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Original Research

Analysis of Content and Distribution of Chlorophyll-a on the Sea Surface through Data from Aqua/MODIS Satellite

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Abstract

Phytoplankton are tiny creatures floating on water mass. Inside their cells, there is the pigment chlorophyll-a, a kind of substance used in photosynthesis. As a result, it is essential for the ecosystem of water sources because it is considered as the primary producer. This research aims to analyze the content and distribution of chlorophyll-a on the sea surface. It uses data from the Aqua/MODIS Satellite in a case study of the upper Gulf of Thailand in 2020. The SeaWiFS Data Analysis System (SeaDAS) program analyzed the obtained data. The results revealed that the content and distribution of chlorophyll-a on the sea surface in the area of the upper Gulf of Thailand were based on seasons and the influence of monsoons. It was found that the content of chlorophyll-a was highest in the southwest monsoon period (May-October) and lowest in the northeast monsoon period (November-April). The content of chlorophyll-a was highest in October with a mean of 3.148 mg/m^3, followed by November, and it was lowest in February with a mean of 1.514 mg/m^3. Moreover, it was also found that, if the sea surface temperature was higher than 30°C, phytoplankton exhibited proper growth and propagation. As a result, the content and distribution of chlorophyll-a were consistent with seasonal changes and weather variability.

Keywords: remote sensing, chlorophyll-a, algae blooms, upper Gulf of Thailand

Introduction

An algae bloom is a phenomenon caused by the rapid growth of algae in water caused by the excessive consumption of nitrogen, phosphorus, and light in conjunction with higher temperatures brought about by global warming. As a result, this phenomenon stimulates growth of algae leading to rapid multiplication [1]. Consequently, sea colors change due to the increasing amount of algae pigment. Most blooms consist of suspended sediment in water in the form of clusters or tabs with their direction dependent on the movement of the wind and waves. This phenomenon is caused by nature [2]. However, human activities can also be the cause, for example, draining water from agricultural land, draining wastewater to water sources and fisheries [3]. All algae blooms in Thailand occur

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in the coastal area of the Gulf of Thailand, especially the upper Gulf of Thailand [4]. They are the subject of great interest because they directly and indirectly affect human health and the economy related to coastal aquatic animals. Their effects are as follows: (1) damage to aquaculture and aquatic animals; (2) damage to consumers after consuming aquatic animals that have eaten toxic algae; (3) effects on the economy of fisheries and aquatic animals exportation in the case of excessive contamination; and (4) effects on tourism, i.e., the deterioration of scenery and the unpleasant smell in large areas [5, 6].

Photosynthesis is the process by which plants synthesize organic matter from inorganic compounds in the presence of light. All living things need energy for growth and maintenance. Algae, high plants and some bacteria can get energy directly from sunlight and use this energy to synthesize substances needed to sustain life. For plants to receive light energy from the sun directly, plants must have a special substance: green pigments called chlorophylls. Chlorophylls have a structure consisting of four pyrrole rings arranged next to each other with Mg in the middle; the light-absorbing part is called the head, and phytol – the tail. Chlorophyll, a pigment present in chloroplasts, captures energy from light [7]. Chlorophyll-a is the pigment or substance used in photosynthesis inside the cells of phytoplankton. It is also in unicellular algae that float on water mass and are relocated by the waves, wind, and water streams. As a result, phytoplankton is important for the ecosystem of water sources because it is considered as the preliminary producer and, therefore, indicates the viability of water sources [8-11]. The upper Gulf of Thailand is a semi-enclosed gulf that looks like a square with an open side in the south; it is connected to the central Gulf of Thailand [12-15]. The upper Gulf of Thailand is the emptying point of four important rivers located in the north, i.e., Mae Klong River, Tha Chin River, Chao Phraya River, and Bang Pakong River [16, 17]. Its weather is influenced by monsoons, i.e., the southwest monsoon from May to September or in the beginning of October and the northeast monsoon from November to February and in the beginning of March [18]. Most contents of wastewater from these four rivers drain directly into this gulf without any treatment. Consequently, nutrients and pollution have been increasingly accumulating in this area, leading to poor quality sea water and red tides.

