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Spatiotemporal variability of sea surface temperature and its relationship with salinity, chlorophyll-a concentration and bathymetry in Bangladesh

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Abstract

The present research aimed to examine the long-term connections (i.e. from 2010 to 2021) between monthly chlorophyll-a, sea surface temperature, and sea surface salinity. The long-term variability of SST in the Bay of Bengal (BoB) was analyzed using open access data sets of monthly SST, Chlorophyll-a and Sea Surface Salinity to understand trends, relationships, and bathymetric influences on these oceanographic parameters. The SST records for the Bay of Bengal indicates a gradual increasing trend over the period studied. The Sea Surface Salinity (SSS) follows a seasonal trend and plays an essential effect in the distribution of SST in the BoB. The SST for the corresponding time range has been compared, and a strong correlation (R^2=0.81) between SST and SSS has been found. The salinity value for the near-coastal zone is less than the away from the coast. The monsoon season lowers the value of SSS, which might be related to monsoonal rainfall and fresh water influx in the Bay of Bengal. Moreover, the Chlorophyll-a concentration, which is a direct indicator of the phytoplankton productivity, has been analyzed for this study. The chlorophyll-a concentration follows a locational and seasonal trend. The correlation between sea surface temperature (SST) and chlorophyll-a concentration was determined to be quite weak, primarily due to the minimal fluctuations in chlorophyll-a levels. For all of the data (i.e. SST, SSS, chlorophyll-a concentration and bathymetry), seasonal and locational variability have been observed. A strong positive correlation was observed between the variability in sea surface temperature (SST) and sea surface salinity (SSS). The value of SST varies with increasing depth; with increasing depth the mean value for SST value decreases and the dispersion of values increases from the mean. This study would help ocean scientists and policy makers in understanding the interaction between physical parameters with the biological parameters and benefit them in further study as well as in maritime planning.

Keywords: Bay of Bengal, chlorophyll-a, correlation, sea temperature, salinity

Introduction

The Bay of Bengal (BoB), the largest bay in the world situated in the Indian Ocean, is a home to a wide range of marine species. Due to the convergence of multiple ocean currents in the Bay, tropical cyclones are common and require monitoring using sea surface temperature (SST) data. Since the oceans have a great capacity for heat storage, which impacts the atmosphere via energy exchange at the ocean's surface, SST plays a crucial role in controlling the climate and its variability. Slow changes in SST serves as a valuable indicator for forecasting seasonal and longer-term climatic changes (Deser et al., 2010). The Earth's climate and weather are greatly influenced by SST, especially as it relates to the development of tropical cyclones. SST changes continuously but more slowly than air temperature, and scientists are investigating how the ocean and atmosphere interact as well as how climate change may be influencing SST (Kotal et al., 2009; Yu and McPhaden, 2011; Sebastian and Behera, 2015). The SST in the Bay of Bengal's northern zone is crucial for understanding climate change in Bangladesh, forming sea fog and sea breezes. The fluctuation in water quality in the BoB is largely impacted by some factors such as seasonal SW and NE monsoons, pollution discharge from rivers and numerous industries on the coast, and regular tropical cyclone (TC) episodes (Miranda et al., 2021). A rise in SST leads to increased river flow, more rapid channel shifts, and intense cyclones and rainstorms. Temperatures in Bangladesh have risen by 0.5°C in the last century and is expected to rise by 1.5-2.0°C by 2050. This will lead to more intense hydrologic cycles, increased evaporation, and a rise in global precipitation, resulting in an increase in rainfall in Bangladesh.

In continental regions, sea surface temperature (SST) can affect water and climatic conditions. SST is a

crucial parameter that defines some areas because of the interaction between oceans and the atmosphere. Weather, currents, and seasonal fluctuations are some variables that affect SST. Two important climate change factors that significantly influence the hydrological cycle are SSS and SST. Anthropogenic climate change often interacts with hydrological processes (Belward et al., 2016). Hydrodynamic processes have shown a strong link between SSS and SST in the tropical Pacific. Freshwater inflow impacts SSS, density, and marine stratification, which in turn impacts SST. Precipitation and river runoff dilute the oceanic surface layers, causing high stratification of surface-level salinity (Girishkumar et al., 2011; Rao and Sivakumar, 2003; Thadathil et al., 2007). The significant stratification of surface-level salinity strengthens the longitudinal consistency of the uppermost ocean layer and contributes to the maintenance of a thin mixed layer (Maes and O'Kane, 2014; Mignot et al., 2007; Thadathil et al., 2007; Girishkumar et al., 2013). A stabilization layer forms as a result of salinity stratification, located beneath the mixed layer. In the BoB, these barrier layers start developing in fall (October-November) and are at their highest in winter (December-March). (de Boyer Montegut et al., 2007; Rao and Sivakumar, 2003). Since density is the driving force behind the global thermohaline circulation, it's important to investigate the connection between SSS, SST, and chlorophyll-a (Chl-a). The concentration of chlorophyll-a is a biological measure that shows the number of phytoplankton. Monitoring it can aid in the detection of circumstances that could lead to marine biological disasters such as red tide and cyanobacteria. (Tomlinson et al., 2004; Steidinger and Haddad, 1981). Numerous factors can influence the Chlorophyll-a concentration, as previously reported (Thomas et al., 2001; Gong et al., 1996). Cyclonic rings connect to regions with a large field of view for sea-viewing Chlorophyll-a. The anticyclonic rings correspond to regions with a low concentration of Chlorophyll-a (Chu and Kuo, 2009).

The Bay of Bengal (BoB) holds immense ecological, economic, and climatic significance, particularly for Bangladesh, a nation intrinsically linked to its coastal and marine ecosystems. Studying the relationships between SST, SSS, and Chlorophyll-a (Chl-a) concentration is important because these factors affect marine life, fish availability, and the health of the ocean. Changes in these conditions, driven by climate change, can impact the livelihoods of millions of people who depend on the sea. Understanding these patterns helps in protecting marine resources, planning for climate challenges, and ensuring sustainable use of the BoB's rich natural resource.

