Evaluating Environmental Fluctuations in Bivalve Bed Ecosystems of the Southeastern Arabian Sea: A Year-Long In-Situ and Remote Sensing Approach

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Abstract

This study examines the seasonal changes in key physicochemical parameters of coastal waters near Calicut, located in the southeastern Arabian Sea (SEAS), and their ecological implications. The sea surface temperature (SST) peaked in May and reached its minimum in August, aligning with historical data. Salinity followed a similar pattern, increasing in May and decreasing after the monsoon. Surface dissolved oxygen levels also increased in June due to mixing during the monsoon but declined by October, leading to low oxygen conditions near Puthiyappa Harbour. The highest nutrient concentrations were recorded during the monsoon period. This area supports thriving bivalve (*Perna viridis*) populations, with optimal growth observed during the high-salinity months (April-May) and spawning timed with monsoon-driven productivity. These findings highlight the ecosystem's ability to adapt to natural seasonal variations while emphasizing the importance of ongoing monitoring to mitigate anthropogenic and climate-related challenges. The study underscores the necessity of long-term environmental evaluations for effective coastal management in a changing climate.

Keywords: Coastal water quality, upwelling, monsoon dynamics, phytoplankton succession, bivalve ecology, anthropogenic impact

Introduction

The health of an aquatic ecosystem is shaped by a variety of biological, physical and chemical interactions (Mishra et al., 2023). Understanding integrated physicochemical parameters is vital for expertise in sustainable development and for maintaining a healthy marine ecosystem (Nair & Nayak, 2023). Moreover, it is important to understand the water quality of aquatic ecosystems and its impact on aquatic biodiversity, especially for managing fishery resources to achieve greater stability and environmental balance (Çelekli, & Zariç, 2023; Wang et al., 2024).

The bivalve fishery plays a crucial role in the coastal economy of Calicut. Natural beds of bivalve are located along the laterite rocks that extend into the sea, providing habitat for significant numbers of *P. viridis* (Rohit et al., 2017; Laxmilatha & Sreeram, 2022). Bivalves primarily obtain their nutrition by filtering phytoplankton from the surrounding water. The composition and dynamics of the phytoplankton community are shaped by several physical and chemical factors. Variations in these chemical and physical parameters—such as temperature, salinity, pH, nitrate, nitrite, ammonia, silicate, and dissolved inorganic phosphate—significantly affect the spatial and temporal patterns of phytoplankton distribution (Vajravelu, Martin, Ayyappan, & Mayakrishnan, 2018; Vase et al., 2018). Sudden changes in these physico-chemical conditions can notably affect the presence and distribution of various phytoplankton species, and subsequently, the growth of bivalves.

Calicut, a coastal area along the southeastern Arabian Sea (SEAS), is well known for its seafood sector. In recent years, there has been substantial interest in examining the various elements that influence phytoplankton growth in relation to

physicochemical properties. Nevertheless, there is a lack of knowledge about the specific physicochemical conditions associated with the phytoplankton community in this area, affecting the bivalve fishery in the region. The present study aims to provide insights into the chlorophyll dynamics and the physicochemical water parameters, thereby enhancing our understanding of the variations in distribution patterns within this study region through in-situ methods and ocean colour remote sensing techniques. Such scientific information on water quality and the compilation of chlorophyll concentration will help in developing effective management strategies to maintain a healthy ecosystem in this coastal zone.

Materials and Methods

Sampling was performed off the coast of Calicut, located in the northern Kerala along the SEAS. Five sampling sites were chosen (Fig. 1). Sampling stations were randomly distributed across defined bivalve beds to capture inherent environmental variability. The potential influence of site-specific factors was acknowledged and later analyzed as explanatory variables for observed data fluctuations. This design ensured that the collected data was representative of the entire bed ecosystem while allowing for the examination of local spatial biases. The positions of the sampling sites were marked using the Global Positioning System (GPS). St-01

was situated near Puthiyappa harbour, St-02 at Elathur, south of the Korappuzha river's mouth, St-03 at Kappad, a popular tourist spot, St-04 at Parapally, a site of pilgrimage, and St-05 at Thikkodi, close to a mini harbour along an open beach with minimal tourist activity. Stations 01, 02, and 05 were located in regions with abundant laterite rocks, while Stations 03 and 04 were positioned along solid rock formations. Stations 02 and 05 are home to seaweeds and various reef organisms.

