Defence Science Journal, Vol. 69, No. 2, March 2019, pp. 131-135, DOI : 10.14429/dsj.69.14219

Formulation of an Empirical Relation between Chlorophyll and Sea Surface Temperature in the Southeastern Arabian Sea

Eldhose Cheriyan*, P.A. Maheswaran, A. Raghunadha Rao, and K.V. Sanilkumar

DRDO-Naval Physical and Oceanographic Laboratory, Kochi - 682 021, India
**E-mail: eldhosecheriyanm@gmail.com*

ABSTRACT

Present study formulates an empirical relation between sea surface temperature (SST) and chlorophyll (Chl) in the Southeastern Arabian Sea using data collected during 2017. SST was found to decrease due to upwelling of cold nutrient rich waters, thus causing enhancement of Chl in the coastal and nearshore waters. Based on this, an empirical relationship exists which is inversely correlated during peak upwelling and intense biological production. The linear regression generated a significant correlation coefficient ($0.52 \leq R^2 \geq 0.64$) in the month of July, August and October. Although other factors influence Chl, SST can be considered as a significant indicator of biological production with respect to seasonal upwelling. Among the empirical relations, a definite single equation requires the assessment of subsurface Chl to reveal the underlying relationship.

Keywords: Upwelling; Sea surface temperature; Chlorophyll; Arabian Sea

1. INTRODUCTION

Arabian Sea experiences strong seasonality in biological production in which the summer monsoon induces intense upwelling, vertical mixing and phytoplankton blooms along the southwest coast of India[1,2,3]. On the other hand, pre-monsoon causes stratification in the water column thereby limiting the availability of subsurface nutrients for phytoplankton proliferation. Moreover, the surface layer of the Arabian Sea waters seems to be warmer (> 30 °C)[4] during the pre-monsoon season (April-May). The anthropogenic pressures along the coast is high, due to agriculture, industrial growth, excessive fishing, mariculture, terrestrial runoff and fresh water influx thus, increasing the nutrient budget of the coastal waters[5,6]. All these factors significantly alter the physical oceanography of the region which might influence positively or negatively the biogeochemical processes occurring in the ocean. As phytoplankton constitutes the primary trophic level, it has been directly affected by environmental changes due to different climatic scenarios. Understanding these biophysical relationships in ocean environment is a milestone in explaining marine ecosystem response to different environmental forcings[7,8]. Phytoplankton plays a major role in oceanic carbon cycle since it accounts for 50 per cent of global biological production[9]. Primary productivity fluctuates seasonally as well as regionally in the marine environment affected by the variation in numerous physical and chemical factors. Specifically, the physical drivers such as temperature, wind speed, sea surface height, light availability, etc. profoundly alter the biological production intensity in coastal and marine systems[10]. In this regard, several studies have been carried out in the Atlantic and Pacific region to reveal the relationship between biophysical variables particularly, sea surface temperature and Chlorophyll[11-14]. Interestingly, these studies suggest that a significant linear relation exists between the physical variables and phytoplankton abundance. In this context, the present study aims to verify the relation between seasonal physical forcing namely, SST and seasonal Chl in the Southeastern Arabian Sea using linear regression analysis. Furthermore, the objective includes the formulation of an empirical relation between the variables studied.

Received : 08 January 2019, Revised : 12 February 2019
Accepted : 17 February 2019, Online published : 06 March 2019

2. MATERIALS AND METHODS

Surface water sampling were carried out onboard five cruises of *INS Sagardhwani* (Cruise No. 194, 202, 203, 204 and 207) in 12 transects running perpendicular to the coast of Southwest India in the Arabian Sea. The study area lies between 7 °N to 15 °N latitude and 72 °E to 79 °E longitude, and sampled during February to October 2017. The map showing sampling locations is as given in Fig. 1.

Chl in the water samples were analysed fluorimetrically using turner designed 10AU Fluorometer. Water samples were filtered through 25 mm 0.45 µm GF/F filter and followed by extraction with 90 per cent acetone. Then, the samples were vortexed and kept in darkness at −4 °C for 24 h. After centrifugation, fluorescence was measured in the extracted samples and Chl is calculated. The SST was obtained from conductivity-temperature-depth (CTD) profiler deployed at respective stations.