There hasn't been much research on the combined study of SST, salinity, and chl-a concentration in the BoB in Bangladesh. The goal of this work is to analyze the trends and patterns of SST anomalies across various regions of the Bay of Bengal. The study conducts an analysis of temporal data trends of SST, SSS, chlorophyll concentration, and SST anomalies. Their relationship with each other has been analyzed using statistical methods, as well as their variation over temporal and spatial differences has been mapped and graphed with statistical and geospatial tools to find out their independent variability within the temporal and spatial frame for different locations of the Bay of Bengal over the last 10 years. This study attempts to compare the SST and other parameters and investigate each parameter for different geolocations with temporal variability, which is unique for the Bay of Bengal.

Methodology

Study area: The Bay of Bengal, located between latitudes 5°N to 22°N and longitudes 80°E to 100°E, has been chosen for this study. It covers a surface area exceeding 2.2 million square kilometers, with an average depth of 2,600 meters and a maximum depth of 5,258 meters. Bangladesh is situated on the eastern coast of the Bay.

Data used in the study: Data were collected in NetCDF format and then exported to dataframes for easier manipulation. They were indexed in time-series. The depth dataset had been subset into the zones of depth mentioned further into the paper. As all the datasets came georeferenced, the datasets were easier for comparisons and associations to other datasets. The kinds of analyses are explained in the later parts.

Sea Surface Temperature (SST) data were acquired from GHRSST. It is available as a retrospective dataset with

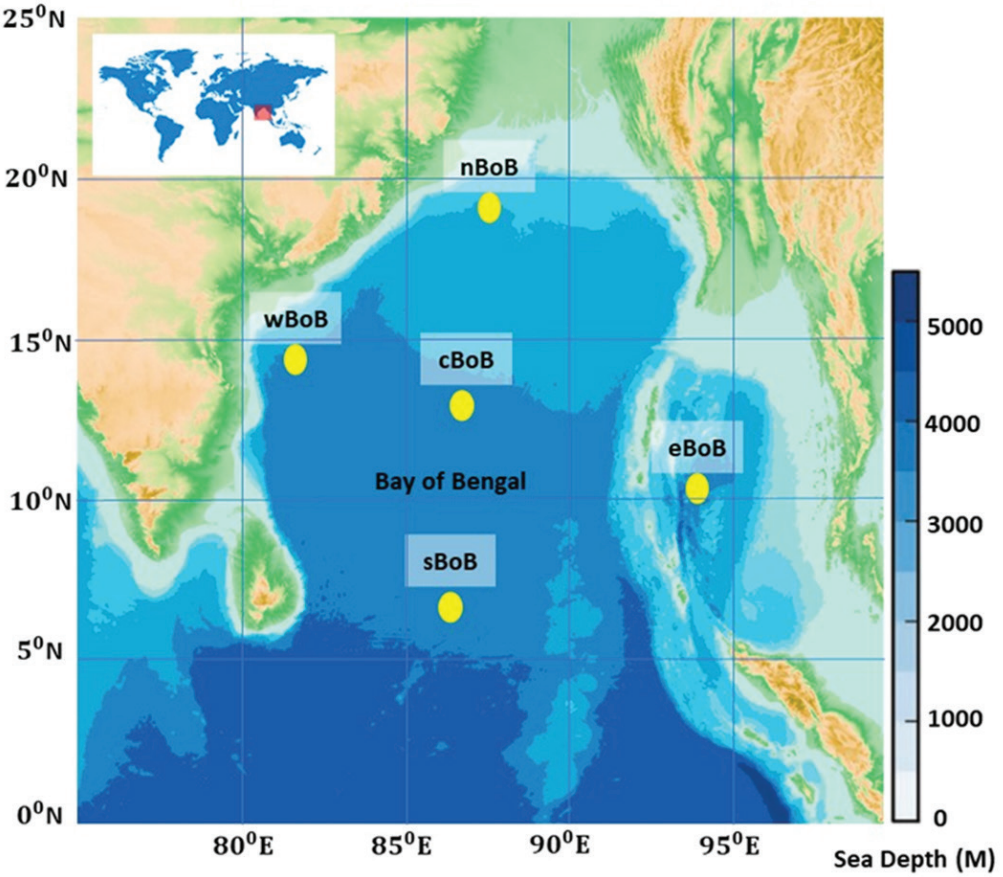


Figure 1. The Bay of Bengal and its adjacent regions used for assessing seo surface temperature. The yellow dots are the locations selected for addressing in-depth relationships among SST, SSS and chlorophyll-a concentration.

a four-day delay and a near-real-time dataset with a one-day delay. The data is produced using an optimal interpolation approach with wavelets as the basic functions on a global 0.01-degree grid. The spatial resolution for SST analysis data is 0.01 degrees for both latitude and longitude, and the temporal resolution is hourly to less than daily. The projection type for these datasets is cylindrical Lat-Lon projection, and each pixel includes geolocation information. The World Geodetic System (WGS 84) is used as the coordinate system. The data for Sea Surface Temperature and Chl-a concentration were obtained from MODIS Aqua measurements, which were obtained from the ocean color website. SST and Chlorophyll-a monthly data at level 3 (4 km) from January 2010 to December 2021. All of the data were located at 80°-100°E and 5°–25°N. Sea surface salinity (SSS) data has been downloaded from NASA salinity website for the time frame of 2010 to 2021, and the 4-year interval has been used to condense the data to a level where it is sufficient to measure the correlation between SST and SSS and also the locational and seasonal variability measurement could easily be drawn from this time frame. The correlation between SST and SSS indicates variations in the atmospheric and oceanic systems and is crucial to the overall climate system

The pearson correlation coefficient: The Pearson correlation coefficient (Equation i) assesses the linear relationship between two variables (Pearson, 1985). It

also shows how closely related the two variables are.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]\,[n(\sum y^2) - (\sum y)^2]}} \quad \text{.....(i)}$$

where, n denotes the sample size. A Pearson correlation coefficient of +1 represents an ideal positive linear relationship, meaning that an increase in one variable corresponds to a proportional increase in the other. In contrast, a coefficient of -1 indicates an ideal negative linear relationship, where an increase in one variable leads to a proportional decrease in the other. A coefficient of 0 suggests that there is no linear relationship between the two variables.

