World Applied Sciences Journal 21 (6): 879-887, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.21.6.2659

Satellite Derived Measurements of Coastal Water Chlorophyll-a Variability

S.M. Nazmi, A.M. Mustapha and T. Lihan

School of Environmental and Natural Resource Sciences,
Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract: Variability of Chlorophyll-a (Chl-a) were intensively investigated at the coastal water inPahang Malaysia. Data of Chl-a derived from Aqua MODIS satellite at 1 km spatial resolution from January 2006 to December 2010 was processed to climatological images. The seasonal progressions of Chl-a distribution during the monsoon period shows that high values were detected during the Northeast monsoon and spread over a wide region. The spatial and temporal dynamics of Chl-a were explained using an analysis of Empirical Orthogonal Function.The first EOF mode explains 76 % of the total variance which indicated the seasonal cycle with high variability along the coast and the mouth of Pahang River. The second EOF mode explains variability of the Southwest and the Northeast monsoon with 4.18 % of variance. The third EOF mode indicates about 2.08 % of total variance explaining more on the Northeast monsoon that shows the Chl-a distributed along-shelf direction. Mode 4 of Chl-a EOF explained the inter-monsoon period with 1.37 % of total variance showing high variability at the river mouth (positive signal) and along the coast (negative signal). Variability of Chl-a in this area was influenced by river outflow, wind forcing and terrestrial discharge.

Key words: Coastal waters % Chlorophyll-a % Nutrient % Satellite sensing % Monsoons % Empirical Orthogonal Function

INTRODUCTION

Coastal water plays an important role to the marine aquatic ecosystem. With the various terrestrial inputs to the ocean, coastal ecosystem may regulate this composition with the surroundings [1]. However, high inputs of sediments and nutrients may worsen the ecosystem and causes the accumulation and increase of Chlorophyll-a (Chl-a) concentration within the area. Understanding the distribution of Chl-a will enable determination of the environmental conditions. Concentration of these pigments in water column is mainly caused by the abundance of phytoplankton in the water column [2]. Chl-a can be observed through a satellite sensor by analyzing the ocean color data [3, 4]. The temporal variability of phytoplankton biomass appears to depend primarily on physical processes occurring on wide spatial and temporal scales [5].

The Pahang coastal region lies between 2.66°N-4.25°N and 103.30°E-104.26°E in the eastern part of Peninsular Malaysia (Figure 1A). Pahang River is the largest and longest river in Peninsular Malaysia with an annual average discharge of 718.7 m^3/s for periods between 1973-2003. The basin has an annual rainfall of about 2170 mm and large proportion occurs during the Northeast monsoon. Along the parts of the coast, aquaculture activities occupies an area about 283 hectares. The treated water from these aquaculture ponds are discharged to the nearest man-made stream/monsoon drain that finally flows to the ocean. Apart from that voluminous runoff from the Pahang River and the Kuantan River gives a high concentration of suspended matter as well as nutrients to this area. Under the influence of meteorological factors, the river discharge will affect the coastal area due to mixture of fine silts, clays and dissolved organic matter [6].

The variability of Chl-a along the coastis also significantly affected by the annual reversal of the winds associated with rainy summer and dry winter of South China Sea region [7]. The presence of these occurrences may vary due to monsoon period which is associated with the Southern Oscillation Index [8]. The transition and

Corresponding Author: A.M. Mustapha, School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia. Tel: +603-89213472, Fax: +603-89253357.

onset of these systems happens due to atmospheric internal dynamics, intra-seasonal oscillation and sea/land surface conditions [9]. The Pahang Malaysia coastal water is also directly related with the East Asian monsoon, the Australian winter monsoon and other inter-annual and decadal variations in the Pacific and Indian Ocean [10].

Understanding the variations of physical and biological environments in this area is important because the presence of nutrients and other particulate substances will affect the distribution of Chl-a which are prominently substantial to the coastal fisheries and productivity in this region. The objectives of this study were to identify Pahang coastal water Chl-a variability and determine factors that influences its spatial distribution and temporal variations.

MATERIALS AND METHODS

Satellite Data: In this study, we used Aqua MODIS satellite images of Chl-a and SST that were downloaded from the NASAs GSFCs Distributed Active Archive Center (DAAC). Level 1 products intersecting the region between 0.0°N-10.0°N and 100.0°E-120.0°E were downloaded from January 2006 to December 2010. Data were then processed using the SeaWiFS Data Analysis System (SeaDAS) software [11, 12]. Generated Level 3 products with 1 km^2 spatial resolution were subset from the images to geographic extents of 2.5°N-4.5°N and 103.0°E-104.45°E. Monthly composites and climatology data were produced using ERDAS Imagine (Version 9.1) software.Wind data used in this study were downloaded from the Environmental Research Division (ERD) Live Access Server.

