Vietnam Journal of Marine Science and Technology; Vol. 21, No. 3; 2021: 233–245
DOI: https://doi.org/10.15625/1859-3097/15875
http://www.vjs.ac.vn/index.php/jmst

Monthly anomalies of sea surface chlorophyll-a concentration in the Khanh Hoa waters of Vietnam related to ENSO phenomenon

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Received: 8 February 2021; Accepted: 3 May 2021

Abstract
Based on the monthly averaged sea surface chlorophyll-a concentration data continuously for more than 17 years (Jul. 2002–Dec. 2019), the analyzed results show that the averaged chlorophyll-a concentration in Khanh Hoa waters was 0.58 mg/m^3, and the monthly average variation was ± 0.14 mg/m^3 (that is equivalent to about ± 24%). Under the impact of ENSO phenomena, in the years when the double La Niña events occurred (two consecutive years in the La Nina event occurs), the chlorophyll-a anomaly index fluctuated from -0.99 mg/m^3 to 1.62 mg/m^3. These are very strong fluctuation levels, corresponding to the decrease or increase in chlorophyll-a concentration from 86% to 279%. In the El Niño years, the fluctuations of chlorophyll-a concentration were little affected unless the two previous years in which the double La Niña event occurred. These fluctuations have significantly impact nutritional resources and water quality because chlorophyll-a concentration is one of the key indices in studying the health status of any natural marine ecosystem. In addition, chlorophyll-a concentration in Khanh Hoa waters often varies between seasons. The averaged chlorophyll-a concentration reaches its maximum value in the winter, then decreases gradually in the spring and usually reaches the minimum value in the summer, then rises gradually again in the autumn.

Keywords: Southeast Asian studies, climate change, Khanh Hoa, chlorophyll-a anomaly, ENSO events.

Citation: Van Vu Tac, 2021. Monthly anomalies of sea surface chlorophyll-a concentration in the Khanh Hoa waters of Vietnam related to ENSO phenomenon. *Vietnam Journal of Marine Science and Technology*, *21*(3), 233–245.

INTRODUCTION

Global climate change has been having a substantial negative impact on human life and other organisms on Earth and is becoming a growing threat to the survival of humans. Global Climate Risk Index 2020(CRI) [1] report presented at the ongoing 25th Conference of the Parties (COP25) to the UN Framework Convention on Climate Change in Madrid, Spain, Vietnam has worsened from 9th spot in the CRI 2019, which reviewed 1998 to 2017, to 6th in 2018 on the global vulnerability ladder. Puerto Rico remains at the top of the list, while Myanmar and Haiti are the top three; next come the Philippines, Pakistan and Vietnam. Climate change threatens urban infrastructure and the quality of people's lives, especially in coastal areas. This report also shows that during the period from 1999 to 2018, about 495,000 people died worldwide, and losses of US$ 3.54 trillion (in PPP) were incurred as a direct result of more than 12,000 extreme weather events. Over the last two decades, Vietnam has had more than 226 severe weather events, killing an average of 285.80 people and causing economic losses of US $2 billion per year (according to Statistics from 1999–2018), the report said.

In studying the anomalies of global climate change, scientists pay special attention to the El Niño Southern Oscillation (ENSO). The ENSO is one of the most important climate phenomena on Earth due to its ability to change the global atmospheric circulation, which influences temperature and precipitation across the globe. The ENSO significantly impacts Earth's ecosystems and human societies [2]. This phenomenon relates to the cycle of warm and cold temperatures, as measured by sea surface temperature (SST) of the tropical central and eastern Pacific oceans. This cycle periodically fluctuates between three phases: Neutral, La Niña, or El Niño. La Niña and El Niño are opposite phases that require specific changes in both the ocean and the atmosphere before an event is declared [3]. El Niño is the warm phase and La Niña is the cold phase of ENSO. The Neutral phase of ENSO indicates normal sea surface temperature, with no obvious warmer or colder than normal waters [2]. Vietnam is located in the north of the equator of the Western Pacific Ocean, is the area affected by ENSO. There has been a lot of research to show the social-economic impacts of ENSO. Marine phytoplankton played a very important role in the global carbon cycle via photosynthetic carbon fixation and produced nearly half of the world's oxygen via photosynthesis [4, 5]. Whenever the ENSO phenomenon occurs, climate and weather change abnormally, causing droughts, floods, and natural disasters in many different regions of the world [6, 7]. The ENSO impacts each region in the world differently depending on the location and topography of the land [8]. Even different areas of Vietnam are also affected differently by the ENSO phenomenon.

The chlorophyll-a (chla) is a green pigment found in microscopic plant phytoplankton. It is known to produce systematic variations in the color of the ocean [9]. When phytoplankton populations are large, the color of the water appears greener because of high concentrations of chla [10]. They can effectively measure of trophic status, are potential indicators of the maximum photosynthetic rate, and are a commonly used measure of water quality.