Current studies on chlorophyll-a have made use of various methods and technologies, especially remote sensing technology (RST) [19-25]. RST is currently used as the main tool for studying spatial phenomena and is extensively based on data from satellites that have been used as tools for recording data on area conditions efficiently and consecutively in surveys of natural resources such as water on and under the surface. It can cover wide areas and obtain continuously updated data [26-39]. In Thailand, the application of RST to chlorophylla research is at a low level. Because of the importance of such research, this article aims to analyze the content and distribution of chlorophyll-a on the sea surface. It uses data from the Aqua/MODIS Satellite in a case study of the upper Gulf of Thailand in 2020.

Material and Methods

Study Area

The upper Gulf of Thailand (Fig. 1) is located at the geographic coordinates of longitude 100°–101°E and latitude 12.3°–13.3°N and appears as a semi-enclosed gulf in the form of a square shape. The total surface area is around 10,000 km^2 with an average depth of 20 m. It covers the coastal areas of Prachuab Kiri Khan, Phetchauri, Samut Songkram, Samut Sakorn, Bangkok, Samut Prakarn, Chachoengsao, and Chonburi. Since the upper Gulf of Thailand is a semi-enclosed gulf, it is influenced by tides. It has diurnal tides, i.e., one high tide and one low tide per day. The difference in the heights of the high tide and the low tide has an average range of 1 m-0.8 m.

The tide types and heights cause different accumulations of sediment. Moreover, the upper Gulf of Thailand also receives water released from four important rivers: Mae Klong River, Tha Chin River, Chao Phraya River, and Bang Pakong River, as well as from some short rivers along the coast affecting the saltiness, the sediment content, and nutrients. Consequently, its appearance becomes sandy mud, mud, muddy sand, and sand. The weather in this area is influenced by monsoons, i.e., the southwest monsoon from May to September or in the beginning of October

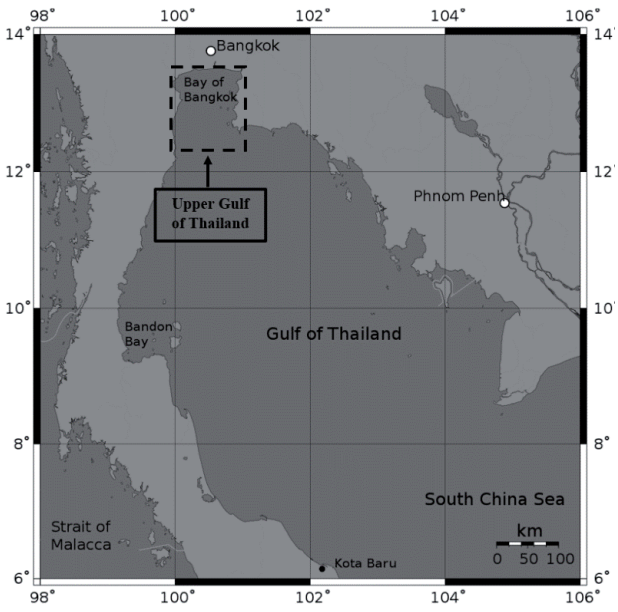

Fig. 1. The Upper Gulf of Thailand.

and the northeast monsoon from November to February and the beginning of March.