Empirical Orthogonal Function (EOF): The method of Empirical orthogonal function (EOF) analysis was applied to the monthly averaged Chl-a images. The datasets were extracted datasets into a series of orthogonal functions that describes the spatial and temporal variability of the region [13, 14]. The dataset is presented by spatial modes with a variance which explains the variability in a series of time. The data ware interpolated using the Distance Weighting function, which uses a set of reference data points that are weighted by a value corresponding with the distance between each point to derive a prediction for an unmeasured location. Monthly composite images were standardized with the time-series and decomposed using:

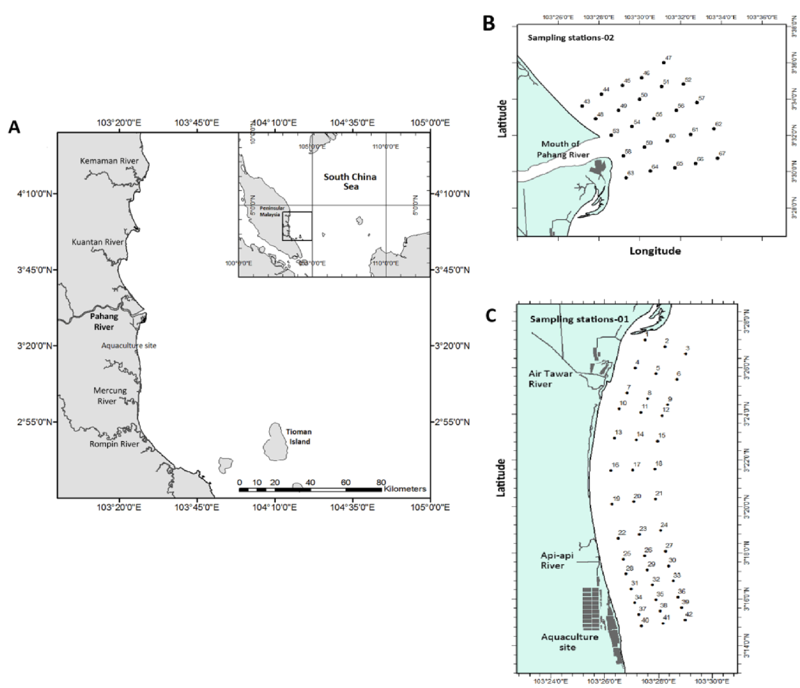

Fig. 1. A: The study area of Pahang Malaysia coastal water in the South China Sea region; B) the location of sampling station at the mouth of Pahang River (main river); and C) showing other smaller river systems and the location of the aquaculture sites.

$$F(x,t) = \sum_{i=1}^{N} a_i(t) c_i(x)$$

Where $a_i(t)$ are the principal component time-series or the expansion coefficients of the spatial components $c_i(x)$. The temporal and spatial components are calculated from the eigen vectors and eigen functions of the covariance matrix R, where R=F'•F. This analysis results in N statistical modes, each with a vector of expansion coefficients related to the original data time-series by $a_i=Fc_i$ and a corresponding spatial component map c_i [15].

Field Data: Sea water samples were collected from 67 stations including the area of the Pahang river mouth and to the south of east Pahang coastal region. 25 stations were located at the area immediately of the Pahang river mouth and 9 km offshore to examine the effect of large river to this area (Figure 1B). The other 42 stations were situated at the east coast of Pahang to the extent of 4.5 km offshore to represent the condition of coastal water in response of smaller rivers and aquaculture site within this area (Figure 1C).

Analytical technique for measuring nutrients concentration was applied using USEPA approved methods for the Hach DR2800 Spectrophotometer. Absorbance was measured at 890 nm, 425 nm and 500 nm for PO_4^{3-}, NH_3-N and NO_3^--N respectively [16]. Dilutions were made for nitrogen-ammonia as necessary and two replicates were used for each test. A quality control was taken out using an appropriate reagent standards and blanks along with the samples. Meanwhile, total suspended solid (TSS) was determined using the gravimetric method of non-filterable residue. 500 mL samples was filtered through 0.45 µm Whatman Glass fiber filter and dried for at least one hour at temperature of 103-105°C [17]. Kriging technique was applied to estimate and predict these parameters concentration at unmeasured locations [18] and mapped using ArcGIS (Version 2011). Kriging is a geostatistical method that applies a semivariogram approach which is widely used in spatially distributed data [19-21].