Sampling was performed on a monthly basis from April 2023 to May 2024. Sea surface temperature (SST) was recorded using a digital thermometer with an accuracy of 0.1 °C. Salinity was determined through the Mohr-Knudson Argentometric titration method. Dissolved oxygen (DO) was assessed using the modified Winkler's Method (Strickland & Parsons, 1972). Nutrients were analyzed with nitrite (NO_2^-) measured via a colorimetric method using sulfanilamide, nitrate (NO_3^-) assessed through the cadmium reduction method, phosphate (PO_4^{3-}) measured by the ascorbic acid method, and silicate (SiO_4^{4-}) evaluated using the molybdate method with a PC-based double-beam UV-spectrophotometer (Thermo), while ammonia was tested with the indophenol method following standard procedures (Grasshoff, Kremling, & Ehrhardt, 2009). All measurable parameters were collected and analyzed in triplicate. The mean values of these triplicate measurements were used for all subsequent data

Table 1. Results of the principal component analysis performed using IBM-SPSS Statistics-25 software.

	Total Variance Explained								
Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.940	21.553	21.553	1.940	21.553	21.553	1.600	17.780	17.780
2	1.602	17.797	39.349	1.602	17.797	39.349	1.591	17.675	35.455
3	1.502	16.690	56.039	1.502	16.690	56.039	1.543	17.148	52.603
4	1.028	11.425	67.464	1.028	11.425	67.464	1.338	14.861	67.464
5	.856	9.506	76.971						
6	.790	8.774	85.745						
7	.506	5.618	91.362						
8	.430	4.778	96.140						
9	.347	3.860	100.000						

Extraction Method: Principal Component Analysis.

Table 2. Results of the rotated component matrix after principal component analysis performed using IBM-SPSS Statistics-25 software.

| | Rotated Component Matrix[a] | | | |
| | Component | | | |
	1	2	3	4
Temperature	-0.151	0.283	-0.207	0.718
Salinity	0.257	0.843	0.013	0.079
Dissolved Oxygen	0.641	0.383	-0.103	0.169
Chlorophyll	0.347	-0.744	-0.020	-0.080
Nitrite	0.082	-0.195	0.854	-0.094
Nitrate	-0.065	0.211	0.864	0.016
Phosphate	0.776	-0.078	-0.024	-0.346
Silicate	0.586	-0.102	0.089	0.137
Ammonia	.152	-.045	.071	.796

Extraction Method: Principal Component Analysis.Rotation Method: Varimax with Kaiser Normalization.

visualizations, and statistical analysis presented in this study.
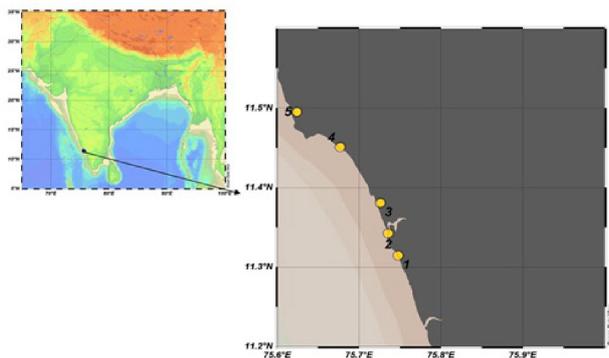

Fig. 1. Location map of Study area.

For the measurement of chlorophyll-a (Chl-a), 2 L of water samples were filtered using Whatman GF/F filter papers with a pore size of 0.7 µm and a diameter of 47 mm. Following solvent extraction in 90% acetone, pigment concentration was assessed using a UV-Visible Spectrophotometer (Shimadzu 1800) as described by Strickland and Parsons (1972). A Chl-a standard (Sigma-Aldrich, USA) was used for calibrating the UV-VIS spectrophotometer. Temporal variations were illustrated using Microsoft Excel and Ocean Data Viewer (ODV ver. 5.8).