3. RESULTS AND DISCUSSION

The monthly variation of SST in the Southeastern Arabian Sea is as given in Fig. 2. SST ranged between 24.4 °C and 30.9 °C

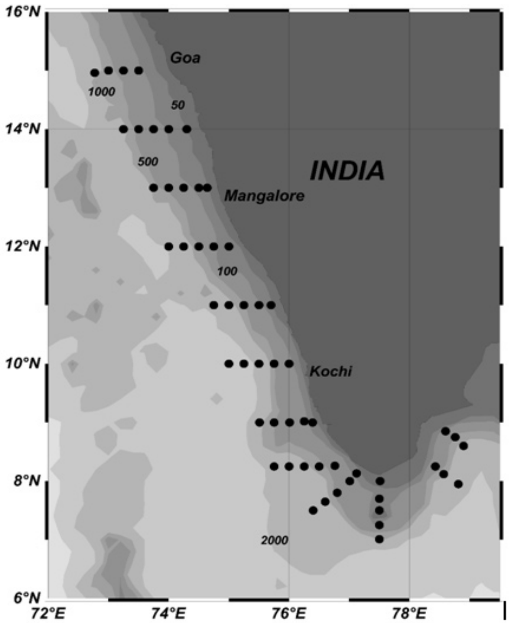

Figure 1. Map showing study area, bathymetry and sampling locations.

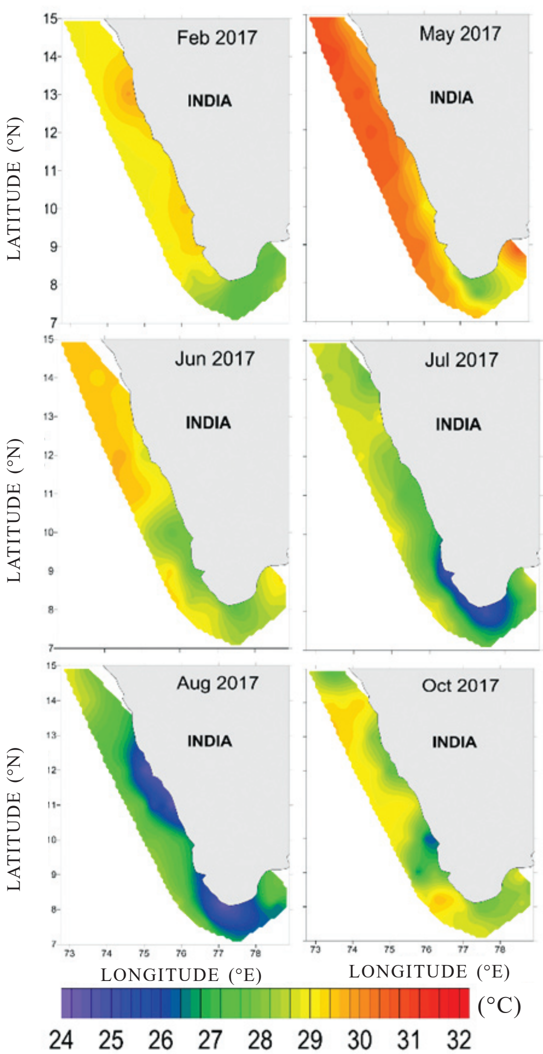

Figure 2. Monthly SST in the Southeastern Arabian Sea during Feb-Oct 2017.

in the entire study region. It shows a maximum in May and a gradual decrease from June to August followed by an increase in October 2017. High SST during April-May is driven by the net heat gain during pre-monsoon and minimum wind mixing. During southwest monsoon, upwelling along the western boundary drove low SST from June-August. As the monsoon withdraws consequently, decay of upwelling process causes SST rise in the succeeding months. This change in physical oceanography obviously have an influence in the biological production in terms of Chl which can be observed in its distribution pattern as given in Fig. 3. The concentration of Chl varied from 0.05 mg m^{-3} to 5.95 mg m^{-3} during Feb-Oct 2017. The minimum Chl in the pre-monsoon results from nutrient limitation in the surface layers. This is because the warming stratifies the ocean and suppress the mixing of nutrients from the subsurface reducing Chl[15]. To assess the biophysical relationship between SST and Chl, linear regression was