Methodology

The image data of chlorophyll-a on the sea surface used in this study was a Level-2 Product obtained from data measured by a MODIS sensor installed on an Aqua Satellite. Data were downloaded via the Ocean Color Website (http://oceancolor.gsfc.nasa.gov) with geometric-correction capability of a pixel size of 1,000 m. Data on chlorophyll-a on the sea surface were processed by using SeaWiFS Data Analysis System (SeaDAS) program installed on a Windows 10 platform. The SeaDAS program was downloaded via https://seadas.gsfc. nasa.gov/downloads/. Data on wind were downloaded via the Remote Sensing Systems website, www.remss.com/ measurements/wind. Data on sea surface temperature were downloaded via the EARTHDATA website, https://giovanni.gsfc.nasa.gov/giovanni/.

Moreover, data on the wind and temperature of the sea surface would be used for analyzing changes of the mean of chlorophyll-a on the sea surface in the Result Criticism stage. During the operational process, chlorophyll-a map images were corrected by adding geographic coordinates based on a processing method using the SeaDAS program to create a new map determining the projection as Universal Transverse Mercator. The image of the studied areas in the upper Gulf of Thailand was specifically cut with the boundaries at longitude 100°–101° E and latitude 12.3°–13.3° N. Images from daily data were collected and became monthly data. Subsequently, the content and distribution of sea surface chlorophyll-a were analyzed each month along with the wind and temperature of the sea surface.

Results and Discussion

Results of the Analysis of the Content and Distribution of Chlorophyll-a

Fig. 2 and Table 1 show the results of the analysis of the monthly content and distribution of chlorophyll-a on the sea surface of the upper Gulf of Thailand in 2020 based on data from Aqua/MODIS Satellite. Fig. 2 reveals that the content and distribution of chlorophyll-a on the sea surface in the upper Gulf of Thailand in 2020 were highest in October with the mean of 3.148 mg/m^3, followed by November; they were lowest in February with a mean of 1.514 mg/m^3. They became high again in June with a mean of 2.681 mg/m^3.

Average monthly content of chlorophyll-a on the upper Gulf of Thailand sea surface in 2020 was high from June to October during the southwest monsoon period. The average monthly content of chlorophyll-a in the same area in 2020 was low from November to April during the northeast monsoon period before becoming high again in June. The content of chlorophyll-a tended to increase or decrease based on seasonal changes and weather as well as on the density and distribution of phytoplankton in each area. This interrelationship suggested that the average content of chlorophyll-a in each year tended to increase or decrease based on seasonal changes.

Results of Analysis of the Effect of Wind on the Content and Distribution of Chlorophyll-a on the Sea Surface

Fig. 3 shows the results of analyzing the relation of the wind to monthly content and distribution of chlorophyll-a on the sea surface in the upper Gulf of Thailand.

Fig.3 shows that in January, the tide came from the northeast of the Gulf of Thailand and flowed to the southwest. The average monthly content of chlorophyll-a was around 1.903 mg/m^3 with a considerable amount found in Samut Songkram Province.

In February, the tide came from the south of the central Gulf of Thailand and flowed up before moving to the north of the upper Gulf of Thailand. The average monthly content of chlorophyll-a was around 1.514 mg/m^3 with a large amount found in Samut Songkram Province.

In March, the tide came from the south of the Gulf of Thailand and flowed up before going to the north of the Gulf of Thailand. The average monthly content of chlorophyll-a was around 1.821 mg/m^3 with a large amount found in Samut Prakarn and Chonburi Province.

In April, the tide came from the south of the Gulf of Thailand and flowed up to the north of the upper Gulf of Thailand and went to the north again.

Table 1. Mean of Chlorophyll-A.

Month	mg/m^3
January	1.903
February	1.514
March	1.821
April	2.285
May	2.197
June	2.681
July	2.878
August	2.497
September	3.083
October	3.148
November	2.520
December	2.066

The average monthly content of chlorophyll-a was around 2.285 mg/m^3 with a large amount found in Samut Prakarn and Chonburi Province.

In May, the tide came from the southwest of the central Gulf of Thailand and flowed up before moving to the northeast of the upper Gulf of Thailand. The average monthly content of chlorophyll-a was around 2.197 mg/m^3 with a great amount found in Samut Prakarn Province.