RESULTS

The spatial distribution of the climatological (5 year mean) monthly time series gives the evident of Chl-a variabilityat the surface of the water column. The seasonal progressions ofChl-a distribution during the monsoon period (Figure 2) was inresponse to the South China Sea physical processes and the characteristics of the region. Chl-a average concentration were computed from the area immediately off the mouth of the Pahang River shows that high values were detected during the Northeast monsoon in November, December and January with values at 4.21, 4.36 and 3.84 mg/m^3 respectively. The spatial pattern is spread over a wide region extending over 100 km offshore. The value decreases in February to April and remain constant until September with the lowest in August (1.94 mg/m^3) during the Southwest monsoon. From April to October, offshore values were at the lowest and spatial pattern of high Chl-a concentration extended along the coastline.

The evidence of Chl-a variabilitywas explained by the decomposition of EOF analysis during 5 year period indicated by a total variance of 83.63 % in the first four modes. The first EOF mode explains 76 % of the total variance distribution of Chl-a (Figure 3A). The spatial pattern indicated the seasonal cycle with high variability in the coastal region and from the river mouth to the Southward direction. High Chl-a concentration was distributed along the coastline towards offshore region. The time series associated with mode 1 showed positive signals which explained the variability during the Southwest monsoon (low positive signals in June 2006, August 2007, early October in 2008, August 2009 and July 2010) and Northeast monsoon (strong positive signals in December 2006, November 2007, January 2008, November 2009 and December 2010).

The second EOF mode explains variability ofthe Southwest and the Northeast monsoon with 4.18 % of variance (Figure 3B). The temporal amplitude showed strong negative signals in April 2006, June 2007, July 2008, September 2009 and June 2010. This signal was detected slightly off Pahang River mouth during the Southwest monsoon. However, the spatial pattern of the Northeast monsoon showed a strong positive signal that occurred along the coast especially in January 2006, January and December 2007, January 2008, January 2009 and January 2010.

The third EOF mode indicates about 2.08 % of total Chl-a variance (Figure 3C). Strong positive signals occurred in March 2006, February 2007, February 2008 and January 2010 explaining more on the Northeast monsoon. The spatial pattern of Chl-a was distributed along-shelf direction. Meanwhile, mode 4 of Chl-a EOF explained the inter-monsoon period with 1.37 % of total variance (Figure 3D). Variability was observed at the river mouth (positive signal) and along coast (negative signal). High positive peak was detected in April 2006, April 2007, March 2008, March 2009 and April 2010. Strong negative

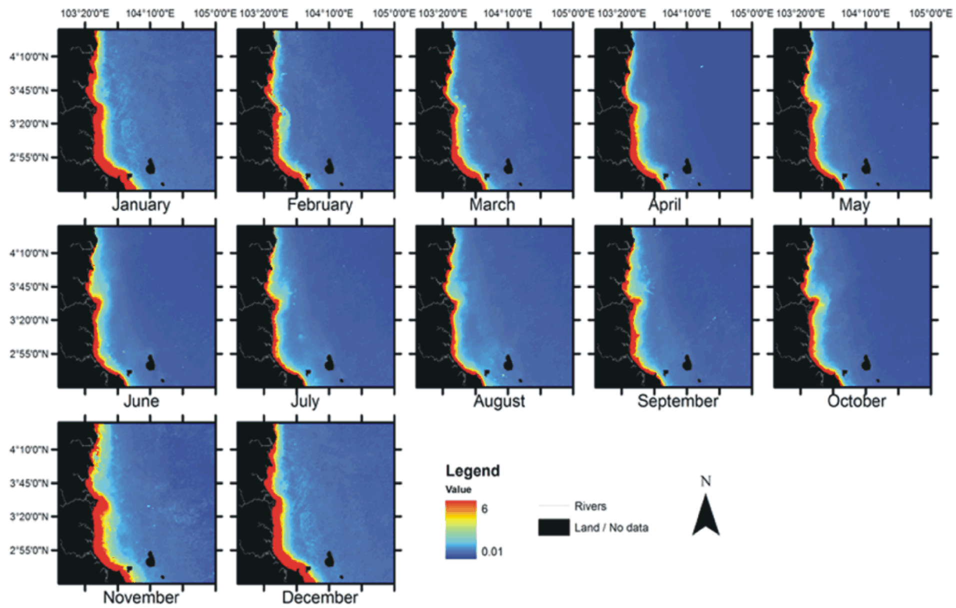

Fig. 2: The climatological (5 years) inter-annual cycle of Chl-a distribution of MODIS composite images. The time series show the progression ofChl-a concentration. Seasonal progression can be seen over the timescale showed by high concentration of Chl-a distribution near the coast during the wet season (November-January). The decreased value showed in February to April and remains constant until September indicate a dry season.