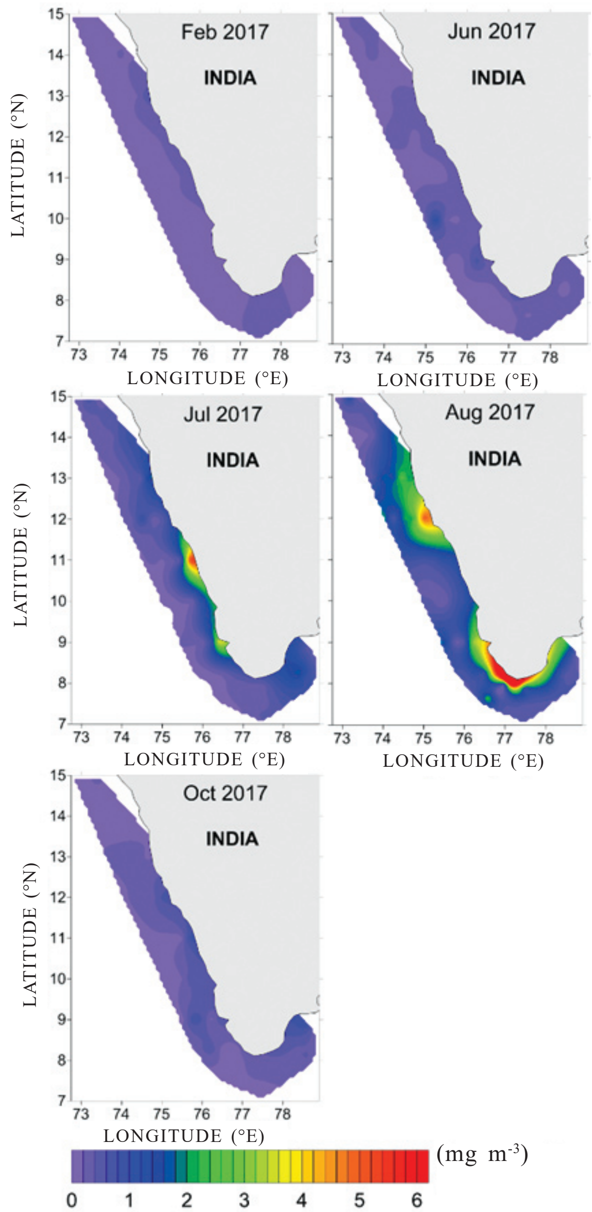

Figure 3. Monthly Chl during the study period.

adopted and the scatter plot generated significant results as shown in Fig. 4. Here, the pre-monsoon plot (Feb) shows moderate correlation indicating that stratification is partially correlated to reduction in Chl. Chl averages 0.16 mg m^{-3} (Feb) to 1.43 mg m^{-3} (Aug) which implies a gradual increase from pre-monsoon to monsoon season. The maximum Chl concentration was observed during the monsoon due to intense upwelling which brings cold nutrient rich subsurface water to upper layer thus, promoting biological production.

The upward movement of cold waters to the surface concurrently with increase in Chl level substantiates an inverse relation between these variables. As can be seen from the correlation plot, there exists a significant correlation between SST and Chl even though, numerous factors influence primary productivity. The correlation coefficient (R^2) amounts to 0.62, 0.64 and 0.52 in the month of July, August and October, respectively. This indicates that the progression of upwelling generates favourable conditions for phytoplankton growth as well as a significant decrease in SST. In addition, phytoplankton blooms can be observed along the coast suggesting the interaction of coastal waters with rocky shorelines inducing horizontal and vertical gyres as a source of nutrient inputs to surface layers. Chl was found to be enhanced between 7 °N – 9 °N latitude and 75.5 °E – 79 °E longitude due to high nutrient inputs preferably through upwelling as previously reported by Thomas[16], *et al.*.