The studies on fluctuations of chla concentration related to the ENSO phenomenon have also received much attention in the world. Based on agricultural statistics and monthly Southern Oscillation Index data to quantitatively evaluate regional agricultural meteorological disasters and assess the regressive models used to predict the grain yield and climatic yield losses caused by drought disasters. The results showed that during the La Niña stage, the probability of a drought disaster was higher than during the El Niño stage, especially in Hebei, China [11]. In the context of a strong El Niño prediction for 2015–2016, there was a remarkable change in the physicochemical environment of the reef water and massive coral bleaching in the Kavaratti reef waters, a major coral atoll along the southeast coast of India [12]. Analysis results based on daily temperature, precipitation, and sunshine hours for 50 years (1956–2006) showed that precipitation decreased, and temperature and sunshine hours increased in both El Niño and La Niña years but remained stable in neutral years [13]. A study on surface chla anomalies associated with Indian Ocean Dipole and El Niño Southern Oscillation in North Indian Ocean showed that the strong negative chla anomalies over the Western Indian Ocean from November to April are due to the changes associated with the El Niño [14]. The research used rainfall data to analyze the characteristics of extreme storm events and their relationships with the ENSO phenomenon in Korea. It showed that the annual maximum storm events in Korea were not greatly affected by ENSO. However, as the return period of a storm event grew, the probability of it being related to El Niño increased significantly due to the combined effects of domestic and global climate factors [15]. The analysis of the impact of ENSO on the regional chla anomaly in the Papua waters is found that when El Niño events occur, the negative SST anomaly in the Papua waters, as well as the enhanced upwelling, cause the increase of chlorophyll-a concentration [16]. Another analysis, using 148 months of chla data to study the variability of chla associated with El Niño [17], reveals that the effect of reduced surface solar radiation on chla is larger in the central Pacific Ocean than in the eastern and western Pacific Ocean, and this regional difference of the impact induces a distinctly asymmetric response of ocean chla to El Niño and La Niña in the central Pacific Ocean.

In Vietnam, there have been many studies related to the ENSO phenomenon so far. The studies on the variability of the upwelling system in the South-Central Vietnam waters under ENSO events and its impact on hydrographic conditions of the Ninh Thuan-Binh Thuan waters [18] have shown that the La Niña events can degrade and eliminate the upwelling phenomenon. The study of abnormal features of oceanographic characteristics in upwelling Vietnam waters under the influence of El Niño events [19] has partly clarified the impact of the El-Niño phenomenon on the occurrence time and position of the center region of the Vietnam upwelling waters. Based on 28 years of reanalysis data, the analyzed results showed that in the El Niño years, autumn rainfall in Central Vietnam is reduced by about 10 to 30% [20]. Another notable study was analysis results based on MODIS satellite images of the US National Aeronautics and Space Administration. It showed that in the coastal marine area of the South-Central Vietnam, the sea surface chla concentration in summer and autumn of La Niña years higher by 0.22–0.38 mg/m^3 compared to other years [21].

In particular, in 2019, the analyzed results of the variability of sea surface chlorophyll-a (SSchla) concentration in South Vietnam coastal waters (SVNC) showed that the ENSO phenomenon has greatly affected the fluctuation of SSchla concentration in the SVNC [22]. However, in the SVNC, Khanh Hoa waters have very special features of climate, topography and marine resources. Compared to other provinces in the North from Ca Pass northward and in the South from Ghenh Da Bac southward, the climate in Khanh Hoa is relatively mild due to the nature of the ocean climate. There are only two seasons: rainy and sunny season. The rainy season is short, from the middle of September to the middle of December in the solar calendar, focusing on October and November; the rainfall is more than 50% of the rainfall in the year. The remaining months are the sunny season, with an annual average of 2,600 hours of sunshine there [23]. Therefore, in the Khanh Hoa waters, the remote sensing images have often given much better interpretation results than in other areas of Vietnam. In addition, Khanh Hoa is one of the provinces with advantages of marine resources, economic and cultural center of the South-Central region, and a major tourist center of Vietnam. These are the main reasons this study was conducted in order to determine the characteristics, cycle, and variability of SSchla concentration in the Khanh Hoa waters and their relationships with the ENSO phenomenon. The results of this study will assist the scientists and managers in taking effective measures to prevent and mitigate the damage caused by climate change to biodiversity, the environment in Khanh Hoa waters.

MATERIALS AND METHODS

Materials

In this study, the data was collected and processed, including:

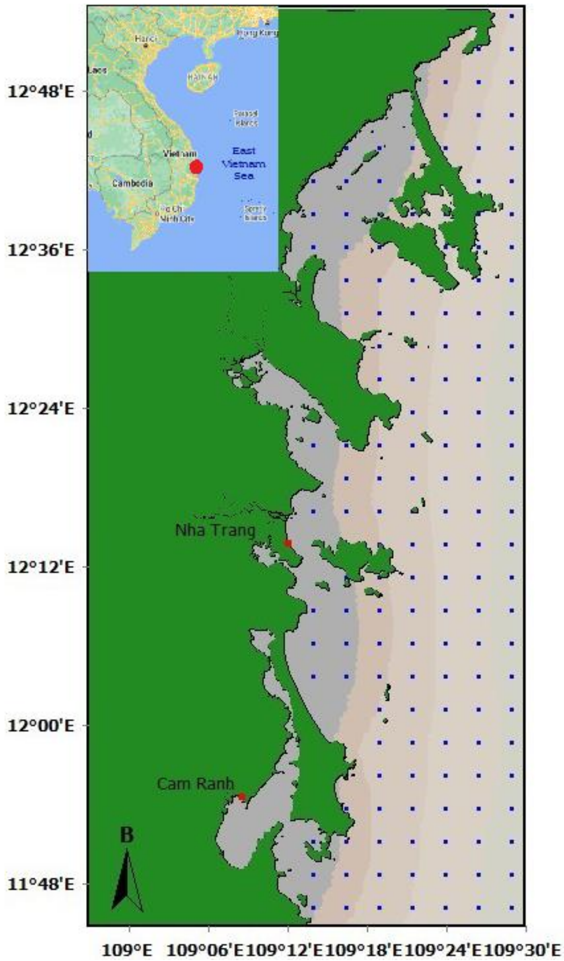

Figure 1. The study area and the spatial distribution of collected SSchla data

Monthly mean SSchla concentration data was extracted from the Level-3 Product Suite of the Aqua MODIS with a spatial resolution of 4 × 4 km^2 for more than 17 years (Jul. 2002–Nov. 2019). MODIS is the NASA Ocean Biology Processing Group (OBPG) data product, the official NASA data center that archives and distributes ocean color data. The dataset is available at the National Aeronautics and Space Aistration (NASA) Ocean Color website (https://oceancolor.gsfc.nasa.gov/) [24]. SSchla values in the dataset were estimated by applying the Ocean Chlorophyll MODIS OCx algorithm. Significantly, this data product ensures spatial synchronization and is long enough to cover the cycles of the ENSO phenomenon.

The GEBCO_2020 Grid is the global bathymetric product released by the General Bathymetric Chart of the Oceans (GEBCO) and developed through the Nippon Foundation-GEBCO. The bathymetric product has a spatial resolution of 15 arc-second (~ 450 m). This product includes bathymetric and the boundary, which is used to determine the depth and boundary of the study area (fig. 1).

The Oceanic Niño Index (ONI) data table is calculated by the National Oceanic and Atmospheric Administration (NOAA), which is available in the Golden Gate Weather Services (http://ggweather.com/enso/oni.htm) [24]. This index is a measure of the departure from normal sea surface temperature in the east-central Pacific Ocean. It represents the standard means to determine, gauge and forecast each El Niño episode. El Niño episodes are characterized by sea surface temperature increases of more than 0.5°C and La Niña episodes are indicated by sea surface temperature decreases of more than 0.5°C for at least five successive overlapping three-month seasons [25]. Currently, the ONI is considered as the de-facto standard that NOAA uses for identifying the phases of ENSO in the tropical Pacific. Based on the data table, the years of El Niño, La Niña and their intensities are described in table 1.

Based on the cadastral map of Khanh Hoa province, the study water area is limited from longitude 108^{o}56’52.1376E to 109^{o}28’12.0792E, and latitude from 11^{o}44’45.5748N to 12^{o}54’7.038N, as depicted in fig. 1.

Table 1. El Niño and La Niña years and their intensities

El Niño			La Niña		
Weak	Moderate	Very Strong	Weak	Moderate	Strong
2004–2005	2002–2003	2015–2016	2005–2006	2011–2012	2007–2008
2006–2007	2009–2010		2008–2009		2010–2011
2014–2015			2016–2017		
2018–2019			2017–2018		

Methods

Files downloaded from the NASA Ocean Color website include 210 netCDF files corresponding to 210 months (Jul. 2002–Dec. 2019). These files archived the monthly SSchla concentration (mg/m^3) for the global scope (fig. 2 illustrates some of these files). The downloaded SSchla data were extracted to text files for the study area and compiled into a table in a Microsoft Access database. Fig. 3 illustrates about the SSchla data table in this database. The data quality control and statistical calculations for the study are performed on this database through mathematical & statistical functions in Microsoft Access.

The total number of SSchla values in the dataset (210 months) is 20,532. Therefore, the average of each MODIS image file has approximately 97 SSchla values evenly distributed in the study area. The study area and the spatial distribution of SSchla value points are described in fig. 1.