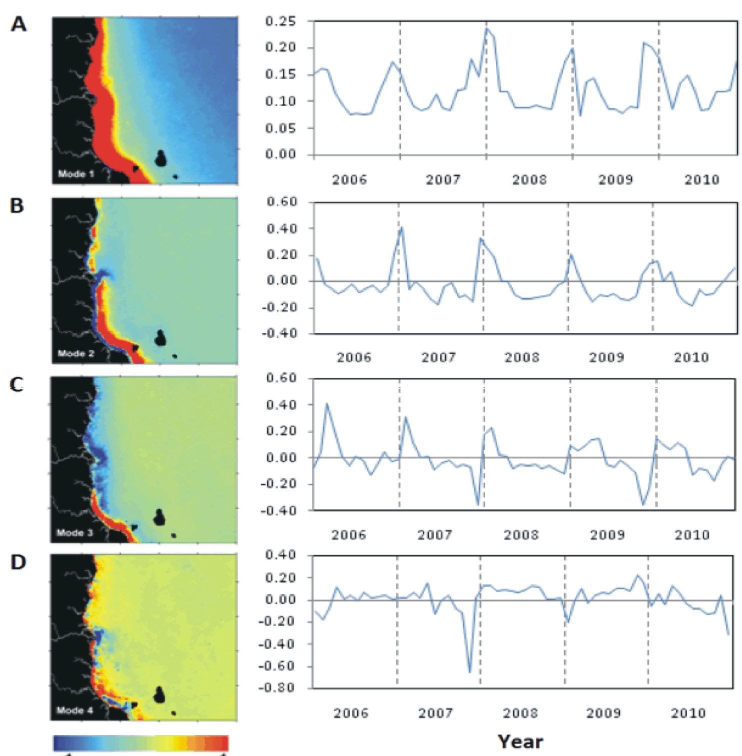

Fig. 3: EOF analysis showing inter-annual variability of Chl-a off Pahang coastal water: Each mode consist of spatial pattern (left) and the time-series (right). (A): First mode represents 76 % of variance indicating seasonal cycle, (B): second mode 4.18 % of variance explaining the Southwest and Northeast monsoon, (C): third mode 2.08 % explaining the Northeast monsoon and (D): fourth mode 1.37 % of variance indicating the inter-monsoon period.

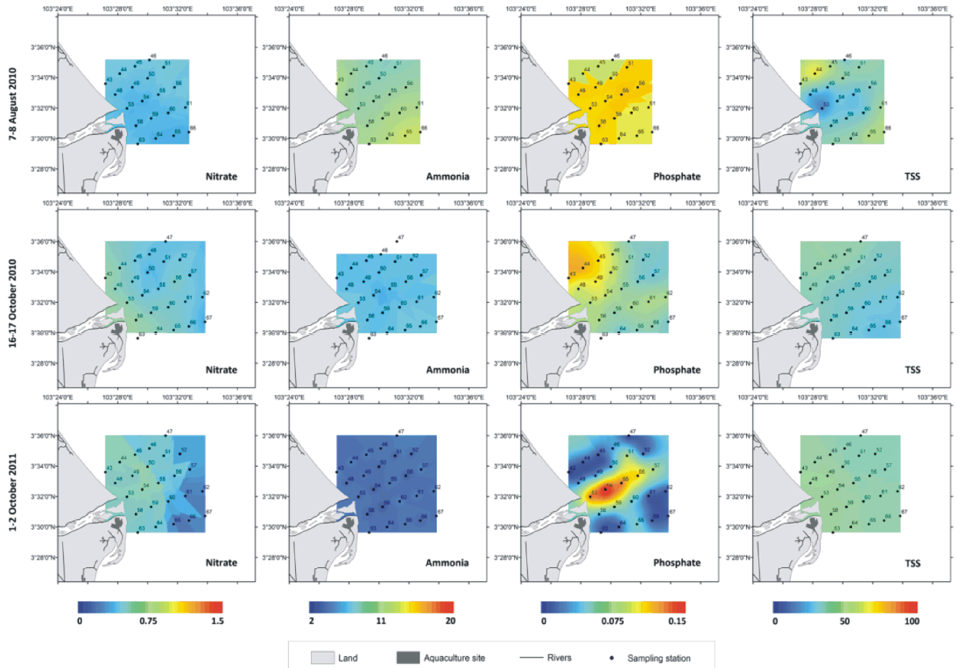

Fig. 4: Surface distribution of nitrate, ammonia, phosphate and TSS at the mouth of Pahang River during dry (August) and wet (October) seasons.