In addition to the in-situ Chl-a, mapping of the total chlorophyll concentration was also carried out across the study area. The Copernicus Marine Environment Monitoring Service (CMEMS) provided the netCDF files for total chlorophyll extraction (Le Traon et al., 2015). The CMEMS GlobColour product is a daily composite dataset of Chl-a obtained from multiple sensors, including SeaWIFS, MERIS, MODIS-Aqua, MODIS-Terra, VIIRS-SNPP and JPSS1, and OLCI-S3A and S3B. It combines Chl-a fields that have been reconstructed using a similar methodology for each sensor (Garnesson, Mangin, d'Andon, Demaria, & Bretagnon, 2019). The daily composite data from multiple sensors provide cloud free (minimal), data after default atmospheric correction. For coastal regions, the OC5 algorithm (Gohin, Druon, & Lampert, 2002) is utilized, which is based on the standard OC3 and OC4 (Antoine, André, & Morel, 1996; O'Reilly et al., 1998; O'Reilly et al., 2000) systems for clearer waters, along with specific modifications for complex water bodies. The size class chlorophyll utilized 4 km OLCI data, whereas total chlorophyll employed a higher resolution derived from 300-meter daily OLCI inputs.

Results and Discussion

The samples were analyzed for physico-chemical parameters and the variations are shown in Figures 2-4. The samples were analyzed in triplicate, and the figures present mean values for better clarity. Standard deviation values were omitted to maintain visual focus on the overall spatial and temporal trends across the sampled stations. The same has been incorporated in the results section.

The sea surface temperature (SST) averaged 31.59 ± 2.70 °C, with a peak of 37 °C in May 2023 (St-02) and a minimum in August 2023 (St-03). In May 2023, SST across all stations was higher compared to May 2024. The lowest temperatures were observed in August 2023 at all stations throughout the study period. Overall, May 2023 demonstrated elevated temperatures during the entire study period.

The sea surface salinity (SSS) levels ranged from 29 to 37 psu across the study area, with a mean of 33.69 ± 1.85 psu. Lower SSS levels were noted in September and October 2023, followed by February 2024, with the exception of Station 05 in October 2023, which measured 34.84 psu. In May 2023, two stations, St-02 and St-04, showed elevated SSS levels exceeding 35 psu.

The dissolved oxygen (DO) concentration averaged 5.05 ± 1.45 ml L^{-1}. The highest DO value of 8.06 ml L^{-1} was recorded at St-03 in June 2023. St-01 displayed low DO concentrations on several occasions, specifically in August, October, and November 2023. Additionally, the lowest DO level was noted in St-02, measuring 1.61 ml L^{-1} in October 2023.

The concentration of Chl-a ranged from 0.3 to 112.57 mg m^{-3}. On average, Chl-a concentration in the study area throughout the observation period was 15.74±20.67 mg m^{-3}. The highest Chl-a level was observed at St-02 in October 2023, while the lowest was noted in November 2023 at the same station. The variation over time indicated that August 2023 exhibited the highest Chl-a levels across all stations, exceeding 20 mg m^{-3}.