Mann–Kendall (MK) test

The MK (Mann 1945, Kendall 1957) trend analysis is a widely used statistical method for detecting increasing and decreasing trends in climatic time series data (Zarenistanak et al., 2014; Liang et al., 2010; Yue and Pilon, 2004). The MK analysis was conducted on the time series data to identify increasing and decreasing trends in SST, SSS, and Ch-a levels in the Bay of Bengal. To conduct the test, the below formula was used (Equation ii):

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(xi - xj) \quad \text{.....(ii)}$$

Where, x_i, x_j indicate data values and n indicates the extent of data collection.

Using the Z-values identified the statistically significant trends. The Z value that was positive indicates an increasing trend, while a negative Z value signifies a decreasing trend.

Results

Variability of sea surface temperature: A time series of seasonal variations of SST in the Bay of Bengal from 2010 to 2021. indicates that SST of the BoB varies within the range of approximately 24°C to 31°C (Fig. 2). The minimum surface temperature occurred in 2010 in this time series SST of 2010 to 2021, and the maximum occurred in 2010 and 2020.

Between 2010 and 2020, Bay of Bengal experienced an apparent seasonal variability in SST. Seasons are broadly classified in this part as pre-monsoon (February–May), monsoon (June–September), and post-monsoon (October–January). In the summer season the months of April and May typically have the highest ambient temperatures, while the winter season in the months of December and January have the lowest.

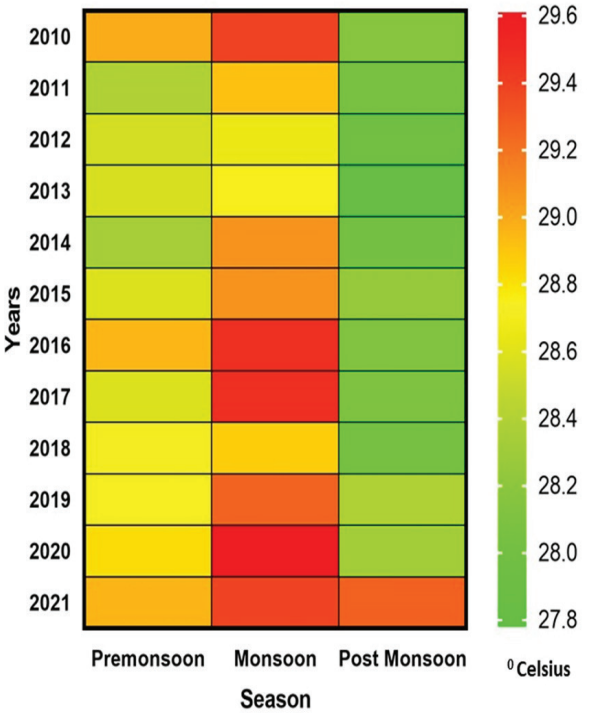


Figure 2. Yearly average seasonal changes in sea surface temperature (2010-2021).

At the start of the pre-monsoon, which is likely to be the month of February, the sea surface temperature stays as low as 26°C, whereas, in the following months, it increases gradually and reaches up to around 30 degrees Celsius. At the end of the pre-monsoon, the prominent monsoon season coincides with the summer season/ summer monsoon in this region. The monsoon season

retains the SST with an average temperature of 29.38°C, with a minimum SST value of 28°C and rises to the maximum of 31°C. In post-monsoon season during which the sea surface temperature mostly gets to its low point less than 26 ° C and maintains the SST range of 27-28°C in its peak stage.

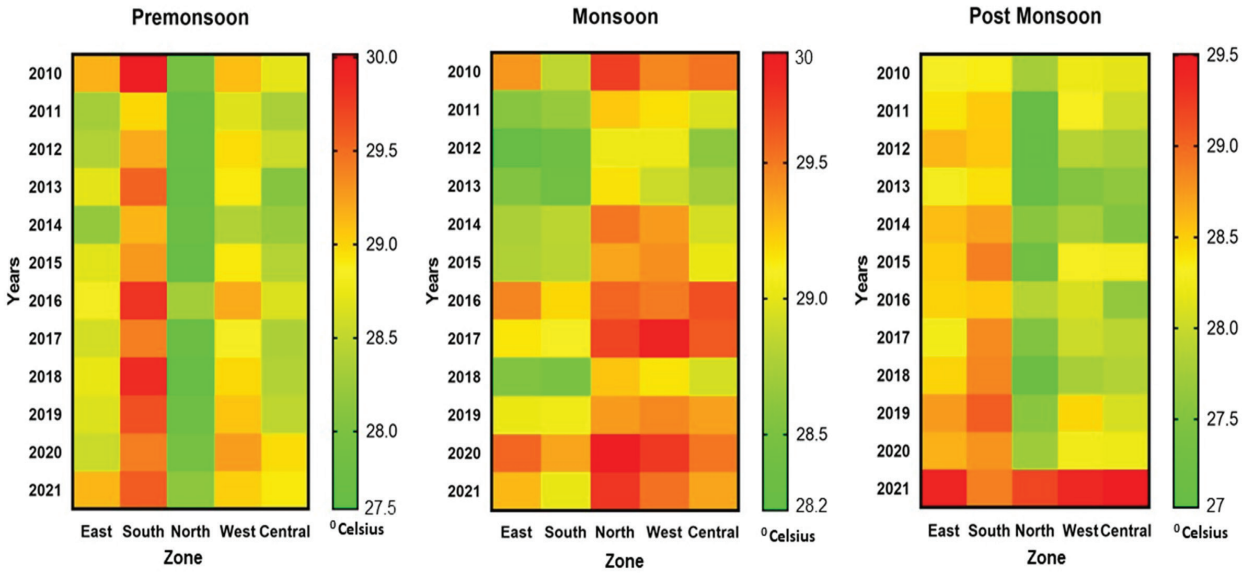


Figure 3. Time series analysis (2010-2021) for the average sea surface temperature in all zones of the Bay of Bengal.