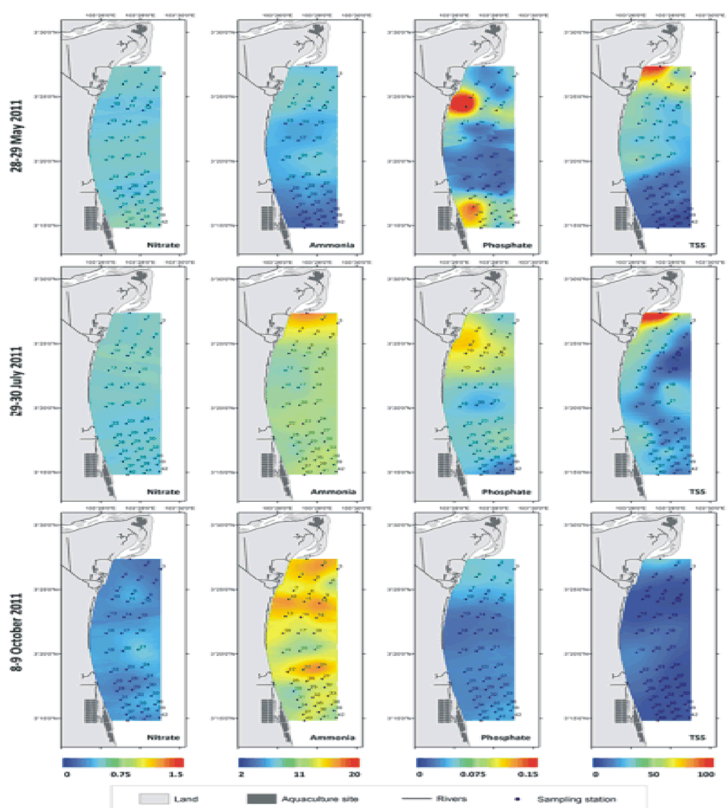

Fig. 5: Surface distribution of nitrate, ammonia, phosphate and TSS along the coast of Pahang for dry (May and July) and wet (October) seasons.

signal occurred in November 2007, September 2010 and low positive signal in October 2008 indicating the transitional period from the Southwest to the Northeast monsoon.

Figure 4 and Figure 5 shows the surface distributions of nitrate, ammonium, phosphate and TSS (total suspended solid) for a total of six field sampling at the mouth of Pahang River and along the coast of Pahang respectively. The surface nutrient concentrations measured at the mouth of Pahang River shows lower nitrate concentrations during the first sampling (0.1-0.7 mg/L). The surface distribution of TSS forms a clear connection with river discharge slightly peripheral off Pahang River mouth. High concentrations of ammonia and phosphate were also observed during this first sampling. The increases in river outflow and associated runoff in October caused higher concentration of TSS during the second and third sampling. Nitrate concentrations were high (0.4-0.9 mg/L) and change considerably with TSS concentration. We also recorded a general depletion of ammonia concentrations during the second and third sampling with concentration less than 4.5 mg/L. However, phosphate concentrations were high particularly off the Pahang River mouth in all three samplings.

Meanwhile, the nutrient distribution recorded at the coastal areaoff Pahang indicated much higher concentration in several areas. For nitrate, lower concentrations were detected in all three samplings but showed high concentration at the area close to the Pahang River and within the part of large aquaculture site in May 2011. Clear occurrences of high phosphate concentration (over than 0.19 mg/L) were recorded at the northern part influenced by small aquaculture site and river within the area, as well for the area in the southern part (larger aquaculture site) with value over than 0.12 mg/L. In July 2011, higher nutrient concentrations were detected concentrated at the northern part. TSS was relatively low for this area but high at the area close to Pahang River due to the accumulation of sediments. Small traces were also detected influenced by smaller river along the coast. Nutrient concentration was detected lower in October 2011, but showed an increase in value for ammonia compared with the previous sampling with value of 6.2-19.4 mg/L.

DISCUSSION

Spatial mapping of coastal water Chl-a can be described using satellite images of ocean color properties. The optical properties of the near-surface water depend on the dissolved and particulate matters that are transported to the ocean from various sources. Analysis of the spatial distribution of Chl-a resulting from the climatological time series gives differences in optical pattern of visible reflectance in a given area.

In this study, inter-annual and seasonal differences of Chl-a was documented effectively in the climatology series and the EOF analysis. High reflectance value observed at near shore area was due to the dissolved and suspended particles derived from terrestrial environments. High Chl-a concentration that has been observed from November to April is much influenced by river discharge and spreads further during its peak. Early study showed that phytoplankton abundance in South China Sea was highly affected by monsoonal pattern [22]. High Chl-a concentration detected at the mouth of Pahang River shows the evident of the influence of high river outflow on the Chl-a concentration during the Northeast monsoon. However, lowest Chl-a concentration was detected in May until September indicated the occurrence of the Southwest monsoon. During this period, river outflow were decreased with the weaker wind condition. Large sea surface heating occurs and results to the developing of the water stratification which is limit the upwelling of nutrients and phytoplankton growth [23].