In June, the tide came from the southwest of the Gulf of Thailand and flowed up before flowing to the right side and northeast of the upper Gulf of Thailand. The average monthly content of chlorophyll-a was around 2.681 mg/m^3 with a large amount located in Chonburi and Samut Prakarn Province.

In July, the tide came from the southwest of the Gulf of Thailand and flowed to the northeast of the upper Gulf of Thailand. The average monthly content of chlorophyll-a was around 2.878 mg/m^3 with a concentration in Chonburi and Samut Prakarn Province.

In August, the tide came from the west of the central Gulf of Thailand and flowed up before going to the right side and moving to the northeast of the upper Gulf of Thailand. The average monthly content of chlorophyll-a was around 2.498 mg/m^3 with a concentration found in Chonburi Province.

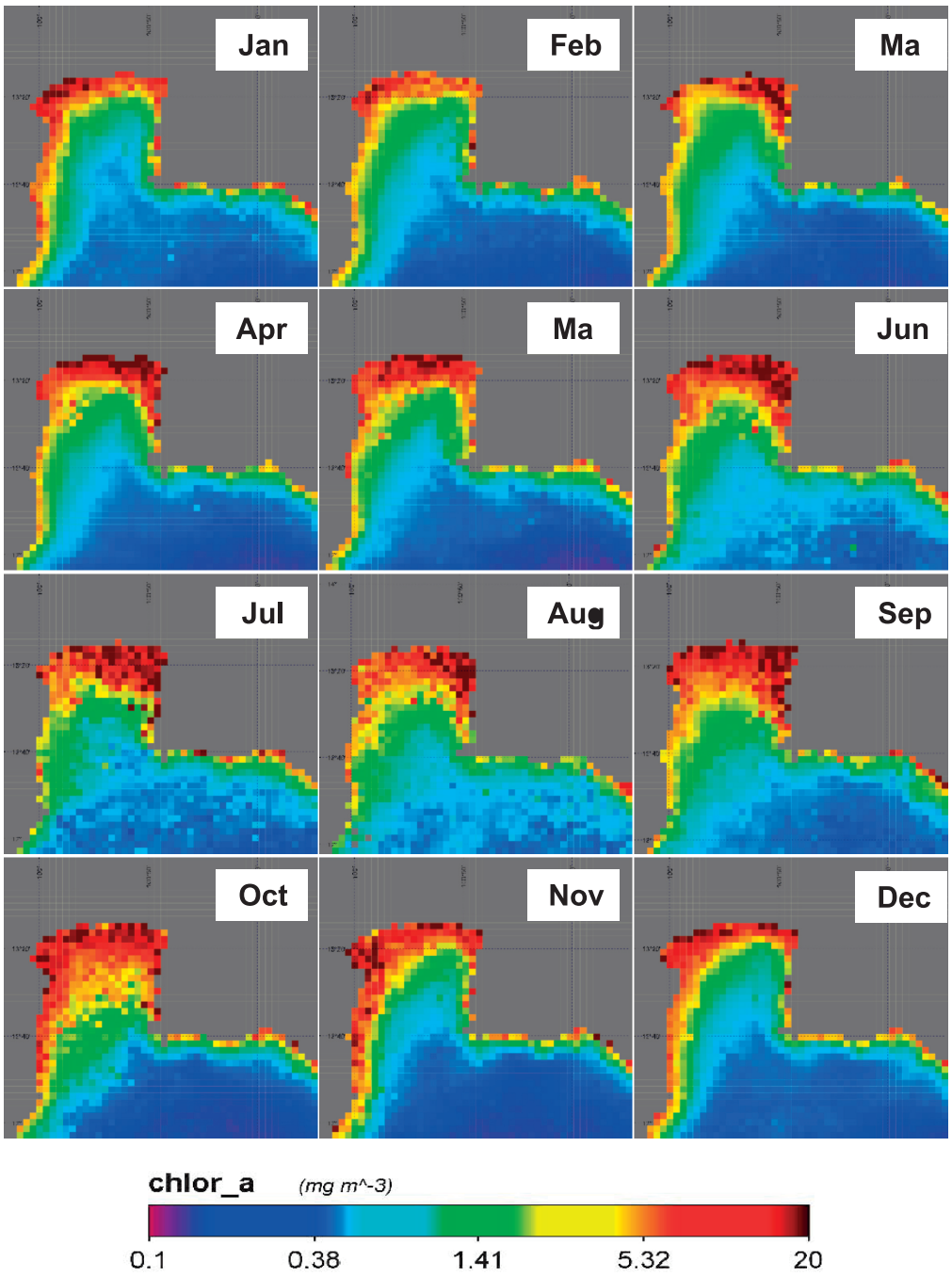

Fig. 2. Average amount and distribution of chlorophyll-a at the sea surface in the Gulf of Thailand.