The average nitrite level recorded was 1.38 ± 1.32 μmol L^{-1}, fluctuating between 0.119 μmol L^{-1} and 5.46 μmol L^{-1}. The minimum nitrite level was observed in November 2023 at St-03, while the peak was documented in September 2023 at St-02. Generally, higher nitrite levels were noted from June to September, followed by a decrease from October 2023 through May 2024. The mean nitrate level throughout the study was 0.91 ± 1.04 μmol L^{-1},
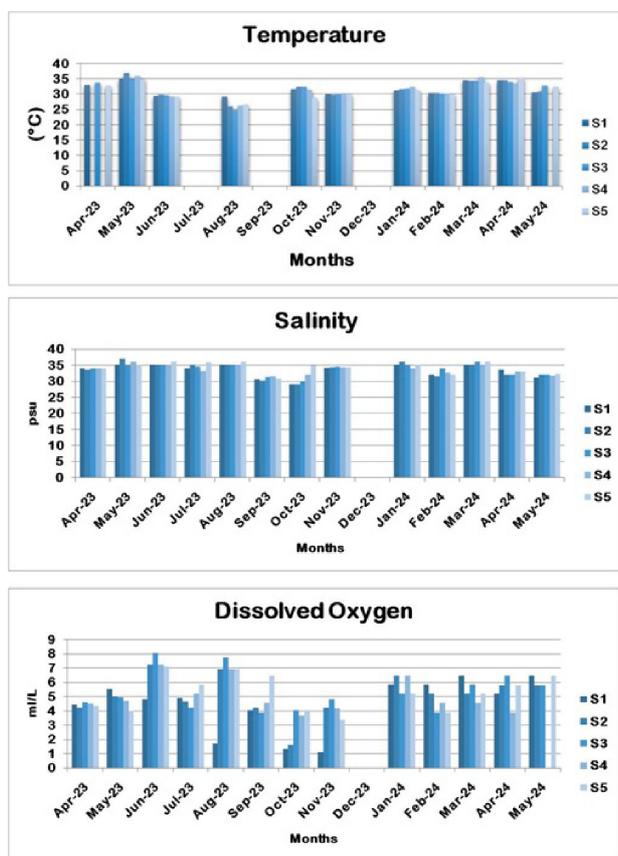

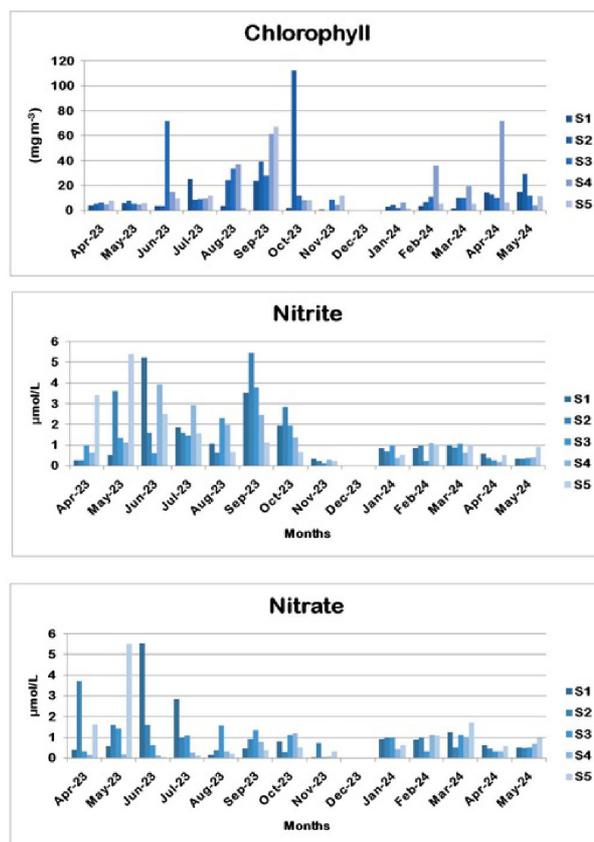Fig. 2. Spatio-temporal variability of temperature, salinity and dissolved oxygen in the study area.

Fig. 3. Spatio-temporal variability of Chlorophyll-*a*, nitrite and nitrate in the study area.

ranging from 0.027 μmol L^{-1} to 5.51 μmol L^{-1}. The lowest nitrate concentration occurred in November 2023 at St-03, whereas the highest concentration was recorded in June 2023 at St-01. In general, nitrate concentrations were low across all stations, with exceptions at St-02 (April 2023), St-05 (May 2023), St-01 (June and July 2023). Phosphate concentrations varied from 2.86 μmol L^{-1} to 57.008 μmol L^{-1}, with an average of 17.78 $\pm$ 11.32 μmol L^{-1}. The lowest phosphate level was recorded in April 2023 at St-05, while the highest occurred in June 2023 at St-03. Typically, phosphate concentrations peaked between June to September. The average silicate concentration was 5.19 $\pm$ 4.73 μmol L^{-1}. The lowest silicate concentration, recorded at 0.1002 μmol L^{-1}, occurred in June 2023 at St-01, whereas the highest concentration of 26 μmol L^{-1} was seen in May 2023 at St-03. In May 2023, silicate levels exceeded 14 μmol L^{-1}, surpassing those of other months at most stations, except at St-02, where it measured 5.935 μmol L^{-1}. The lowest ammonia concentration observed in the study area was 0.010 μmol L^{-1} at St-01 in May 2024, while the highest concentration was 71.66 μmol L^{-1} at St-05 in April 2024. The average