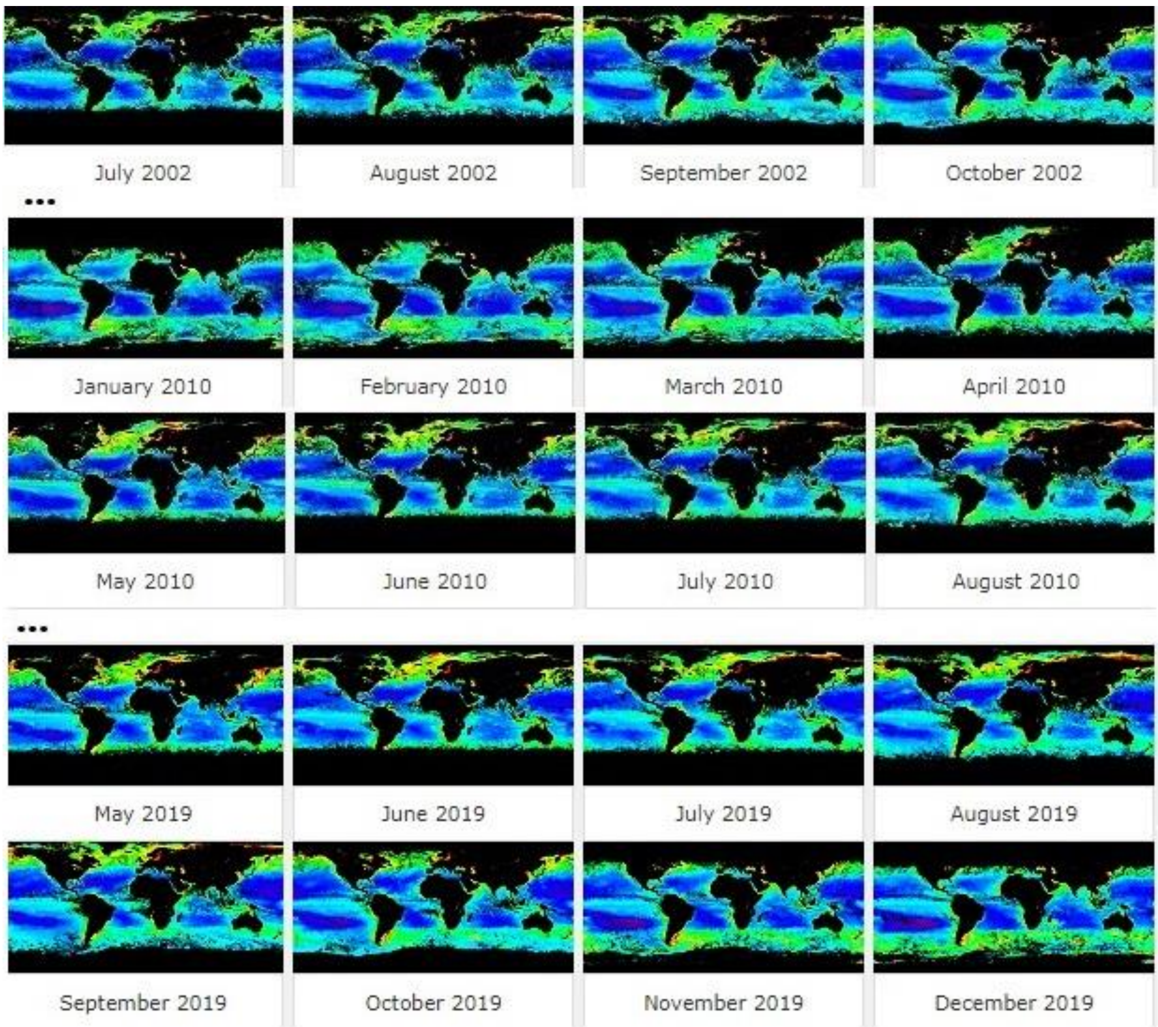

Figure 2. Illustrating of some netCDF level 3 files on the NASA Ocean Color website (resolution 4 km, Jul. 2002–Nov. 2019)

The minimum and maximum SSchla values in the SSchla data table are 0.068 mg/m^3 and 14.779 mg/m^3, respectively. However, there are 99% SSchla values in the range (0.68–2.99 mg/m^3), which show s in the histogram of the frequency of chlorophyll-a values (fig. 4). According to World Ocean Database 2013 [26], the SSchla range in the Coastal North Pacific is [0–50 mg/m^3]. In addition, an article shows that the SSchla concentrations in the East Vietnam Sea and adjacent waters are in the range of 0–20 mg/m^3 [27]. These indicate that 100% of the SSchla data used for this study is within the above ranges, and the data source is very reliable.

In data analysis, we used Microsoft Access statistical functions to calculate the averaged SSchla concentration, grouped by months, seasons, and ENSO type years (Neutral, El Niño and La Niña years). The analyzed data were exported to Microsoft Excel files to build the graphs and charts describing the variations of SSchla concentration over time. In the Access database, there were three months without data due to bad weather. Those months were November 2008, November 2010, and December 2011. Therefore, these months' average SSchla concentration is calculated by the average SSchla concentration of the two neighboring months (the month before and after the missing data month).

sDate	Longitude	Latitude	Chlorophyll
07/2002	109.4375	12.85416	0.512942
07/2002	109.4791	12.85416	0.22922
07/2002	109.3541	12.5625	0.329326
07/2002	109.3958	12.5625	0.276961
07/2002	109.4375	12.5625	0.239406
07/2002	109.4791	12.5625	0.171788
07/2002	109.4791	12.47916	0.197498
07/2002	109.4375	12.4375	0.232929
07/2002	109.4791	12.4375	0.17311
07/2002	109.3541	12.35416	0.164456
07/2002	109.3958	12.35416	0.18185
07/2002	109.4375	12.35416	0.170717
07/2002	109.4791	12.35416	0.160402
07/2002	109.4791	12.8125	0.359982
07/2002	109.4791	12.72916	0.317359
07/2002	109.4791	12.60416	0.142334
07/2002	109.4375	12.52083	0.22399
07/2002	109.4791	12.52083	0.20682
07/2002	109.4791	12.39583	0.169772
07/2002	109.3125	12.3125	0.332304
07/2002	109.3541	12.3125	0.183199
07/2002	109.3958	12.3125	0.150414

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Figure 3. Illustration of the SSchla data table in Microsoft Access