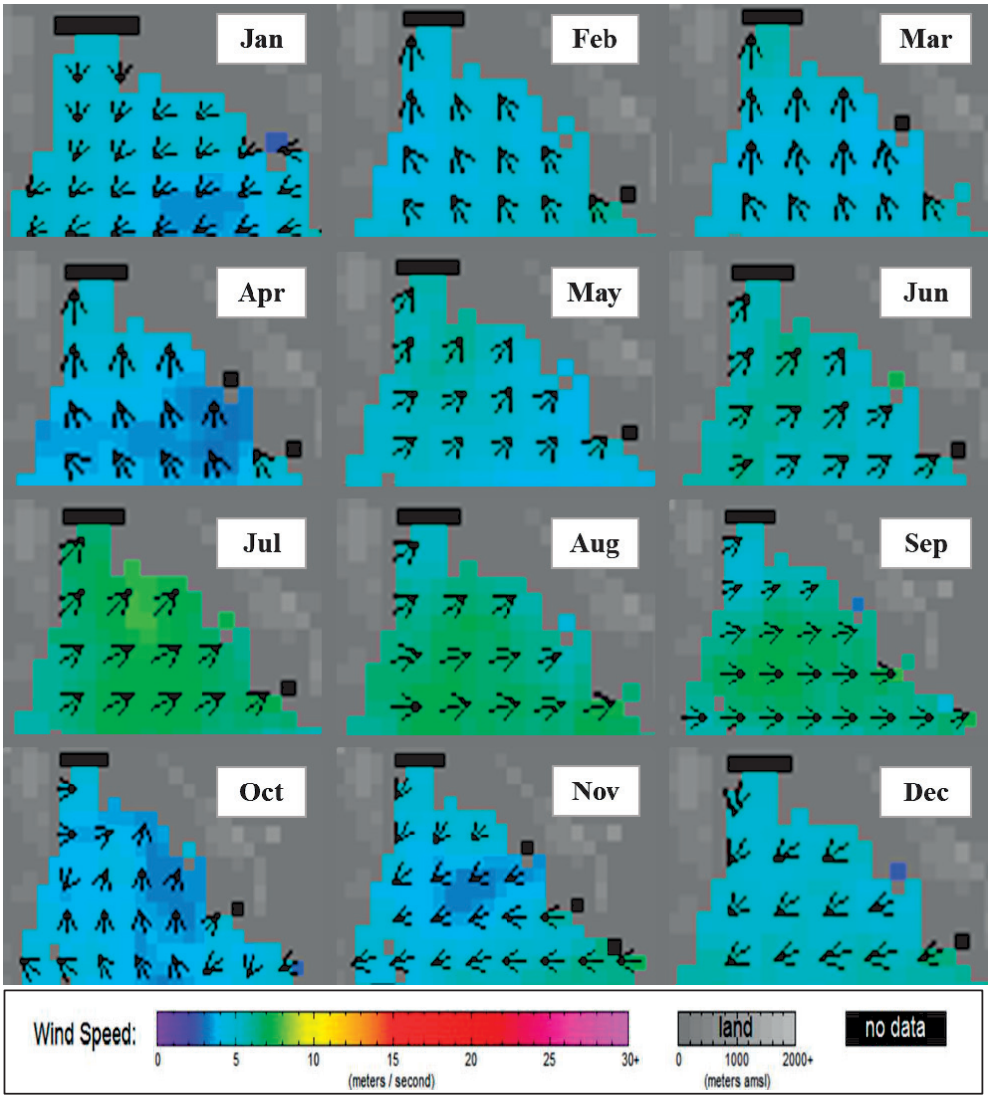

Fig. 3. Monthly average wind currents in the upper Gulf of Thailand in 2020.

In September, the tide came from the west of the central Gulf of Thailand and flowed up to the north before moving to the northeast. The average monthly content of chlorophyll-a was around 3.083 mg/m^3 with a concentration found in Samut Prakarn, Chachoengsao and Chonburi Province.

October is the month of transition from the southwest monsoon to the northeast monsoon with various directions of tide. However, in the upper Gulf of Thailand, the tide came from the west of the Gulf of Thailand and flowed to its east. The average monthly content of chlorophyll-a was around 3.148 mg/m^3 with a large amount found in Samut Prakarn, Samut Songkram, Samut Sakorn and Chonburi Province.

In November, the tide came from the northeast of the upper Gulf of Thailand and flowed to the southwest of the gulf. Average monthly content of chlorophyll-a was around 2.520 mg/m^3 with a great amount found in Samut Sakorn, Samut Songkram, and Phetchaburi Province.

In December, the tide came from the northeast of the upper Gulf of Thailand and flowed up to the north before going to the southwest of the gulf. The average monthly content of chlorophyll-a was around 2.066 mg/m^3 with a large amount found in Samut Songkram and Samut Sakorn Province.

Monsoons influenced wave formation and water flow leading to the diffusion of sediment from the lower layer or seabed to the sea surface giving more nutrients to plankton and leading to the rapid distribution and growth of plankton. As a result, the tendency to increase or decrease chlorophyll-a was based on seasons, especially the rainy season when the distribution of chlorophyll-a was high from May to October. In the case of monsoons, the content of chlorophyll-a was high in the southwest monsoon period that normally occurred from June to October and was low in northeast monsoon period from November to April.