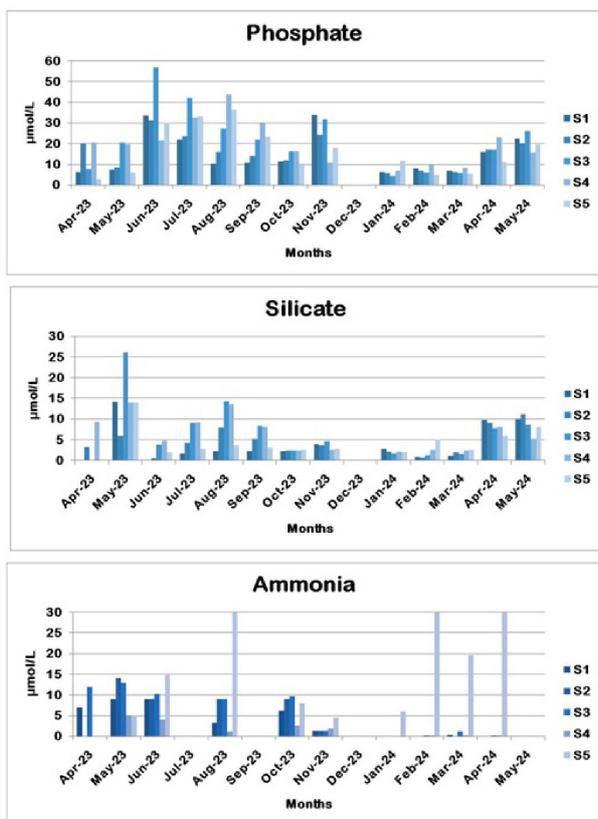ammonia concentration across the region was 7.045 $\pm$ 12.27 μmol L^{-1}. Compared to 2023, ammonia levels in 2024 were predominantly lower, except at St-05 during January to May 2024.

The overall chlorophyll concentration was analyzed using data from the CMEMS portal. This approach provides a more comprehensive understanding of the chlorophyll concentration trends in the area, rather than focusing solely on specific locations. Field data were collected between April 2023 and May 2024. To avoid redundancy and aid in understanding, the months of January to March 2024 were combined with April and May 2023 in the Ocean colour Chl-a (Fig. 5). The chlorophyll concentration in the coastal waters was less than 2 mg m^{-3} from January to March 2024. A slight increase was observed in April, with values varying between 2 and 4 mg m^{-3}, while May exhibited higher Chlorophyll concentrations in certain regions. By June 2023, chlorophyll concentrations in coastal waters generally ranged from 4 to 6 mg m^{-3} and continued to increase until September, exceeding 10 mg m^{-3} throughout the coastal zone. Offshore regions also had higher concentration during this period. In October, a decline in chlorophyll concentration was observed relative to September, although
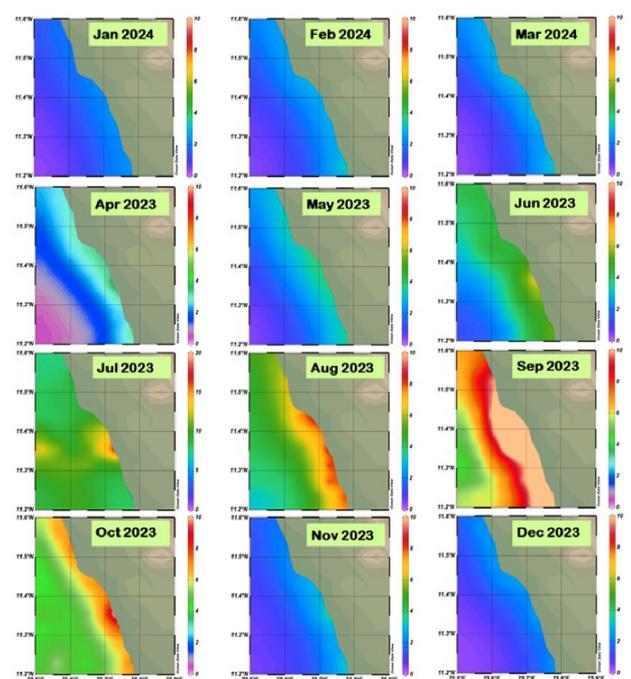

Fig. 4. Spatio-temporal variability of phosphate, silicate and ammonia in the study area.