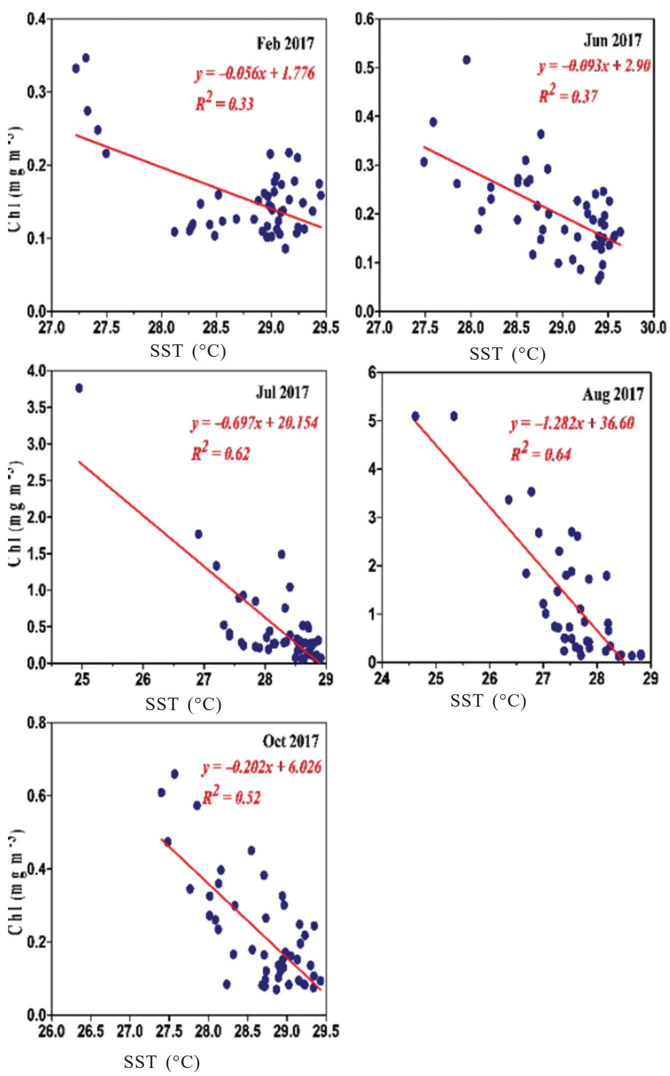

Figure 4. Scatter plot of SST *vs* Chl.

In contrast to this, a similar peak of Chl was observed between 10 °N – 13 °N latitude and 73.75 °E – 76 °E longitude which can be attributed to nutrient loaded fresh water influx through riverine/estuarine discharges. Although high levels of Chl persists in the month of August, it decreased to 0.07 mg m^{-3} – 0.91 mg m^{-3} averaging 0.26 mg m^{-3} in October due to the decay of upwelling and the Chl concentration may be associated with nutrient regeneration from biodetritus. In general, Chl recorded high concentration along the near shore and coastal waters compared to offshore regions.

The linear regression suggests numerous empirical relations of significant correlation coefficient (Table 1) above 0.5 between surface Chl and SST. The R^2 values for respective months indicate that the inverse correlation becomes more significant when the system changes from high SST/low Chl to low SST/high Chl domain. This baseline study supports the hypothesis that a variation in SST with respect to upwelling would affect the distribution of Chl in the Southeastern Arabian Sea and an inverse relationship exists. For a comprehensive evaluation of Chl and SST relationship in the study region, future work should include the assessment of subsurface Chl concentration.

Table 1. Result of linear regression analysis

Region	Month	Linear Regression	R^2
All region	Feb	Chl = −0.056*SST + 1.776	0.33
	Jun	Chl = −0.123*SST + 3.77	0.38
	Jul	Chl = −0.697*SST + 20.154	0.62
	Aug	Chl = −1.282*SST + 36.60	0.64
	Oct	Chl = −0.202*SST + 6.026	0.52
7–9 °N	Feb	Chl = −0.064*SST + 1.960	0.53
75.5–79 °E	Jun	Chl = −0.112*SST + 3.386	0.41
	Jul	Chl = −0.301*SST + 8.785	0.21
	Aug	Chl = −2.256*SST + 62.893	0.44
	Oct	Chl = −0.244*SST + 7.183	0.81
10–13 °N	Feb	Chl = 0.073*SST − 1.992	0.24
73.75–76 °E	Jun	Chl = −0.022*SST + 0.840	0.01
	Jul	Chl = −0.331*SST + 9.757	0.27
	Aug	Chl = −1.474*SST + 41.472	0.79
	Oct	Chl = −0.286*SST + 8.497	0.66