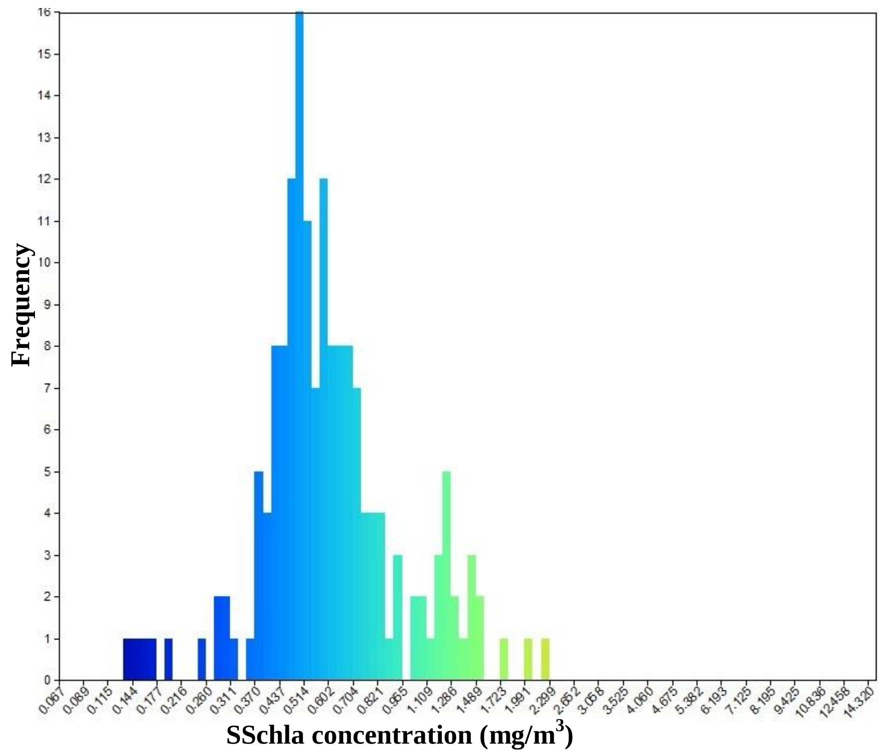

Figure 4. The histogram of the frequency of chlorophyll-a values (mg/m^3)

STUDY RESULTS

To have a comprehensive and visual overview of the fluctuations of SSchla concentration in the study area, we constructed graphs have been built to describe the monthly average change of SSchla concentration over time (fig. 5), the monthly fluctuations of ONI, and SSchla anomalies over time (fig. 6), and spatial distribution of monthly averages of SSchla concentration in the Khanh Hoa waters (fig. 7). The calculated results of monthly averaged SSchla concentration in the Khanh Hoa waters are listed in table 2. The analysis results of the SSchla anomaly in the study area are described in table 3.

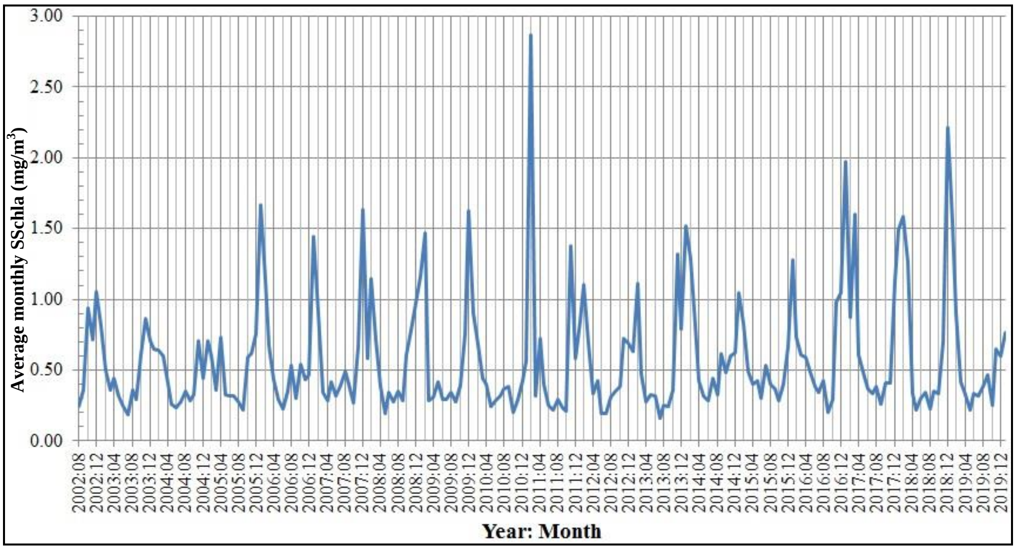

Figure 5. The monthly average fluctuation of SSchla concentration over time in the study area (2002–2019)

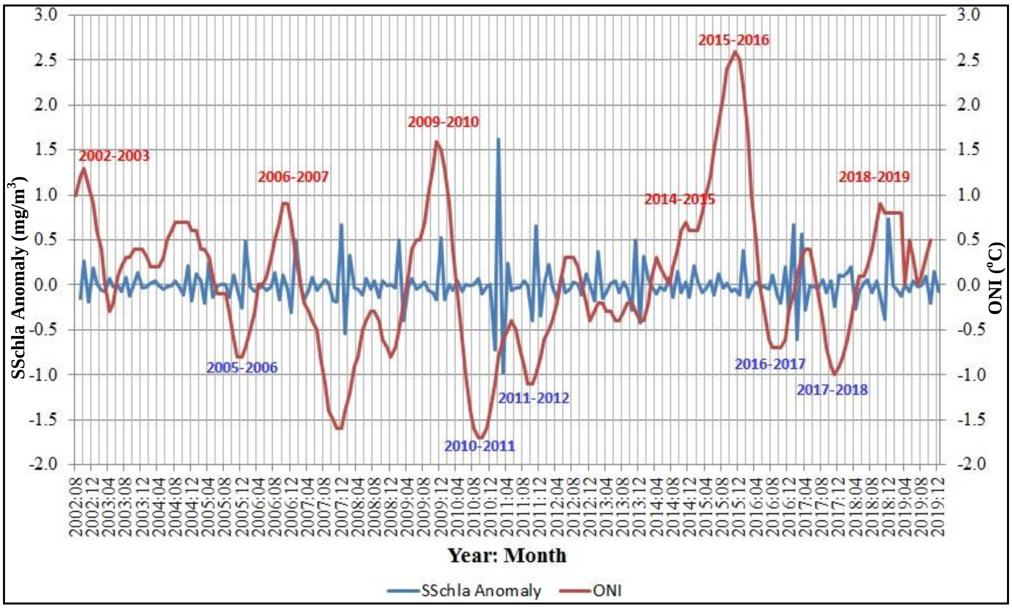

Figure 6. The monthly fluctuations of ONI, and SSchla anomalies over time in the study area (2002–2019)