The monthly average values for each year were plotted in a time series, revealing a seasonal and yearly variation in SSTs in different zones of the BoB. Figure 3 illustrates the seasonal and yearly variations in SST across different zones of the BoB from 2010 to 2021. In the north part of the BoB the SST values showed a yearly fluctuation, with the highest temperature reaching around 31 °C in 2020 and the lowest temperature recorded as around 24.5 °C in 2012. The SST values fall and rise within the range of 24 °C to 31° C in the northern part of the sample area, and the trend is increasing. The central and southern parts of the Bay of Bengal showed a consistently higher mean temperature than the northern region, with the central zone recording the highest monthly average of around 30.5 °C in 2010, 2020, and 2021. The eastern zone of the BoB had a slightly lower mean temperature than the western zone, with a maximum temperature of 31.31 °C and a minimum temperature of 26.43 °C. The findings suggest that SSTs in the BoB have been increasing over the last decade, with notable regional differences in temperature fluctuations. According to the Mann-Kendall test SST value, all the zones follow an increasing trend.

Yearly SST for Different Parts of the Bay of Bengal: The SST values in the BoB from 2010 to 2021 have fluctuations, and there is a seasonal variation in the SST values in various parts of the Bay (Fig. 4). In 2010, the SST was lowest during January-February and peaked in May. In 2011, the SST distribution was even, and the western part of the Bay had the highest values. The lowest temperature was near most coastal areas, and the temperature variation was dependent on the seasonal variation. The SST values for 2012 followed a six-month rise and falls pattern. The highest SST was recorded in the BoB's south-eastern and south-western regions. The SST for 2014 was quite similar to that of 2010, where the south-eastern part retained the highest SST values. In 2015, the variability in the SST was the lowest, and the coastal region had the lower SST values. The temperature distribution for 2016 was a cluster with higher values in the central BoB. In 2018 and 2019, the highest temperature was recorded in the south-eastern part of the Bay of Bengal. The SST distribution in 2020 showed a seasonal variation in the temperature, with the seasonal increase in temperature during pre-monsoon season and monsoon season. The 2021 composite SST

map shows that the temperature retains its higher value in large portion of the BoB. SST reaches its low value near the coastal areas of the BoB and at the border of the southern part with the Indian ocean.

Relation between chlorophyll-a concentration and SST: The correlation coefficient between Chlorophyll-a and sea surface temperature (SST) was calculated using the monthly mean data sets for both Chlorophyll-a and SST. The Bay of Bengal's Chlorophyll-a and SST correlation coefficient distribution from 2010 to 2021 is shown in Fig. 5.

The correlation coefficient between chl-a and SST value in the Bay of Bengal is low (R^2=0.115), indicating a weak correlation. According to Kumar (2016), this may be since chlorophyll concentration varies little seasonally and has a weak annual cycle in the region, with high concentrations in winter (October-December) and low concentrations in summer (June). In contrast, SST is lower in the post-monsoon season and tends to increase in summer.

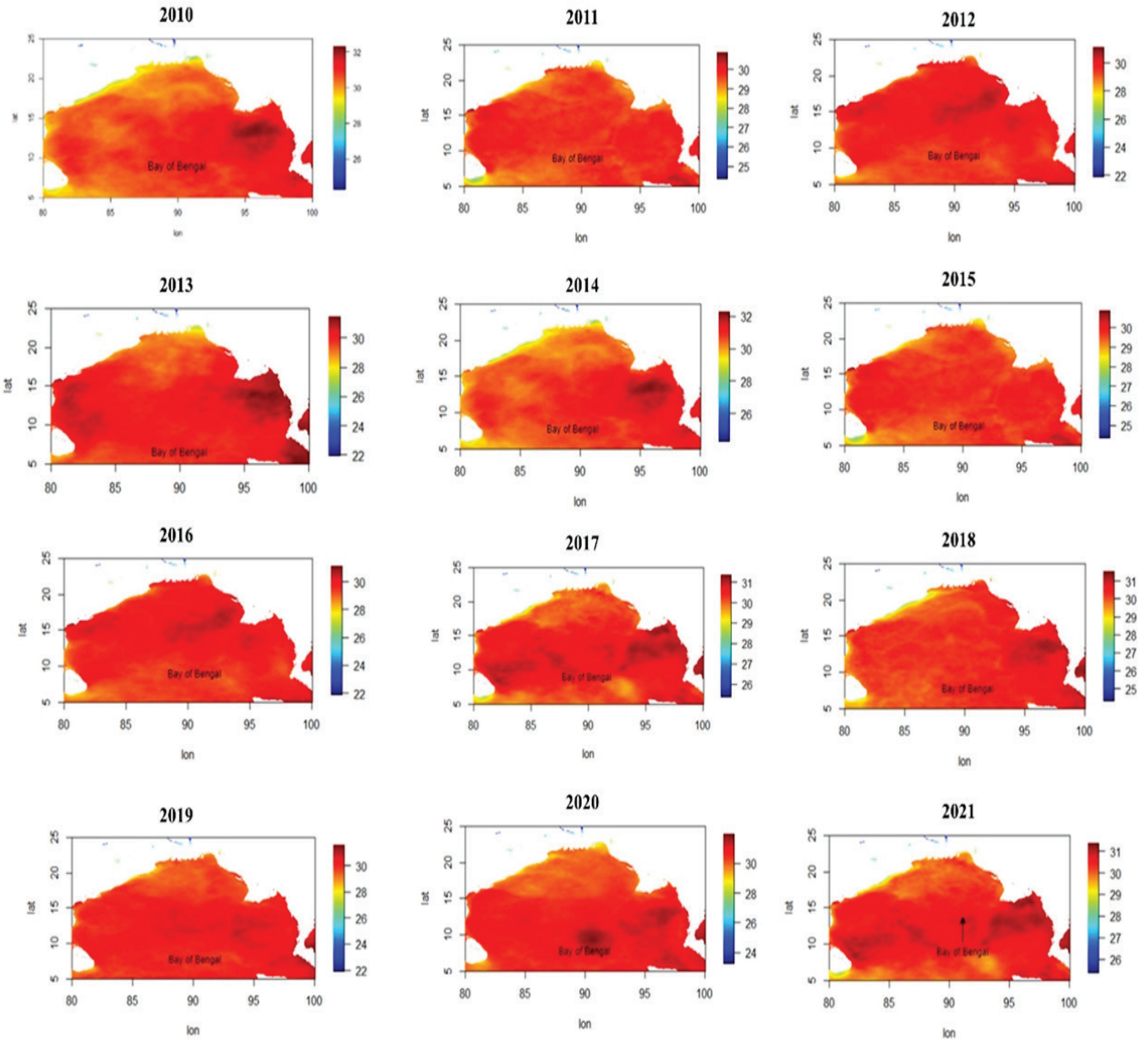


Figure 4. Sea surface temperature composite for each year from 2010-2021.