The evidence of Chl-a seasonal cycle was shown by EOF analysis mode 1. The high and low positive signals showing Chl-a concentration was clearly influenced by the wet and dry seasons. Variability results from the occurrence of episodic wind condition that brings the circulation of low and high SST to this region (Figure 6) [24]. EOF signals were clearly divided showing a comprehensive concurrent Chl-a concentration. Further analysis was explained by EOF mode 2 showing coastal water pattern during this period. Previous work has shown that seasonal differences in Chl-a concentration and productivity in the South China Sea region were higher during the Northeast monsoon (winter) than the Southwest monsoon (summer) [23, 25]. Low signals occupied near shore region and oriented northeastward evident of summer pattern. The transition between major circulation systems over the Indian Ocean and the western Pacific causes theonset of South China Sea summer monsoon and results in high SST to this region [9, 10].

Chl-a distribution pattern was higher near the coast and are clearly seen resulting from the river discharge and terrestrial environments. This is shown by the spatial pattern of EOF mode 3 (Figure 3C). High Chl-a concentration occurred off the river mouth of the Pahang

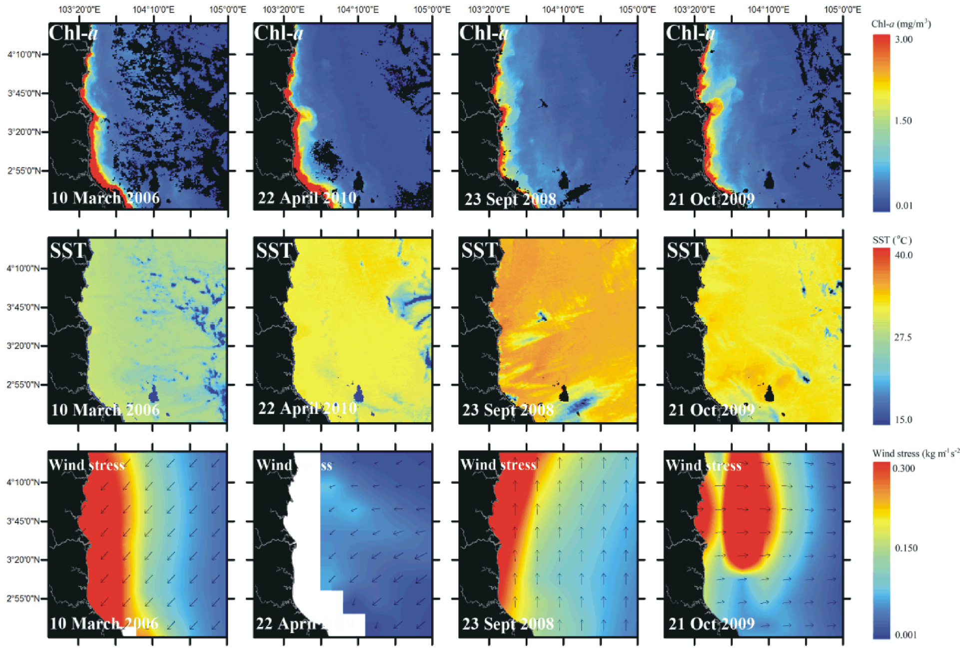

Fig. 6: Influence of wind stress and its direction to the Chl-a distribution and SST. Daily time series explained the occurrences during the Northeast monsoon (10 March 2006), Inter-monsoon periods (22 April 2010 and 21 October 2009) and the Southwest monsoon (23 September 2008).

River and along the coast. During November and December, precipitation was maximal in this region [24]. The occurrences were strongly correlated with discharge water that is well known as the major source of TSS and nutrients in coastal areas [26].

The transition period of monsoons (basically during April and October) were marked as the preliminary of higher and lower Chl-a concentration. Sea surface circulation was highly affected by wind forcing conditionas well as SST in South China Sea region (Figure 6). The transition period of the Northeast to the Southwest (April) shows high Chl-a concentration along the coast. The Intertropical Convergence Zone (ITCZ) becomes its weakest and the South China Sea is its driest during the pre-monsoon period from March to mid-May [24]. Onset of rainy season during inter-monsoon period is a transition from the Southwest to the Northeast monsoon in October. Wind forcing conditions were reverse from the Southwesterly to the Northeasterly directions. These occurrences resulted in the variability of Chl-a distribution (Figure 3D) and its concentration levels are in between summer and winter [23].

During the period of 2006-2010, Chl-a in particular behaved conservatively along the coastline with the impact of voluminous discharge upon the coastal water [26]. Under the influence of summer and winter monsoons, an average concentrations of Chl-a corresponds to the increase of nutrients along the coast. The water quality of the Pahang coastal region changes due to the effect of nutrient and TSS concentrations that occurred under the condition of terrestrial outflows and river discharge. Within 1-30 km offshore, the surface nutrient concentration is usually found higher where the waters are usually turbid (higher TSS concentration). The area of the Pahang river mouth was found greatly associated with plume loaded with high composition of TSS and suspended particulate matter [27]. The relative changes in nutrients concentration was a result of intra-seasonal differences. High values of nitrate, phosphate and TSS at the mouth of Pahang River in October 2010 and 2011 indicated influence of terrestrial discharge.