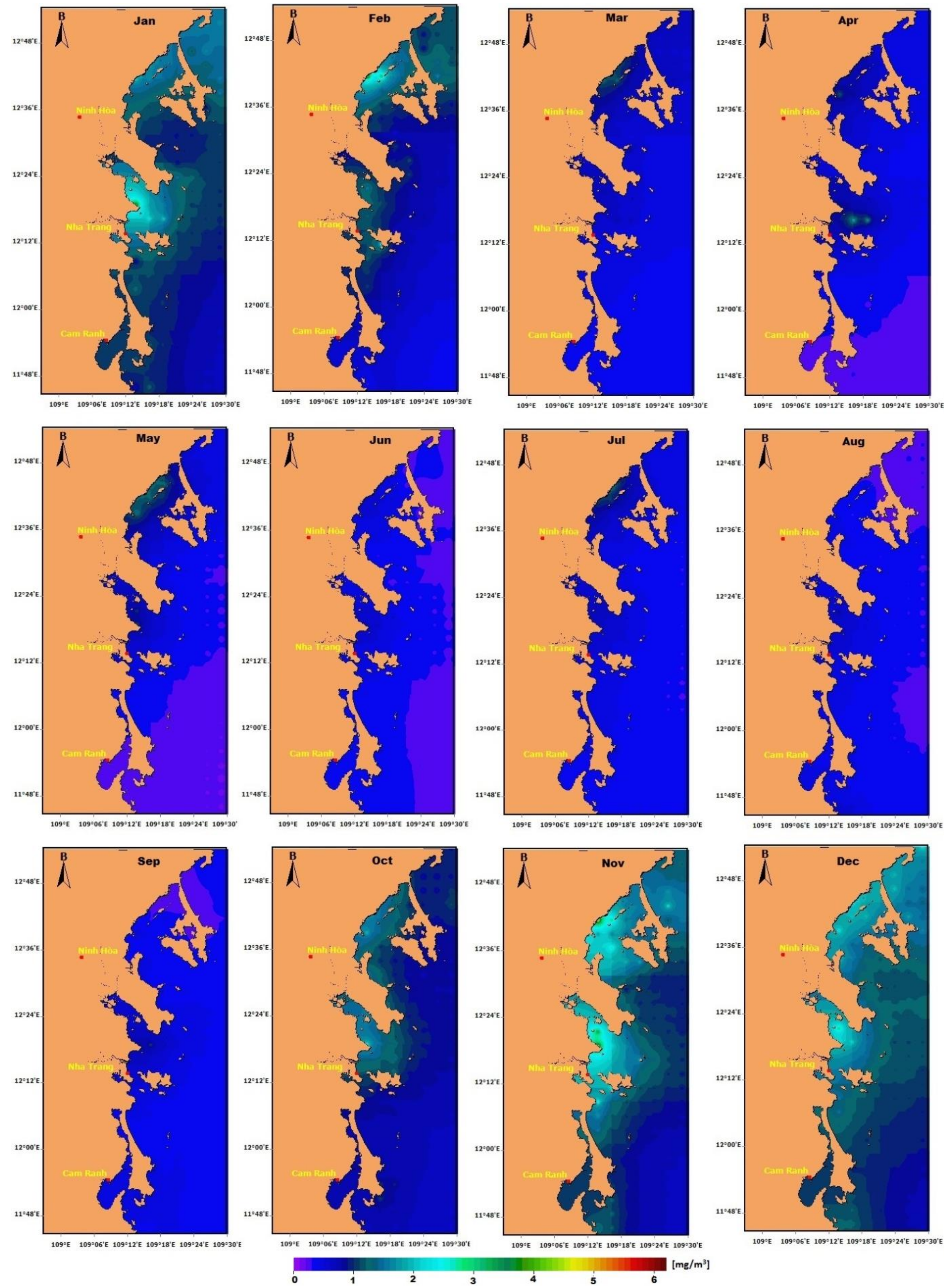

Figure 7. Spatial distribution of monthly averages of SSchla concentration in the Khanh Hoa waters for the period from July 2002 to December 2019

Table 2. The calculation results of monthly averaged SSchla concentration (mg/m^3) in the Khanh Hoa waters, from 7/2002–12/2019