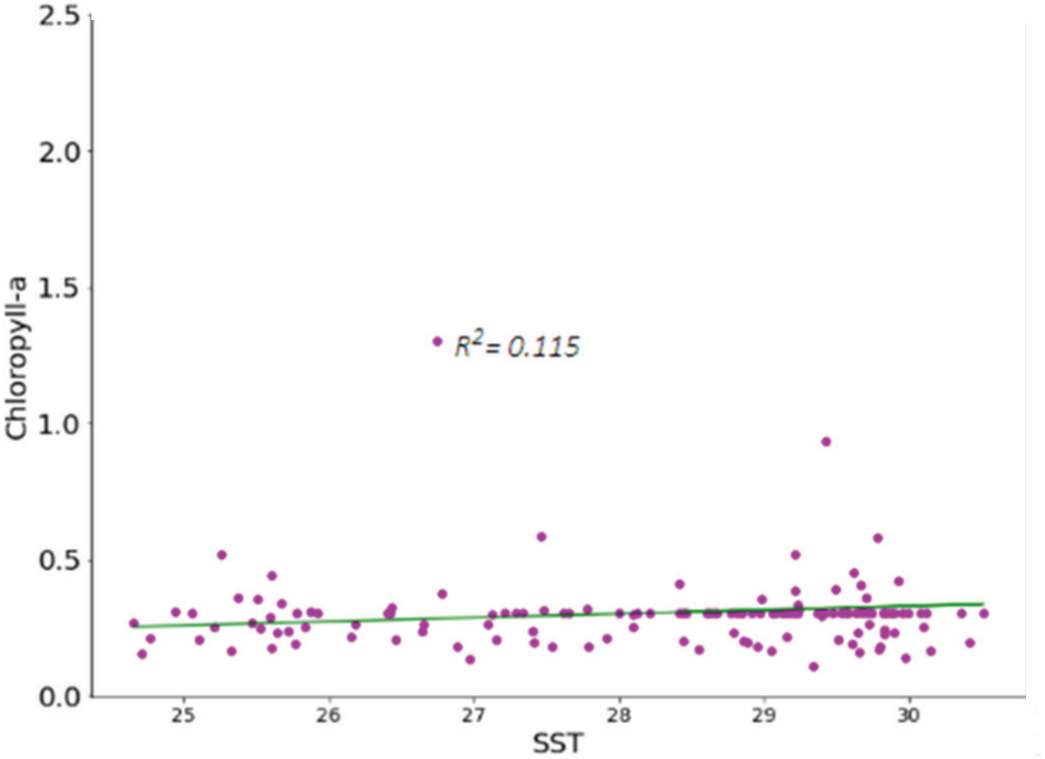


Figure 5. Correlation scatter plot for chlorophyll-a and sea surface temperature.

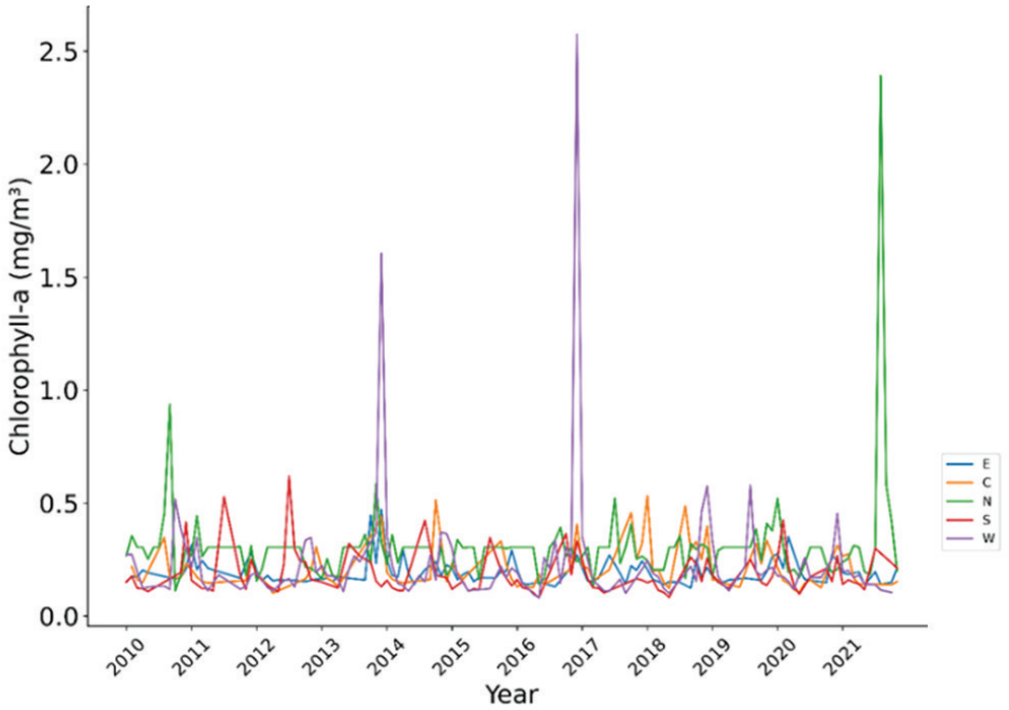


Figure 6. Chlorophyll-a trend for all zone (2010-2021).