The impact of small rivers and aquaculture on the coastal area showed a large variability that is mostly determined by the high compositions of nutrient outflows [28]. This may lead to the high concentrations of Chl-a especially for a region with nitrate and ammonia-enriched waters [29]. Previous study in the northern East China Sea proved these occurrences [30]. However, vertical mixing highly influences the water column and may result to a significant decrease in the nutrients-TSS ratios. This suggest that the surface distribution of Chl-a highly determined by the nutrient availability especially during strong monsoonal periods. During summer, the changes in nutrient concentrations and TSS ratios will affect the water quality due to decrease of river discharge. The extent to which accumulation of TSS and water stratification may have been responsible for limiting Chl-a concentrations and productivity within the coastal water requires further study.

CONCLUSION

The spatial and temporal signature of Chl-a distribution off Pahang coastal water was summarized and gave an initial view ofthe seasonal and inter-annual variability of the coastal water area. EOF analysis explained the variability of Chl-a during the Northeast and the Southwest monsoon and the two transitional periods. Measurements of surface water Chl-a data indicated that concentration was highly affected by wind forcing condition and terrestrial outflow of river and aquaculture site within this area. Meanwhile, nutrients concentration at the mouth of Pahang River was influenced by discharge water that is always high within the plume area. Nutrient distribution was also recorded along the coast influenced by the small rivers and aquaculture sites especially during strong monsoons period.

ACKNOWLEDGEMENT

The authors would like to thank the NASA Goddard Space Flight Center for the MODIS-Aqua Level 1A data and the Environmental Research Division (ERD) Live Access Server for the wind data used in this study. This work has been supported by the UKM University-Industry Grant (Industri-2011-012) and the Ministry of Science, Technology and Innovation (04-01-02-SF0589).

REFERENCES

1. Burke, L., Y. Kura, K. Kassem, C. Revenga, M. Spalding and D. McAllister, 2001. Pilot Analysis of Global Ecosystems: Coastal Ecosystems. World Resources Institute, Washington D.C. April 2001 / paperback / ISBN 1-56973-458-5.
2. Yoder, J.A., J.E. O'Reilly, A.H. Barnard, T.S. Moore and C.M. Ruhsam, 2001. Variability in coastal zone color scanner (CZCS) chlorophyll imagery of ocean margin waters off the US East Coast. Continental Shelf Research, 21: 1191-1218.
3. Chauhan, P., M. Mohan, S.R. Nayak and R.R. Navalgund, 2002. Comparison of ocean color chlorophyll algorithms for IRS-P40CM sensor using in-situ data. Marine and Water Resources Group, Space Applications Centre (ISRO), National Remote Sensing Agency, Balanagar, Hyderabad. Journal of the Indian Society of Remote Sensing, 30(l and 2): 87-94.
4. Radiarta, I.N. and S.I. Saitoh, 2008. Satellite-derived measurements of spatial and temporal chlorophyll-a variability in Funka Bay, southwestern Hokkaido, Japan. Estuarine, Coastal and Shelf Science, 79: 400-408.
5. Wahbah, M.I. and M.B. Zughul, 2001. Temporal distribution of chlorophyll a, suspended matter and the vertical flux of particles in Aqaba (Jordan). Hydrobiologia, 459: 1470-1560.
6. Thomas, A.C. and R.A. Weatherbee, 2006. Satellite-measured Temporal Variability of the Columbia River Plume. Remote Sensing of Environment, 100: 167-178.
7. Wang, B., L. Ho, Y. Zhang and M.M. Lu, 2004. Definition of South China Sea Monsoon onset and commencement of the East Asia Summer Monsoon. Journal of Climate, 17: 699-710.
8. Liu, K.K., S.Y. Chao, P.T. Shaw, G.C. Gong, C.C. Chen and T.Y. Tang, 2002. Monsoon-forced chlorophyll distribution and primary production in the South China Sea: observations and a numerical study. Deep-Sea Research I., 49: 1387-1412.
9. Kueh, M.T. and S.C. Lin, 2010. A climatological study on the role of the South China Sea monsoon onset in the development of the East Asian summer monsoon. Theoretical and Applied Climatology, 99: 163-186.
10. Chang, C.P., Z. Wang and H. Hendon, 2006. The Asian Winter Monsoon. B. Wang (ed.), Praxis. Springer Berlin Heidelberg, pp: 89-127.
11. O'Reilly, J.E., S. Maritorena, B.G. Mitchell, D.A. Siegel, K.L. Carder, S.A. Garver, M. Kahru and C. McClain, 1998. Ocean color chlorophyll algorithms for SeaWiFS. Journal of Geophysical Research C: Oceans, 103(C11): 24937-24953.
12. Chavula, G., B. Patrick, T. Prasad, J. Thomas and B. Marvin, 2009. Estimating chlorophyll concentration in Lake Malawi from MODIS satellite imagery. Physics and Chemistry of the Earth, 34: 755-760.