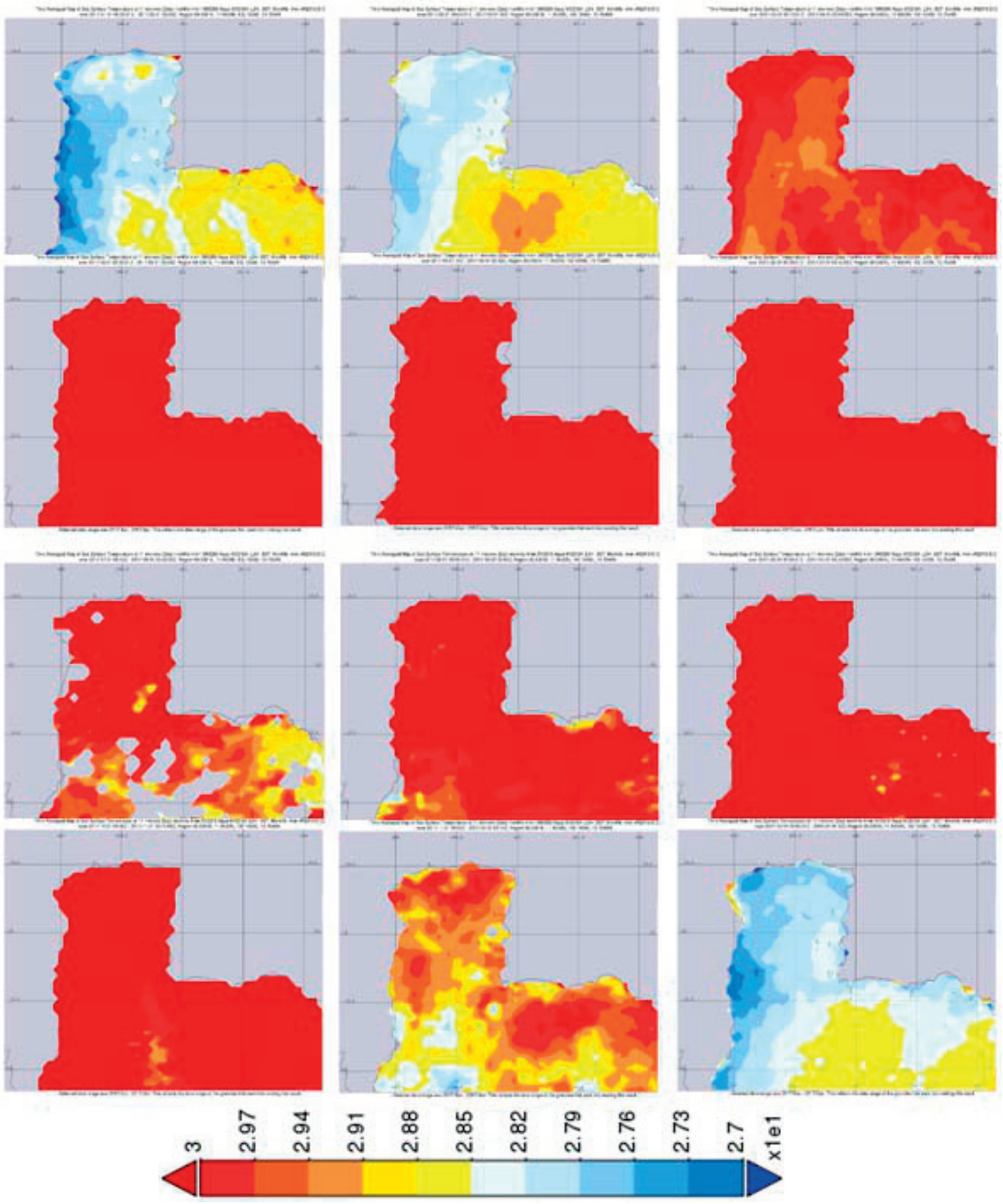

Fig. 4. Sea surface temperature in the upper Gulf of Thailand, 2020.

Results of Analysis of the Effect of Sea Surface Temperature on the Content and Distribution of Chlorophyll-a on the Sea Surface

Fig. 4 shows the results of the analysis of the relation of sea surface temperature to content and distribution of chlorophyll-a on the sea surface in the upper Gulf of Thailand.

Fig. 4 shows that sea surface temperature was low (around 27ºC-29ºC). From November to February, i.e., the northeast monsoon period (winter), water flowing from the southwest of the upper Gulf of Thailand to the west of the upper Gulf of Thailand changed the temperature of sea surface and led to limited growth and propagation of plankton. Consequently, the content of chlorophyll-a was low in this period. Subsequently, the temperature gradually went higher in the transition from northeast monsoon to the southwest monsoon. From March to May (summer) and from June to October (rainy season), the temperature of sea surface was higher (over than 30ºC). The number of phytoplankton floating on sea surface was huge because this period was conducive to its growth and propagation.

This research also found that sea surface temperature affected the density of phytoplankton. This observation was consistent with the hypothesis stating that the temperature of sea surface affected the number of phytoplankton. This was consistent with the research

conducted by [37], who concluded that sea surface temperature was one of the most important influences on phytoplankton. Temperature affected the metabolism in the phytoplankton cells. Moreover, temperature also had a relationship with light intensity, i.e., if light intensity was high, the temperature of sea surface was higher. The upper Gulf of Thailand consisted of four main rivers, including Mae Klong River, Tha Chin River, Chao Phraya River, and Bang Pakong River as well as some short rivers along the coast. In addition, it was also a semi-enclosed gulf causing low-level water circulation and transfer, leading to high distribution of nutrients with long accumulation. A certain combination of environmental factors enabled phytoplankton to increase its number rapidly, leading to red tide.