In the years 2014, 2017 and 2021 there are some large increases in chlorophyll concentration. This rise in chlorophyll concentration has been observed in some specific part of Bay of Bengal. The northern part had an increase in concentration up to 2.4 mg per cubic meter, whereas the western part had an increase in the end of 2016 and 2013. The north-western BoB was distinguished by a seasonal increase in chlorophyll due to strong coastal upwelling caused by alongshore winds throughout the summer monsoon season. Furthermore, nutrients delivered by monsoonal river outflow support increased chlorophyll concentrations in near shore seas.

Relation between SSS and SST : The sea surface salinity has a temporal and spatial variation in the BoB, which is clear from the time series analysis of the SSS for the last ten-year period (2010-2021). The SST is supposed to correlate with the SSS directly, and the Pearson correlation has been calculated to find the correlation between these two-parameter. Using the SSS and SST monthly mean data sets, the correlation coefficient was calculated to assess the relationship between SSS and SST. Figure 7 shows the correlation coefficient distribution for Salinity and SST in the Bay of Bengal from 2010 to 2021. The significant correlation between the SSS and SST is indicated by the correlation coefficient, R^2=0.81.

Relationship of bathymetry with SST : The Bay of Bengal is divided into five zones based on its depths for this study. These zones are divided into very shallow zone (VS) (0-1000 meter), shallow zone (S) (1000 meter-2000 meter), Deep zone (D) (2000 meter-3000 meter), Very Deep zone (VD) (3000 meter-4000meter) and Extremely Deep zone (ED) (4000 meter – 5000 and above meter).

The very shallow zone has the mean SSTs value of 27.50°C, and the minimum and maximum values for this zone are 20.13°C and 30.91°C, respectively. The standard deviation is highest in the very shallow zone for the SST, which is 2.63°C, which signifies that the temperature is widely dispersed from the mean. The mean sea surface temperature for the shallow zone is 28.236 ° C with a standard deviation of 1.54°C. The maximum value for the shallow zone is 30.69 °C, and the minimum value is 24.53°C. The mean temperature for the deep zone is

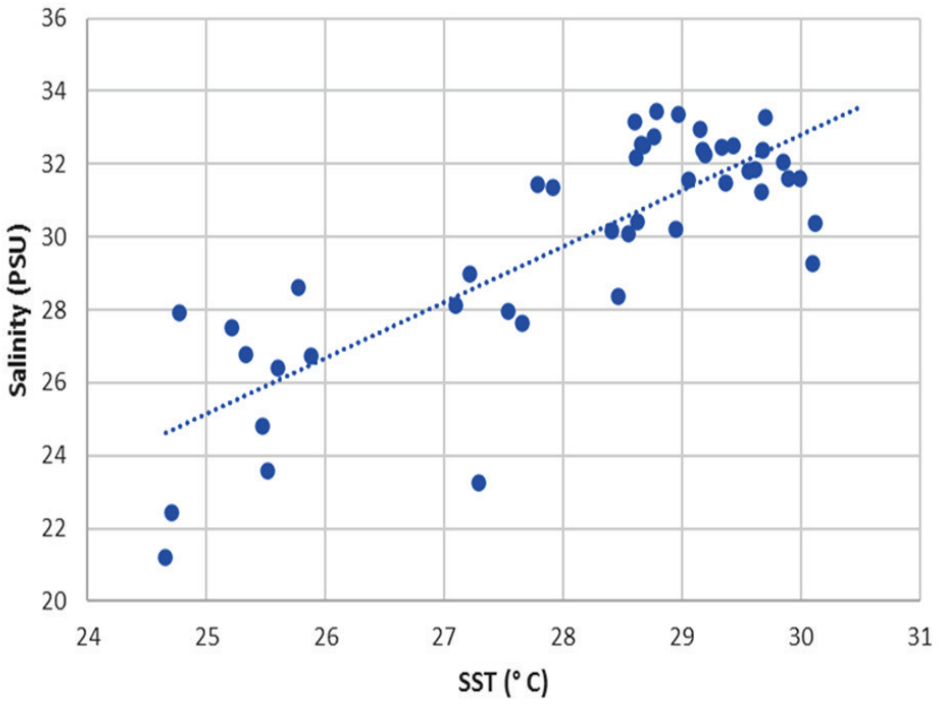


Figure 7. Correlation between salinity and sea surface temperature.

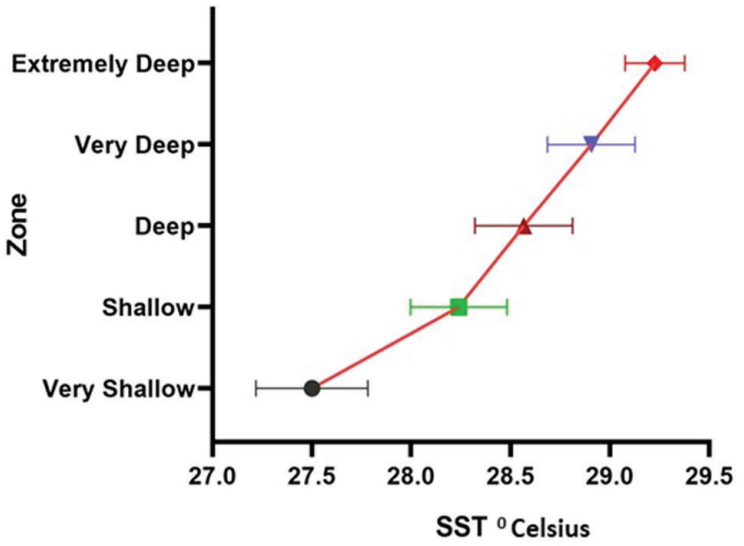


Figure 8. Mean sea surface temperature with varying depths.

28.56 ° C, whereas the standard deviation is 1.52°C with the maximum value of 30.83°C and minimum value of 25.62. On the other hand, the mean values for the very deep and extremely deep zones are 28.91 ° C and 29.23°C, respectively. The standard deviations are 0.91°C and 0.59°C for the very deep and extremely deep zone of the BoB.