Fig. 5. Spatio-temporal variability of total chlorophyll in the study area. The colours indicate concentration expressed in mg m^{-3}.

some regions still exhibited elevated levels. Beginning in November, chlorophyll concentrations returned to the levels observed from January to March.

The result from the Principal Component Analysis (PCA) (Eigenvalue > 1) indicated that four components together accounted for the overall variance (67.464%) in the water quality across the study area. The first component accounted for 21.553% of the variance, followed by the second component at 17.797%, the third at 16.690%, and the fourth at 11.425%. The rotated component matrix highlighted four significant trends in the water quality data: PC1 represents the interactions between nutrients and oxygen (phosphate, dissolved oxygen, silicate); PC2 displays a negative relationship between salinity and chlorophyll, suggesting that increased salinity may stress phytoplankton; PC3 focuses on nitrogen cycling (nitrite, nitrate); and PC4 associates temperature with ammonia, potentially showing thermal influences on decomposition. Collectively, these components account for 67.5% of the total variance, emphasizing the unique environmental processes that influence water quality in the region. Further, Bartlett's Test of Sphericity was computed and showed high significance (X^2 (36) = 264.5, $p < 0.001$), indicating that substantial and non-random correlations existed between the physico-chemical variables.

The health of the aquatic ecosystems is largely influenced by the physico-chemical properties of the water, as these factors significantly impact the survival of the organisms inhabiting the water body. The physico-chemical parameters examined in this research provide important insights into the environmental status of the coastal waters off Calicut, SEAS, and contribute to understanding the region's ecological condition that supports the green mussel fishery. SST was found to peak in May and reach a minimum in August. The increase in temperature during May can be attributed to the intense sunlight at that time of the year. The study area experiences three distinct seasons influenced by monsoon rainfall patterns: the pre-monsoon season extends from February to May, followed by the monsoon season (Summer monsoon or south west monsoon) from June to September, and the post-monsoon season (also known as winter monsoon or North east monsoon) from October to January (Satpathy et al., 2011). Typically, the pre-monsoon season is associated with increased light intensity and warmer temperatures. In addition, 2023 experienced a marine heatwave, which caused a rise in global temperatures (Wernberg et al., 2025). The lowest SST recorded during August can be attributed to strong upwelling in the area. During severe upwelling events, cold, nutrient-rich hypoxic waters ascend to the surface and sometimes extending into the interior of estuaries and rivers (Vinayachandran et al., 2021). Previous studies have reported the thermocline reaching the surface layers in inshore regions, with an eastward temperature gradient observed in the surface layers off Calicut (Mukundan, 1967; Ramamritham & Rao, 1973). Banse (1959) also noted that upwelling off Calicut occurs consistently throughout the SW-monsoon period, with the most pronounced effects felt in July and August, continuing into October. These findings have been corroborated in subsequent studies. An SST of 25 °C was recorded at the Kochi coast in 2016 during upwelling events (Anand, Albert, & Rao, 2019), closely resembling the lowest SST (24.7 °C) observed in this study. They also reported that the upwelling in 2017 was less intense compared to that of 2016, with the former recording an SST of 27 °C. Moreover, surface runoff during heavy rainfall cannot be overlooked as a contributing factor to the lower SST across the region.

