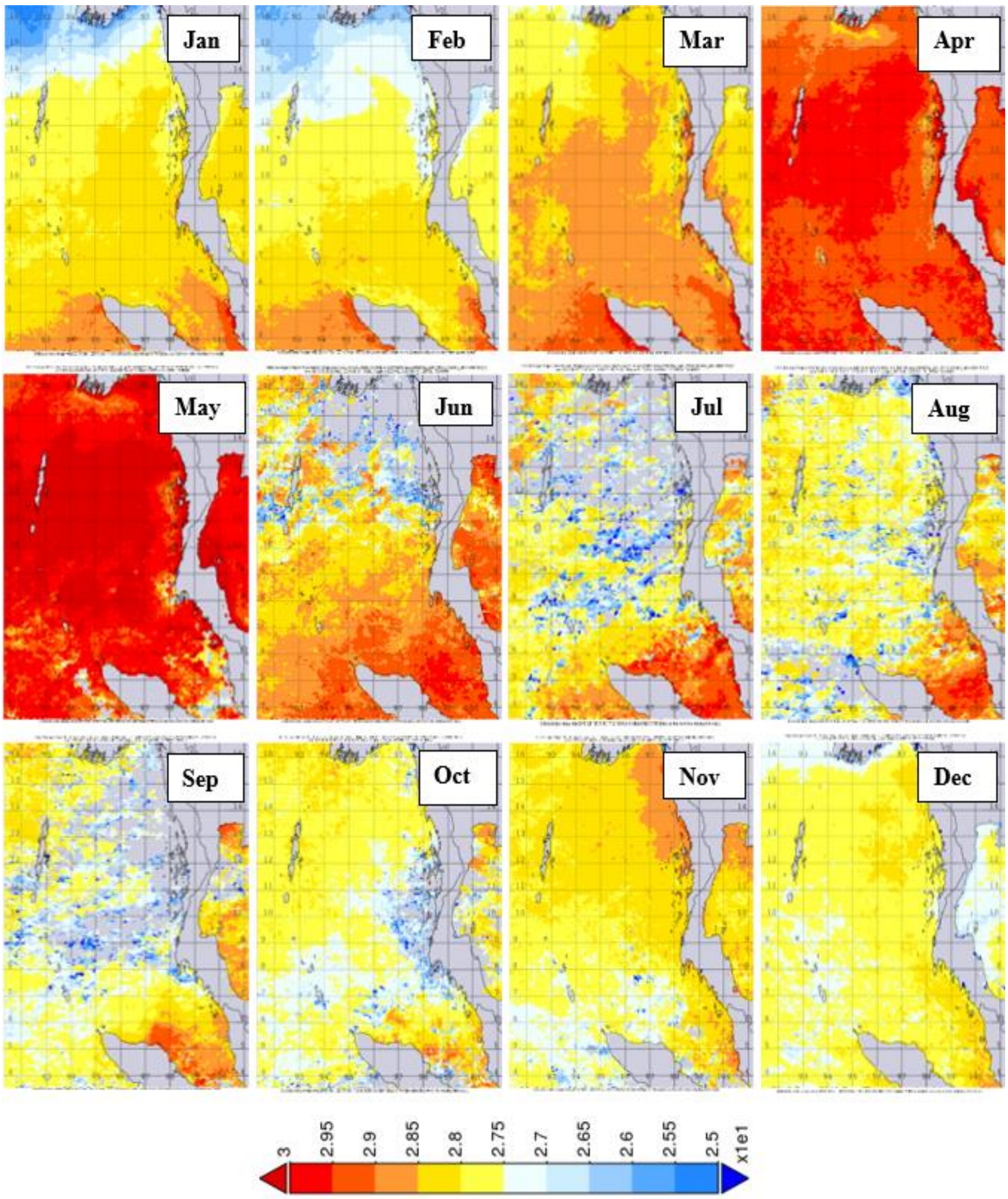

Fig. 8. Temperature of the sea surface in 2022.

This is a sign that upwelling occurred at this time. The decrease of chlorophyll-a during the southwest monsoon (**Fig. 5**) may relate to downwelling from the southwest wind stream that blows into the eastern coast (**Fig.7**). It is consistent with the research of Robinson et al. (2007) and Buranapratheprat and Meesook (2013), which study the relationship between chlorophyll-a, sea temperature, and the weather variation that causes oceanographic processes at Bali, Indonesia. They found that the increase and decrease of chlorophyll-a relate to upwelling, downwelling, monsoon activity, and sea water temperature.

4. CONCLUSION

This study conducted environmental monitoring on the surface of the Andaman Sea over the southwestern coast of Thailand. It examined the spatial and temporal variability of chlorophyll-a by using data from Level-2 product measured by a MODIS sensor installed on the Aqua satellite, finding that chlorophyll-a at the surface of the Andaman Sea in each period of the year tends to vary according to monsoon activity. The period from November to March (the northeast monsoon) had a high value of chlorophyll-a, while the period from May to September (the southwest monsoon) had a low value of chlorophyll-a. The relationship between chlorophyll-a, sea surface temperature during the northeast monsoon, and wind stream in different periods shows that the increase and decrease of chlorophyll-a may be consistent with upwelling and downwelling at the eastern coast of the Andaman Sea.

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