4. CONCLUSIONS

High SST gradient indicates effective upwelling process and prevalence of cold nutrient rich waters in the surface layer. Hence, mixing of nutrients into the surface layer causing enhanced Chl concentrations. The study observed that minimum SST range (24.4 °C − 28.8 °C) was coincident with mean Chl concentrations (1.43 mg m^{-3}) peak. Chl revealed a well-defined coast-offshore gradient showing a decrease in concentration from the coast to offshore waters. Significant inverse relation ($R^2 = 0.52-0.64$) in the months of maximum biological production suggests a rapid transition of the area from high SST/low Chl to low SST/high Chl domain and phytoplankton blooms along the coast, specifically in the coastal waters of Cape Comorin. The empirical inverse relation provides insight to predict the change in SST with Chl in the exclusive economic zone of India where strong upwelling occurs.

REFERENCES

1. Rao, R.R. & Sanilkumar, K.V. Evolution of salinity field in the upper layers of the east central Arabian Sea and northern Bay of Bengal during summer monsoon experiments. *Earth Planet. Sci.*, 1991, **100**(1), 69–78. doi: 10.1007/BF02843485
2. Kumar, S.P.; Madhupratap, M.; Kumar, M.D.; Muraleedharan, P.M.; De Suza, S.N.; Sawant, S.; Gauns, M. & Sarma, V.V.S.S. High biological productivity in the interior Arabian Sea during summer monsoon driven by Ekman pumping and lateral advection. *Current Science*, 2001, **81**, 1633–1638.
3. Wiggert, J.D.; Hood, R.R.; Banse, K. & Kindle, J.C. Monsoon-driven biogeochemical processes in the Arabian Sea. *Prog. Oceanogr*., 2005, **65**(2–4), 176–213. doi:10.1016/j.pocean.2005.03.008
4. Kumar, P.V.H.; Sanilkumar, K.V. & Rao, C.V.K.P. Arabian Sea mini warm pool and its influence on acoustic propagation. *Def. Sci. J.*, 2007, **57**(1), 115–121.
5. Cheriyan, E.; Sreekanth, A.; Mrudulrag, S.K. & Sujatha, C.H. Evaluation of metal enrichment and trophic status on the basis of biogeochemical analysis of shelf sediments of the southeastern Arabian Sea India. *Cont. Shelf Res*., 2015, **108**, 1–11. doi:10.1016/j.csr.2015.08.007
6. Sreekanth, A.; Mrudulrag, S.K.; Cheriyan, E. & Sujatha, C.H. Trace metals enrichment and organic matter sources in the surface sediments of Arabian Sea along southwest India (Kerala coast). *Mar. Pollut. Bull.*, 2015, **101**(2), 938–946. doi: 10.1016/j.marpolbul.2015.10.040
7. Barange, M.; Field, J.G.; Harris, R.P.; Hofmann, E.E.; Perry, R.I.; Werner, F.E. & Ashby, D.M. Marine ecosystems and global change. Oxford University Press, Oxford, U.K, 2010.
8. Feng, J.; Durant, J.M.; Stige, L.C.; Hessen, D.O.; Hjermann, D.Ø.; Zhu, L.; Llope, M. & Stenseth, N.C. Contrasting correlation patterns between environmental factors and chlorophyll levels in the global ocean. *Global Biogeochem. Cy*., 2015, **29**(12), 2095–2107. doi: 10.1002/2015GB005216
9. Ravichandran, M.; Girishkumar, M.S. & Riser, S. Observed variability of chlorophyll-*a* using Argo profiling floats in the southeastern Arabian Sea. *Deep-Sea Res. I*, 2012, **65**, 15–25. doi: 10.1016/j.dsr.2012.03.003
10. Chavez, F.P.; Messie, M. & Pennington, J.T. Marine primary production in relation to climate variability and change. *Ann. Rev. Mar. Sci.*, 2011, **3**, 227–260. doi: 10.1146/annurev.marine.010908.163917
11. Richardson, A.J. & Schoeman, D.S. Climate impact on plankton ecosystems in the Northeast Atlantic. *Science*, 2004, **305**(5690), 1609–1612. doi: 10.1126/science.1100958
12. Gregg, W.W.; Casey, N.W. & McClain, C.R. Recent trends in global ocean chlorophyll. *Geophys. Res. Lett*., 2005, **32**(3), L03606. doi: 10.1029/2004GL021808
13. Raitsos, D.E.; Lavender, S.J.; Pradhan, Y.; Tyrrell, T.; Reid, P.C. & Edwards, M. Coccolithophore bloom size variation in response to the regional environment of the subarctic North Atlantic. *Limnol. Oceanogr.*, 2006, **51**(5), 2122–2130. doi: 10.4319/lo.2006.51.5.2122
14. Irwin, A.J. & Finkel, Z.V. Mining a sea of data: Deducing the environmental controls of ocean chlorophyll. *PLoS One*, 2008, **3**(11), e3836. doi: 10.1371/journal.pone.0003836
15. Bhattathiri, P.M.A.; Pant, A.; Sawant, S.; Gauns, M.; Matondkar, S.G.P. & Mohanraju, R. Phytoplankton production and chlorophyll distribution in the eastern and central Arabian Sea in 1994–1995. *Current Science*, 1996, **71**, 869–877.
16. Thomas, L.C.; Padmakumar, K.B.; Smitha, B.R.; Devi, C.R.A.; Nandan, S.B. & Sanjeevan, V.N. Spatio-temporal variation of microphytoplankton in the upwelling system of the south-eastern Arabian Sea during the summer monsoon of 2009. *Oceanologia*, 2013, **55**(1), 185–204. doi: 10.5697/oc.55-1.185