The SST of the BoB exhibits a direct correlation with depth. Analysis of the mean SST values in the BoB reveals an increasing trend with depth, ranging from 27.50°C to 29.23°C. This trend can be attributed to the proximity of the extreme deep zone to the equator, where SSTs generally increase due to greater heating of the ocean surface caused by direct sunlight. However, this trend

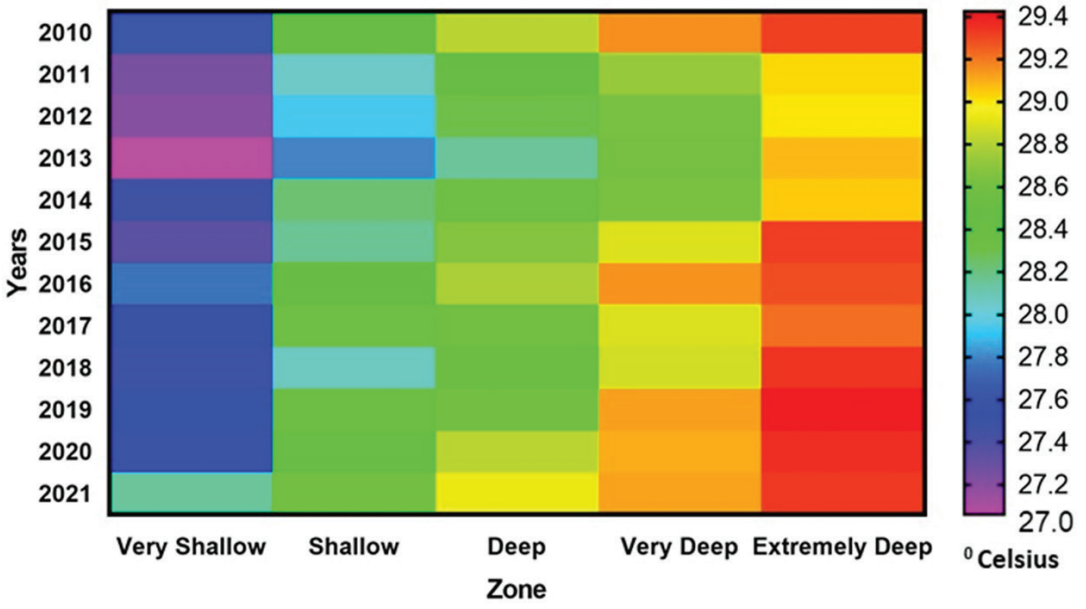


Figure 9. Depth wise sea surface temperature time series for all the depth class.

also implies a positive correlation between depth and the dispersion of SST values from the mean. The standard deviation is lower in the extreme deep zone, indicating that SST values are more closely distributed around the mean in the shallow areas of the BoB. These findings highlight the importance of considering depth when analyzing SST data, particularly in areas such as the BoB where the proximity to the equator can have a significant impact on SST values.

Discussion

The outcomes of this study demonstrate that the SST in the Bay of Bengal has been increasing over the past decade with regional differences in temperature fluctuations. The analysis reveals that the SST values in the BoB varied within the range of approximately 24°C to 31°C from 2010 to 2021. The peak SST values were observed in 2010 and 2020, while the lowest value was recorded in 2012. The study also found that the BoB experiences apparent seasonal variability in SST, with the pre-monsoon, monsoon, and post-monsoon seasons affecting the temperature range. The summer months of April and May typically have the highest ambient temperatures, while the winter months of December and January have the lowest. The monsoon season coincides with the summer season in the region, and it retains the SST with an average temperature of 29.38°C. Conversely, the post-monsoon season has a lower SST, with a range of 27-28°C in its peak stage. The outcomes of this study are align with previous studies that have reported an increasing trend in SST in the Bay of Bengal. The study also revealed that the northern part of the BoB has a yearly fluctuation in SST, with the highest temperature recorded in 2020 and the lowest in 2012. Meanwhile, the central and southern parts of the Bay of Bengal consistently have higher mean temperatures than the northern part, with the central zone recording the highest monthly average in 2010, 2020, and 2021. The eastern region of the BoB had a slightly lower mean temperature than the western zone. The increasing trend in SST values observed in this study may have several implications for the region, including shifts in the marine ecosystem, sea level rise, and changes in weather patterns. Therefore, it is essential to continue monitoring and studying the SST in the BoB to understand its implications and develop appropriate adaptation measures.

The study found a weak correlation between SST and Chl-a concentration in the BoB. This could be due to the weak annual cycle of Chl-a concentration, with increased concentrations in winter and lower concentrations in summer. In contrast, SST is low in the post-monsoon season and increases in summer. However, there were increases in Chl-a concentration in specific areas of the BoB in 2014, 2017, and 2021, particularly in the northwestern region where coastal upwelling and monsoonal river discharge support increased chlorophyll concentrations. These findings highlight the necessity for ongoing monitoring and additional research to gain a deeper understanding of the intricate interactions between sea surface temperature (SST), chlorophyll-a, and environmental factors in the Bay of Bengal.

From 2010 to 2021, a strong link was found between SST and SSS in the BoB. This implies that changes in one can affect the other. Similar connections have been reported in other ocean regions. Both factors are important when studying the Bay's physical and biogeochemical processes. More research is needed to understand the correlation and its impact on the Bay's oceanography and climate.

The findings show that in the BoB, as depth increases, SST decreases. This means that as the depth increases, the mean sea surface temperature decreases. Additionally, the standard deviation increases with an increment in depth, indicating a direct correlation between depth and SST dispersion from the mean. This implies that the SST varies significantly from the mean with the increasing depth.

Moving seawards from the shore towards lower latitudes, temperature increases towards the Equator. There has been studies regarding SST increasing from the mouth of estaury inflow seawards (Bashevkin and Mahardja, 2022). The fact that salinity also increases with depth might be related to increasing salinty with distance from the shore and rendering a positive correlation with SST, but previous studies show some extent of inverse relationship between distance from shore to increase in salinity mainly referring to estaurine inflow (Geawhari, 2014; Guillou, 2022).