Season	Monthly averaged SSchla concentration (mg/m^3)											
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
2002–2003	0.24	0.36	0.94	0.71	1.06	0.81	0.50	0.36	0.44	0.31	0.24	0.19
2003–2004	0.36	0.30	0.61	0.86	0.71	0.65	0.64	0.60	0.41	0.26	0.23	0.28
2004–2005	0.35	0.29	0.32	0.71	0.44	0.71	0.60	0.36	0.73	0.32	0.31	0.31
2005–2006	0.28	0.22	0.59	0.61	0.76	1.67	1.14	0.67	0.43	0.30	0.22	0.35
2006–2007	0.54	0.30	0.54	0.43	0.47	1.44	0.90	0.34	0.28	0.42	0.32	0.40
2007–2008	0.49	0.40	0.26	0.67	1.64	0.58	1.15	0.72	0.39	0.20	0.34	0.27
2008–2009	0.35	0.28	0.61	0.78	0.97	1.16	1.47	0.29	0.31	0.42	0.29	0.29
2009–2010	0.34	0.28	0.40	0.76	1.63	0.90	0.68	0.44	0.40	0.24	0.28	0.32
2010–2011	0.37	0.39	0.20	0.29	0.43	0.56	2.87	0.32	0.72	0.40	0.25	0.22
2011–2012	0.30	0.24	0.21	1.38	0.58	0.85	1.11	0.69	0.33	0.43	0.19	0.19
2012–2013	0.31	0.35	0.38	0.73	0.69	0.63	1.11	0.47	0.28	0.32	0.31	0.16
2013–2014	0.25	0.24	0.36	1.32	0.79	1.52	1.29	0.82	0.43	0.32	0.29	0.44
2014–2015	0.32	0.62	0.48	0.60	0.62	1.05	0.83	0.50	0.40	0.43	0.30	0.53
2015–2016	0.40	0.37	0.28	0.40	0.66	1.28	0.73	0.60	0.59	0.49	0.39	0.34
2016–2017	0.43	0.20	0.29	0.98	1.05	1.97	0.87	1.60	0.61	0.48	0.37	0.34
2017–2018	0.38	0.26	0.41	0.41	1.13	1.50	1.58	1.26	0.33	0.22	0.30	0.35
2018–2019	0.23	0.35	0.33	0.70	2.21	1.54	0.90	0.42	0.32	0.22	0.33	0.32
2019–2020	0.32	0.39	0.47	0.25	0.65	0.60	0.77					

Note: Averaged SSchla in the study area: 0.58 mg/m^3 Note: Averaged SSchla in the study area: 0.58 mg/m^3; Monthly averaged variability of SSchla concentration in the study area: ± 0.14 mg/m^3 (~ ± 24%).

Table 3. The analysis results of SSchla anomalies in the Khanh Hoa waters, 8/2002–11/2019

ENSO Type	Season	SSchla anomalies (mg/m^3)											
		Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
ME	2002–2003		-0.16	0.27	-0.19	0.19	0.02	-0.06	-0.07	0.07	-0.02	-0.01	-0.08
	2003–2004	0.08	-0.12	0.02	0.14	-0.03	-0.02	0.01	0.05	-0.01	-0.04	-0.02	-0.01
WE	2004–2005	0.04	-0.03	-0.12	0.22	-0.18	0.12	0.04	-0.20	0.26	-0.13	0.00	0.01
WL	2005–2006	0.01	-0.14	0.12	-0.04	-0.26	0.48	-0.02	-0.07	-0.03	-0.02	-0.07	-0.02
WE	2006–2007	0.14	-0.16	0.12	-0.05	-0.31	0.50	0.01	-0.17	-0.06	0.08	-0.06	-0.01
SL	2007–2008	0.06	0.02	-0.18	-0.19	0.67	-0.54	0.33	-0.03	-0.05	-0.11	0.07	-0.05
WL	2008–2009	0.05	-0.13	0.05	-0.01	0.00	-0.04	0.50	-0.40	-0.03	0.08	-0.04	-0.01
ME	2009–2010	0.04	-0.06	-0.08	-0.17	0.53	-0.17	0.01	-0.07	0.04	-0.07	0.00	0.00
SL	2010–2011	0.01	0.07	-0.09	-0.01	0.00	-0.72	1.62	-0.99	0.24	-0.06	-0.04	-0.04
ML	2011–2012	0.05	-0.01	-0.40	0.65	-0.35	0.00	0.23	-0.02	-0.15	0.11	-0.08	-0.04
	2012–2013	0.03	0.00	-0.11	0.13	0.01	-0.18	0.37	-0.15	-0.08	0.02	0.05	-0.08
	2013–2014	0.03	-0.04	-0.28	0.49	-0.42	0.32	0.08	-0.03	-0.09	-0.02	-0.06	0.09
WE	2014–2015	-0.14	0.14	-0.09	0.03	-0.13	0.21	0.04	-0.08	-0.04	0.05	-0.12	0.12
VSE	2015–2016	-0.03	0.02	-0.07	-0.05	-0.12	0.39	-0.14	-0.04	0.03	0.00	-0.02	-0.04
WL	2016–2017	0.11	-0.11	-0.20	0.21	-0.28	0.67	-0.61	0.57	-0.29	-0.01	-0.02	-0.03
WL	2017–2018	0.06	-0.09	0.05	-0.24	0.11	0.09	0.13	0.20	-0.27	-0.07	0.02	0.05
WE	2018–2019	-0.08	0.05	-0.13	-0.38	0.73	-0.01	-0.05	-0.13	0.00	-0.07	0.04	-0.03
	2019–2020	-0.01	0.10	-0.20	0.15	-0.07							

Note: ENSO Type: WE = Weak El Niño, ME = Moderate El Niño, SE = Strong El Niño, VSE = Very Strong El Niño; WL = Weak La Niña, ML = Moderate La Niña, SL = Strong La Niña.

As mentioned above, there are only two seasons (rainy and sunny) in the Khanh Hoa waters. However, the study area is also affected by the Southwest and Northeast monsoon winds. The Southwest monsoon wind occurs during the summer months, while the Northeast monsoon wind occurs during the winter. Therefore, in this study, we statistically calculate the average SSchla concentration by season. This result is described in fig. 8.