13. Baldacci, A., G. Corsini, R. Grasso, G. Manzella, J.T. Allen, P. Cipollini, T.H. Guymer and H.M. Snaith, 2001. A study of the Alboran sea mesoscale system by means of empirical orthogonal function decomposition of satellite data. Journal of Marine Systems, 29: 293-311.
14. Mustapha, A.M., T. Lihan and S. Saitoh, 2011. Determination of physical processes influencing Chl a distribution using remotely sensed images. Pakistan Journal of Biological Sciences, 14(2): 82-90.
15. Polovina, J.J. and E.A. Howell, 2005. Ecosystem indicators derived from satellite remotely sensed oceanographic data for the North Pacific. ICES Journal of Marine Science, 62: 319-327.
16. Hach, 2007. DR 2800 Spectrophotometer Procedures manual. Edition 2, Hach Company, Loveland, Colorado, USA. Catalog Number DOC022.53.00725.
17. Environmental Protection Agency, 1983. Residue, non filterable method 160.2 (gravimetric, dried at 103-105°C). In US Environmental Protection Agency (Ed.), Methods for chemical analysis of water and waste. (pp: 160 2.1-160 2.3). Cincinnati, Ohio: Environmental Monitoring and Support Laboratory Office of Research and Development.
18. Johnston, K., J.M. VerHoef, K. Krivoruchko and N. Lucas, 2001. Using Arc Gis Geostatistical Analyst. ESRI, New York, pp: 300.
19. Shad, R., M.S. Mesgari, A. abkar and A. Shad, 2009. Predicting air pollution using fuzzy genetic linear membership kriging in GIS. Computers, Environment and Urban Systems, 33: 472-481.
20. del Río, S., L. Herrero, C. Pinto-Gomes and A. Penas, 2011. Spatial analysis of mean temperature trends in Spain over the period 1961-2006. Global and Planetary Change, 78: 65-75.
21. Arslan, H., 2012. Spatial and temporal mapping of groundwater salinity using ordinary kriging and indicator kriging: The case of Bafra Plain, Turkey. Agricultural Water Management, 113: 57-63.
22. Peñaflor, E.L., C.L. Villanoy, C.T. Liu and L.T. David, 2007. Detection of monsoonal phytoplankton blooms in Luzon Strait with MODIS data. Remote Sensing of Environment, 109: 443-450.
23. Tang, D.L., H. Kawamura, M.A. Lee and T.V. Dien, 2003. Seasonal and spatial distribution of chlorophyll-a concentrations and water conditions in the Gulf of Tonkin, South China Sea. Remote Sensing of Environment, 85: 475-483.
24. Wang, B., F. Huang, Z. Wu, J. Yang, X. Fu and K. Kikuchi, 2009. Multi-scale Climate Variability of the South China Sea Monsoon: A Review. Dynamics of Atmospheres and Oceans, 47: 15-37.
25. Lee Chen, Y.L. and H.Y. Chen, 2006. Seasonal dynamics of primary and new production in the northern South China Sea: The significance of river discharge and nutrient advection. Deep-Sea Research I., 53: 971-986.
26. Cravo, A., M. Madureira, H. Felícia, F. Rita and M.J. Bebiano, 2006. Impact of outflow from the Guadiana River on the distribution of suspended particulate matter and nutrients in the adjacent coastal zone. Estuarine, Coastal and Shelf Science, 70: 63-75.
27. Sierra, J.P., A. Sánchez-Arcillaa, J. Del Río, J. González Flos, E. Movellán, C. Mösso, R. Martínez, M. Rodilla, S. Falco and I. Romero, 2002. Spatial distribution of nutrients in the Ebro estuary and plume. Continental Shelf Research, 22: 361-378.
28. Davies, P.L. and B.D. Eyre, 2005. Estuarine modification of nutrient and sediment exports to the Great Barrier Reef Marine Park from the Daintree and Annan River catchments. Marine Pollution Bulletin, 51: 174-185.
29. Wang, Z., Y. Qi, J. Chen, N. Xu and Y. Yang, 2006. Phytoplankton abundance, community structure and nutrients in cultural areas of Daya Bay, South China Sea. Journal of Marine Systems, 62: 85-94.
30. Kim, D., S.H. Choi, K.H. Kim, J.H. Shim, S. Yoo and C.H. Kim, 2009. Spatial and temporal variations in nutrient and chlorophyll-a concentrations in the northern East China Sea surrounding Cheju Island. Continental Shelf Research, 29: 1426-1436.