The salinity patters observed in this study are also linked to temperature variations. The highest salinity values were found during May, coinciding with rising temperatures, as higher temperatures promote high evaporation, thereby increasing the salinity of surface waters. Likewise, in August, the majority of sampling sites showed a salinity level of around 35 psu, corresponding with significant upwelling in the area. As noted earlier, saline waters from deeper layers were brought to the surface through upwelling driven by Ekman transport (Jayaram & Jose, 2022). In contrast, the reduced salinity observed in September and October can be attributed to increased river runoff in the region. Nonetheless, the instance of elevated salinity observed at St-05 requires further investigation. Thomas et al. (2022) reported a surface salinity of approximately 32.48 psu in September 2017, while Sarangi and Mohammed (2011) observed 35.07 psu in 2002, and Sanilkumar et al. (2009) recorded 34 psu in 2007, highlighting variability in salinity during the monsoon season in this area. This variation in surface waters can be linked to both upwelling and the surface runoff caused by rainfall.

The DO exhibited higher values in June and lower values in October, especially at St-01. The increase in DO during June can be attributed to enhanced surface mixing caused by the onset of the monsoon. As the monsoon progresses, primary production initially increases, followed by enhanced decomposition, resulting in low DO levels (Minu et al., 2020). However, in this study, all stations except St-01 exhibited elevated DO levels in August, suggesting that lower oxygen levels may also be influenced by the anthropogenic activities in the nearby fishing harbour.

Additionally, *Gymnodinium* sp. blooms were reported in August in Thikkodi (according to local news reports), which could have impacted St-01 as well. It is worth noting that St-01 is positioned near the Puthiyappa fishing harbour, which may contribute to various anthropogenic effects. Previous studies have documented extremely low oxygen concentrations, reaching just 0.25 ml L^{-1}, in bottom waters at the end of the monsoon season in adjacent regions (Thomas et al., 2022), and a level of 1.44 ml L^{-1} was observed at Puthiyappa harbour during the *Noctiluca* sp. bloom in September 2003 (Sarangi & Mohammed, 2011). High DO at other stations can be attributed to the high chlorophyll concentration which increased the photosynthetic activity. Total chlorophyll concentration exceeded 20 mg m^{-3}, though not as high as in October, which may have led to reduced microbial activity through decomposition, resulting in higher DO levels.

Phytoplankton growth is facilitated by optimal nutrient concentration and is crucial for primary production to occur. In the SEAS, nutrient concentrations increase during the monsoon season and decline towards the end of monsoon due to reduced runoff as well as biological uptake. Previous studies have also noted reduced nitrite and nitrate levels in November (Madhupratap et al., 1996). During this period, community shift of phytoplankton occurs, from a diatom dominated community during the southwest monsoon season, to dinoflagellates in the post-monsoon season, and finally to blue-green algae in the pre-monsoon (Minu, Shaju, Ashraf, & Meenakumari, 2014). During the southwest monsoon, the nutrient enrichment contributed by terrestrial runoff and upwelling, combined with low light conditions promotes diatom growth. As runoff subsides, nutrient availability decreases and light intensity increases, creating ideal conditions for dinoflagellates (Minu et al., 2014). In the pre-monsoon season, runoff is nearly non-existent, and the available nutrients are already consumed by diatoms and dinoflagellates, leading to nitrogen depletion (although reports of phosphate and silicate depletion in coastal waters are not available), thereby creating an environment suitable for cyanobacteria as nitrogen fixers, which convert atmospheric nitrogen, followed by subsequent reduction steps that result in bio-available nitrogen for phytoplankton. However, recent studies indicate that during the transitional phase between the southwest and northeast monsoons (in October-November), nitrate depletion occurs, with the mixed layer being dominated by mixotrophic phytoplankton (Vijayan et al., 2021). High chlorophyll concentration as evidenced by CMEMS data during September also points to the increased productivity during south west monsoon, which contribute to high nutrient concentration, and low salinity values.