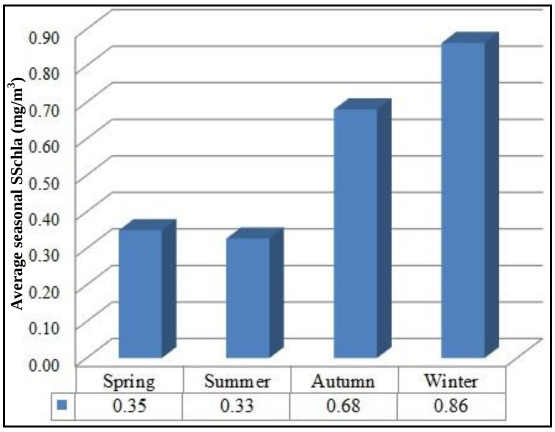

Figure 8. The seasonal average SSchla concentration (mg/m^3) in the Khanh Hoa waters

The above analysis results (tables 1–3, figs. 5–6) show that during the calculation period (17 years), there were 7 El Niño years and 7 La Niña years; the remaining years are Neutral (table 1). In the 7 La Niña years, there have been four years having the SSchla anomalies exceeded the threshold of ± 0.5 and fluctuated continuously for 2 or 3 months. While in the Neutral years, there is not any value exceeding the threshold. Another noteworthy thing is that the SSchla anomalies only exceed the threshold in the years when the double La Niña events occurred (two consecutive cool phases arise). The double La Niña events occurred: 2010–2011, 2011–2012, 2016–2017, and 2017–2018 (table 3). However, in the 7 El Niño years, there is only one year with the SSchla anomalies exceeding the threshold of ± 0.5 with positive value (i.e., the SSchla concentration increased with SSchla anomaly = 0.73 mg/m^3 in November 2018). This El Niño year, but before that year, the double La Niña event occurred (2016–2017, 2017–2018), indicating that the anomaly fluctuations of SSchla concentration only happen when the double La Niña event occurred. In the El Niño years, the changes of SSchla concentration were little affected unless the two previous years in which the double La Niña event occurred.

The averaged SSchla concentration in the study area is 0.58 mg/m^3, and the monthly averaged variability of SSchla concentration in the study area is ± 0.14 mg/m^3 (equivalent to about ± 24%) (table 2). However, as described above, during the double La Niña event, the SSchla anomalies fluctuate from -0.99 to 1.62 mg/m^3. These are extreme fluctuations corresponding to the decrease or increase in SSchla concentration from 86% to 279%.

In addition, SSchla concentration in Khanh Hoa waters often varies between seasons of the years (figs.7–8). The averaged SSchla concentration reaches its maximum value in the winter (December - February), then decreases gradually in the spring (March - May) and usually reaches the minimum value in the summer (June - August), then rises gradually again in the autumn (September - November).

DISCUSSIONS

The SSchla concentration is always affected when ENSO occurs, but, in Khanh Hoa waters, SSchla concentration is only affected when the double La Niña event occurs. However, the affected intensity in Khanh Hoa waters was much greater; the monthly averaged chlorophyll-a concentration in the SVNC varied from 22.4% to 49.3% [22], while in Khanh Hoa waters, it was from 86% to 279%.

According to the general information about the floods that “attacked” the “capital” of Khanh Hoa tourism [29], they were determined at the time: Oct. - Nov. 2006, Nov. 2016, Nov. 2017, and Nov. 2018. Thus, the calculation results in tables 2–3 are very consistent with reality. The times when SSchla concentration fluctuated strongly coincided with when the study area was seriously affected by floods. Nutrients, plankton from the continent through the river system flow to the sea, have increased the SSchla concentration. However, the fluctuation of SSchla concentration depends on many factors, such as temperature, rainfall, upwelling, wind, ocean currents,... Therefore, to explain in detail the causes of the fluctuations at specific times requires more extensive research.

CONCLUSIONS

Summarizing the above analysis results (7/2002–12/2019) leads to the following conclusion:

The average SSchla concentration in the study area was 0.58 mg/m^3, and the monthly averaged variability of SSchla concentration in the study area was ± 0.14 mg/m^3 (equivalent to about ± 24%). Under the impact of the ENSO phenomenon, in the years when the double La Niña events occurred, the SSchla concentration anomalies fluctuated from -0.99 mg/m^3 to 1.62 mg/m^3. These are very strong fluctuations, corresponding to the decrease or increase in SSchla concentration from 86% to 279%. In the El Niño years, the fluctuations of SSchla concentration were little affected unless the two previous years in which the double La Niña event occurred. These fluctuations have greatly impact nutritional resources and water quality because SSchla concentration is one of the key indices in the study of the health status of any natural marine ecosystem. In addition, SSchla concentration in Khanh Hoa waters often varies between seasons. The averaged SSchla reaches its maximum value in the winter, decreases gradually in the spring, usually reaches the minimum value in the summer, and rises gradually again in the autumn.

The provided research results in this paper play an important role in enhancing the awareness of the ENSO phenomenon's influences on Khanh Hoa marine environment, which supports scientists and managers not only in creating feasible environmental measures to reduce and remedy the harm caused by ENSO but also in the protection of biodiversity and marine environment in Khanh Hoa waters. That could be seen as a puzzle piece of the whole picture of the effects of the ENSO phenomenon on global climate change.

Acknowledgments: This paper is a contribution to celebrate the 100 years Anniversary of the Institute of Oceanography, Vietnam Academy of Science and Technology.

Declarations

Funding

The author has received no financial support for the research, authorship or publication of this research.

Conflicts of interest/Competing interests

The author declare that I have no competing interests.

Availability of data and material

All the data and material used for the study is available upon request.

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