ACKNOWLEDGEMENTS

We thank the Director, Naval Physical and Oceanographic Laboratory (NPOL), Kochi for the facilities provided. Research Associateship (NPOL/A/EST/1/127/JRF/RA) from Defence Research and Development Organisation (DRDO), Ministry of Defence, Government of India through Naval Physical and Oceanographic Laboratory is sincerely acknowledged. Special thanks to the officers and crew of *INS Sagardhwani* for their help during sampling.

CONTRIBUTORS

Dr Eldhose Cheriyan obtained his MSc (Chemistry) from Mahatma Gandhi University Kottayam and PhD in Marine Chemistry from Cochin University of Science and Technology, Cochin. He is presently engaged as Research Associate at DRDO-Naval Physical and Oceanographic Laboratory, Kochi. His research areas include Optical oceanography, biophysical relationships in the ocean, trace element biogeochemistry and environmental impact assessment.
In the present study, he has carried out the formulation of empirical relations, performed statistical analysis, preparation of figures and writing the manuscript with input from all authors.

Dr P.A. Maheswaran obtained his Master's and PhD from Cochin University of Science and Technology. Presently working as a Scientist 'D' at Naval Physical and Oceanographic Laboratory, Kochi. His field of specialisation includes : Mixed layer processes, upper ocean dynamics, thermohaline structure and sonar oceanography.

In the current study, he undertook the processing of temperature profiles, assembled the data, provided graphical solutions and contributed interpretation and discussion of results.

Dr A. Raghunadha Rao obtained his MSc (Oceanography) and MTech (Atmospheric Sciences) from Andhra University, Visakhapatnam, and PhD (Oceanography) from Cochin University of Science and Technology. Presently he is working as Scientist 'F', Team Head, Physical Oceanography Division, DRDO-Naval Physical and Oceanographic Laboratory, Kochi. His areas of research interests are: Remote sensing, Indian Ocean circulation, thermohaline structure, sonar oceanography. He has published 21 papers in National and International journals.

In this study, he coordinated data compilation, provided expertise on regression plots, guided the preparation of figures, led the editing and revision of the manuscript.

Dr K.V. Sanilkumar obtained his Master's and PhD from Cochin University of Science and Technology. Presently working as Group Director and Scientist-G of Ocean Sciences Group, DRDO-Naval Physical and Oceanographic Laboratory, Kochi. His field of specialisation includes air-sea interaction, upper ocean dynamics, thermohaline structure, ocean modelling and ASW oceanography.

In the current study, he designed the research, conceptualised and formulated the objectives, carried out pilot studies, directed the analysis of data sets, provided statistical advice and approved the final manuscript.