Conclusions

In this study it was found that the SST trend was positive and varied with the location in the BoB, following a seasonal pattern. The SST starts to rise during the end of pre-monsoon and starts to fall during the monsoon season, which is related to monsoonal rainfall in the BoB region. The southern zone had the highest mean value of SST. The SST is closely linked to the SSS, and Pearson correlation was employed to determine the relationship between these two parameters. The correlation coefficient was calculated using monthly mean data sets. The correlation coefficient retains a higher value, which indicates a strong relationship between SSS and temperature. The mean chlorophyll concentration in the southern BoB is lower than in the other three zones, except for the eastern Bay. With the increase in depth, the mean value of sea surface temperature decreases. With increasing depth, the sea surface temperature deviates significantly from the mean. The standard deviation is lower in the very shallow zone of the Bay of Bengal, indicating that SSTs are more evenly distributed in the shallow areas of the Bay of Bengal. The findings of this study could be valuable for understanding the complex interactions between various oceanic parameters and their impact on the marine ecosystem and climate. The study may also yield valuable insights for managing fisheries, overseeing coastal zones, and planning for climate change adaptation in the Bay of Bengal adjacent area.

References

Bashevkin SM and Mahardja B. 2022. Seasonally variable relationships between surface water temperature and inflow in the upper San Francisco Estuary, Limnology and Oceanography. 67: 684-702. doi: 10.1002/lno.12027.

Belward A, Bourassa M, Dowell M, Briggs S, Dolman H, Holmlund K and Verstraete M. 2016. The global observing system for climate: Implementation needs. World Meteorological Organization, Switzerland. P. 325.

Chu PC and Kuo YH. 2009. Biophysical variability in the Kuroshio Extension from Altimeter and SeaWiFS. In OCEANS 2009. P. 1-8.

De Boyer Mont egut C, Mignot J, Lazar A and Cravatte S. 2007. Control of salinity on the mixed layer depth in the world ocean: 1. General description, J. Geophys. Res. https://doi.org/10.1029/2006JC003953.

Deser C, Alexander MA, Xie S and Phillips AS. 2010. Sea surface temperature variability: patterns and mechanisms. Annual Review of Marine Science. 2: 115-43. DOI: 10.1146/annurev-marine-120408-151453.

Geawhari MA, Huff L, Mhammdi N, Trakadas A and Ammar A. 2014. Spatial-temporal distribution of salinity and temperature in the Oued Loukkos estuary, Morocco: using vertical salinity gradient for estuary classification, SpringerPlus. https://springerplus.springeropen.com/articles/10.1186/2193-1801-3-643

Girishkumar MS, Ravichandran M and McPhaden MJ. 2013. Temperature inversions and their influence on the mixed layer heat budget during the winters of 2006-2007 and 2007–2008 in the Bay of Bengal. Journal of Geophysical Research: Oceans. 118: 2426-2437.

Gong GC, Chen YLL and Liu KK. 1996. Chemical hydrography and chlorophyll a distribution in the East China Sea in summer: implications in nutrient dynamics. Continental Shelf Research. 16: 1561-1590.

Guillou N, Chapalain G and Petton S. 2022. Predicting sea surface salinity in a tidal estuary with machine learning. Oceanologia. 65: Pp. 318-332.

Kendall MG. 1957 Rank correlation methods. Biometrika. 44: 298

Kotal SD, Kundu PK and Roy Bhowmik SK. 2009. An analysis of sea surface temperature and maximum potential intensity of tropical cyclones over the Bay of Bengal between 1981 and 2000. Meteorological Applications: A journal of Forecasting, Practical Applications, Training Techniques and Modelling. 16: 169-177.

Maes C and O'Kane TJ. 2014. Seasonal variations of the upper ocean salinity stratification in the tropics. Journal of Geophysical Research: Oceans. 119: 1706-1722.

Mann HB. 1945. Nonparametric tests against trend. Econometrica. 13: 245-259.

Miranda J, Lotliker AA, Baliarsingh SK, Jena AK, Samanta A, Sahu KC and Kumar TS. 2021. Satellite estimates of the longterm trend in phytoplankton size classes in the coastal waters of north-western Bay of Bengal. Oceanologia. 63: 40-50 (11 pages).

Pearson K. 1895. Note on Regression and Inheritance in the case of two parents. Proceedings of the Royal Society of London (1854-1905). 58: 240-242. doi:10.1098/rspl.1895.0041.

Rao RR and Sivakumar R. 2003. Seasonal variability of sea surface salinity and salt budget of the mixed layer of the north Indian Ocean. Journal of Geophysical Research: Oceans. 108: 9-1.

Sebastian M. and Behera MR. 2015. Impact of SST on tropical cyclones in North Indian Ocean. Procedia Engineering. 116: 1072-1077.

Steidinger KA and Haddad K. 1981. Biologic and hydrographic aspects of red tides. Bioscience. 31: 814-819.

Thadathil P, Muraleedharan PM, Rao RR, Somayajulu YK, Reddy GV and Revichandran C. 2007. Observed seasonal variability of barrier layer in the Bay of Bengal. Journal of Geophysical Research: Oceans. https://doi.org/10.1029/2006JC003651.

Thomas AC, Carr ME and Strub PT. 2001. Chlorophyll variability in eastern boundary currents. Geophysical Research Letters. 28: 3421-3424.

Tomlinson MC, Stumpf RP, Ransibrahmanakul V, Truby EW, Kirkpatrick GJ, Pederson BA and Heil CA. 2004. Evaluation of the use of SeaWiFS imagery for detecting Karenia brevis harmful algal blooms in the eastern Gulf of Mexico. Remote Sensing of Environment. 91: 293-303.

Yu L and McPhaden MJ. 2011. Ocean preconditioning of cyclone Nargis in the Bay of Bengal: interaction between rossby waves, surface fresh waters, and sea surface temperatures. Journal of Physical Oceanography. 41: 1741-1755.

Yue S and Pilon P. 2004. A comparison of the power of the t test, Mann-Kendall and bootstrap for trend detection. Hydrological Sciences Journal. 49: 21-37.

Zarenistanak M, Dhorde AG and Kripalani RH. 2014. Trend analysis and change point detection of annual and seasonal precipitation and temperature series over southwest Iran. Journal of Earth System Science. 123: 281-295.