The strong ammonia-nitrite correlation (r=0.505) in St-01 is likely due to strong organic decomposition, possibly from fish waste from the nearby harbor, which raises the risk of hypoxia. This is further supported by the negative correlations of nitrite and ammonia with DO (r = -0.390 and -0.236, respectively). The results also reveal a natural source of silicate, while nitrogen and phosphate are brought by decomposing harbour wastes. The weak correlation between nutrients and chlorophyll further confirms the limited algal growth, likely due to turbidity originating from harbour traffic. In St-02, the strong salinity–chlorophyll negative correlation (r= -0.707), indicates influence of riverine inputs in the area. The positive correlation between nitrite and ammonia (r =0.811) also suggest nutrient loading and subsequent decomposition. The water properties at this station are mainly governed by mixing of freshwater and marine waters, as evidenced by the positive correlation of DO with salinity (r=0.582) and negative correlation of DO with temperature (r= -0.309). The correlation results at St-03, reflects a non-point source of nutrient loading, evidenced by strong nitrite-nitrate correlation (r=0.769) directly influencing the phytoplankton growth, as indicated by phosphate-chlorophyll (r=0.705) and oxygen-chlorophyll (r=0.650) correlations. The inverse relation between salinity and nitrate (r=-0.53); salinity and ammonia (r=-0.39); DO and nitrite (r=0.54) at St-04 indicates combined influence of terrestrial runoff as well as from sediment re-suspension that supports denitrification through anaerobic process facilitating the release of

phosphate and silicate (r=078). The St-05, had strong salinity–chlorophyll (r=0.62) and nitrate-nitrite (r=0.80) correlations as well as DO-phosphate correlation (r=0.72). This indicates that, phytoplankton growth is supported by high salinity and nutrient enrichment. The source of nutrients is likely benthic driven nutrient regeneration as evidenced by the unusual DO-phosphate correlation. This indicates release of phosphate by the decomposition of seaweeds and soft coral communities is prevalent in the area. The overall results indicate that the study area experiences a variety of pressures, influenced by different anthropogenic and natural drivers, creating a mixture of interconnected biogeochemical environment.

The study area is also famous for its laterite rock formations that extends into the sea, harbouring extensive bivalve beds, particularly that of green mussel, *P. viridis* (Appukuttan, Nair, & Thomas, 1989; Laxmilatha 2013; Kumar, 2017). Various factors, such as temperature, salinity, light, and food availability, are recognized as affecting mussel growth. It has been observed from the literature that *P. virdis* exhibit rapid growth during periods of high salinity whereas poor growth was noted when salinity was low. In Calicut, bivalves start natural spawning in July and continue till November. Maximum spawning occurs from August to October (Narasimham, Selvaraj, & Devi, 1984). These results points that lower temperatures, coupled with salinity around 35 psu and standard oxygen concentrations, creates favourable conditions for bivalve spawning and larval growth. The spawning season coincides with enhanced phytoplankton productivity during the south west monsoon season, as bivalves and their larvae rely on phytoplankton for feeding.

Bivalve fisheries rank among the most heavily overexploited fisheries worldwide. In the context of increasing populations and climate change, along with extreme weather events, managing pollution sources and effective mitigation can be a slow process. Effective monitoring can help elucidate how sensitive bivalve beds are to human-induced pressures, which in turn supports policymaking aimed at addressing and alleviating these challenges. There is a lack of recent studies that document the impact of human induced pollution on the growth and physiology of native bivalves. Pollution can also induce stress in other living organisms. As a result, this research highlights a significant gap in knowledge and suggests that upcoming studies should focus specifically on how these human environmental pressures affect bivalves and other organisms in the region.

This study was conducted in the bivalve beds along coastal waters of Calicut to examine the spatio-temporal variations of physico-chemical parameters that support this critical habitat. The results of this research highlight the crucial connection between physico-chemical factors and the sustainability of bivalve fisheries in the coastal areas surrounding Calicut. Temporal changes play a crucial role in affecting key factors like SST, salinity, DO and nutrient concentrations. These variations provide conducive environments for the development and reproduction of *P. viridis*, especially by coinciding peak productivity and spawning periods with the influx of nutrients that takes place during the monsoon and high salinity periods. The analysis confirms a clear and significant environmental signal within the studied period. This study also reveals that even though natural processes sustain ecosystem resilience, enhanced anthropogenic activities results in pollution creating localized hypoxia, and broader impacts of climate variability pose significant risks to the long-term viability of bivalve populations and the overall coastal ecosystem. Therefore, ongoing and systematic long-term environmental monitoring is essential from a scientific perspective focusing on tracking changes in key physico-chemical and ecological parameters and to establish causal mechanisms and interannual trends. Further, a more extensive spatial survey will broaden the understanding of regional trends.

Acknowledgement

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