Conclusions

After analyzing the content and distribution of chlorophyll-a on the sea surface using data from Aqua/MODIS Satellite, the following conclusions can be made:

The results of the 2020 analysis of the content and distribution of chlorophyll-a on sea surface using data from the Aqua/MODIS Satellite revealed that the average monthly distribution of chlorophyll-a on the sea surface in the upper Gulf of Thailand was at its highest level in October with a mean of 3.148 mg/m^3 before decreasing in November to its lowest level in February with a mean of 1.514 mg/m^3. This article concludes that the average content of chlorophyll-a tended to increase or decrease because of seasonal changes and weather.

Analysis of the distribution of chlorophyll-a on the sea surface in the upper Gulf of Thailand in relation to sea surface wind and temperature revealed that the southwest monsoon period (May-September) had higher wind speed than the northeast monsoon period (November-February) did. In addition, tides caused the sea water to flow in the opposite direction, i.e., during the southwest monsoon period, most tides flowed from the northeast to the southwest of the upper Gulf of Thailand when the temperature of the sea surface was higher than 30ºC. For northeast monsoon, most tides flowed from the northeast to the southwest of the upper Gulf of Thailand with low temperature of sea surface of around 27ºC-29ºC). In monsoon transition period (October), the tides flowed in various directions, but tides would flow from the west to the east in the upper Gulf of Thailand. Therefore, the content and distribution of Chlorophyll-a would be high in southwest monsoon period and low in the northeast monsoon period. In addition, this study is in line with similar works such as "Modis-based Observation of Sea-surface Chlorophyll-a Concentration over Upper Gulf of Thailand" [14], "A Bio-optical Algorithm for the Remote Estimation of the Chlorophyll-a Concentration in Case 2 Waters" [19] and research entitled "Algorithms for Remote Estimation of Chlorophyll-a in Coastal and Inland Waters using Red and Near Infrared Bands" [20] etc. All three topics above have applied remote sensing to monitoring the spread of chlorophyll-a and related factors.

The results of this analysis of the content and distribution of chlorophyll-a on sea surface by using data from the Aqua/MODIS Satellite could be used as a reference for monitoring, reporting, and presenting the distribution of chlorophyll-a on the sea surface in the upper Gulf of Thailand in each period. Each month, the content and distribution of chlorophyll-a tended to change because of the influence of monsoons.

In southwest monsoon period, the content of chlorophyll-a was high. During northeast monsoon, the content of chlorophyll-a was low. The period with high and low content of chlorophyll-a in each month may be consistent with the activity of the tides and temperatures of sea surface in coastal areas. Although the sea surface temperature did not have a clear relationship with changes in plankton, it might influence the amount of chlorophyll-a in combination with other factors that were not studied in this research, for example, light intensity, water quality, saltiness, nutrients, competition for nutrients among various types of plankton, or the ability of some types of phytoplankton to generate and release substances inhibiting the growth of other types of plankton. This research also proved that data processing techniques from modern satellites could provide good data for properly analyzing changes of chlorophyll-a on the sea surface in the upper Gulf of Thailand. However, the limitation of this study is that only source of data was from the Aqua/MODIS satellite. Therefore, it is recommended that the quantity and distribution of chlorophyll-a on the sea surface of the Gulf of Thailand be measured by instrumentation. Then, the instrument measurement results can correlate with the analyzed data from the Aqua/MODIS satellites to increase the accuracy of the analysis results.

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Conflict of Interest

The authors declare no conflict of interest.

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