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RESEARCH ARTICLE OPEN ACCESS

Effect of Physico-chemical Parameters on the Population Diversity of Potentially Harmful Micro-algae during Post-monsoon Season along the Malabar Coast

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Abstract

There are several toxic microalgae species known as Harmful algal bloom (HAB) causing serious effects to the environment and economy. Knowledge on these groups of marine micro-flora is scanty and several areas remain unexplored. The present study focuses on the analysis of microalgal diversity in the Malabar coastal areas at Southwest and Northeast monsoon. The diatoms, dinoflagellates and total microalgal population were analysed and quantified. Predominant species were identified. Physicochemical parameters of the seawater at different time intervals and Correlation between diatoms, dinoflagellates and total microalgae population with physicochemical parameters were identified. From the analysis, a total of 53 diatoms and 15 dinoflagellates were identified. The predominant species including toxic or harmful bloom-forming were found to be *Dinophysis caudata, Noctiluca scintillans, Prorocentrum lima* and *Tripos furca*. The total microalgae population varied from 18,592 cells/L to 7,832 cells/L in the months of April and December. Dinoflagellates were positively correlated with salinity (r = 0.848; p = 0.008), nitrite (r = 0.752; p = 0.032) and total phosphorous (r = 0.734, p = 0.038). Diatoms were positively correlated with temperature (r = 0.804; p = 0.016) and nitrate (r = 0.774, p = 0.024). Total microalgal density was positively correlated with temperature (r = 0.825; p = 0.012) and nitrate content (r = 0.811, p = 0.15).

Keywords: Harmful algal blooms, Malabar Coast, Marine microalgae, Physicochemical properties, Correlation analysis

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INTRODUCTION

Life in the sea consists of three major groups of organisms namely plankton, nekton and benthos, and among these, the plankton is of fundamental importance to fisheries and the environment.[1] Microalgae, the predominant primary producers are restricted to the neritic zone due to the abundance of nutrients, light and favourable physicochemical variables like temperature, pH and salinity.[2,3]

Microalgae constitute 40-50% primary production that occurs by all the algal photosynthesis[4] and the secondary production and tertiary production depend on it. It is estimated that the total annual primary production of the world seas is around $2x10^9$ tons of carbon which could yield 240 million tonnes of sea fisheries products. They are also responsible for the production of 80% of the oxygen that we breathe.[5,6] The microalgae are of great importance to the globe and the food for filter feeding organisms from bivalves to whales.[7] The most important classes of phytoplankton are: Bacillariophyta or Diatoms, Dinophyta or Dinoflagellates, Chlorophyta or Green algae, Cyanobacteria or Blue green algae, Euglenophyta, Chrysophyta and Haptophyta and Xanthophyceae.[8]

Under favourable conditions, certain microalgal species produce excessive growths in a particular area called bloom.[9] Traditionally, the biomass was the criterion most often used to define the bloom. In certain cases, the average cell surface area (µm2) of the microalgae species could serve as the best measure of phytoplankton biomass. There are about 300 phytoplankton species forming blooms and these blooms have both beneficial and harmful activities in marine environment.[7,10-12]

Harmful Algal Blooms can have wide socio-economic and health impacts. Every year, they cause billions of dollars loss through damaging fishes and sea products.[7,13,14] Heavy blooms hinder fishing operations and their weight at times damages the fishing net. Countries all over the world spend millions of dollars to predict and control them. Many environmental factors like light intensity, temperature, salinity, pH and oxygen concentration affect these microalgal populations.[14] Also, both micronutrients and macronutrients play an important role. Harmful Algal Blooms and shellfish poisoning have caused human fatalities and related discomforts across the world and along the Indian coast.[15-18]

Although elaborate studies have been made on marine phytoplankton in many countries of the world, knowledge of these groups of marine microflora is scanty in India. At the same time our country suffers much from the harmful effects of these blooms throughout year. The present study investigates the microalgae and toxic bloom diversity on the Malabar coastal areas at different monsoons (Southwest and Northeast) from October to May 2016. Physicochemical properties and its correlation with total microalgae population were determined.

MATERIALS AND METHODS

Collection of samples

Samples were collected from the Malabar Coastal region between Latitude 11° 43' N and Longitude 75° 33' East in the South West Coast in the Arabian Sea after the South West monsoon in 2016 till the onset of the next South West monsoon in 2017. The sampling was done for a continuous period of eight months at an interval of one month. The samples included for physicochemical analysis

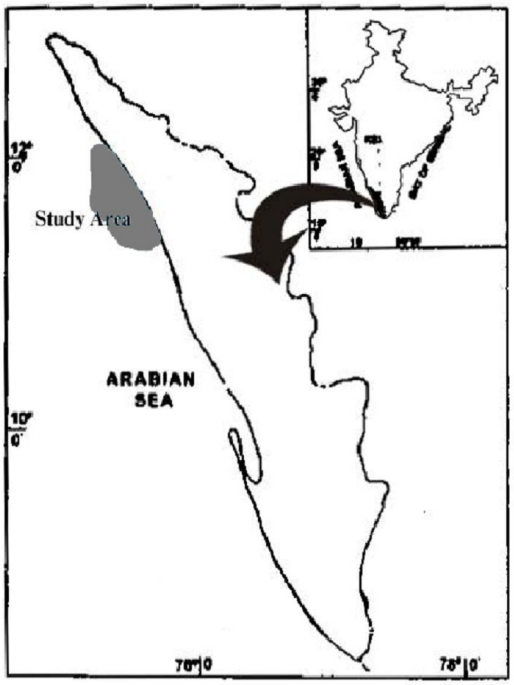

Fig. 1. Geographical location of the study area.

and the microalgae analysis for algal bloom study. Fig. 1 shows the location of the study area.

Sampling for microalgae analysis

Both the qualitative and quantitative analysis of microalgae was performed. The details about the sampling are as follows:

Qualitative microalgae analysis

The phytoplankton were collected for the qualitative analysis from the site of sampling using a standard phytoplankton collection net with a mesh size of 20 µm, a mouth diameter of 50 cm and a length of 1 m. The nets are conical with hoop at the wide end and a bottle attached to the narrow end for the collection of microalgae. The ratio of the net length to the net mouth diameter was between 3:1 and 5:1. The net was hauled horizontally from a boat for 15 minutes at a speed of 15 nautical miles per hour. The sample was transferred to a previously marked plastic bottle and live analysis was made immediately at the laboratory using an inverted microscope.

Identification of the microalgae

Net collected microalgae were observed under an inverted microscope using 4X, 10X, 20X and 40X lenses, and identified to species level wherever possible. The identification was based on the morphological characteristics with the help of keys by Tomas,[19] Santhanam et al.[20] and Subramanyan,[21]

Live Sample Analysis

Immediately after the collection, the live sample was analysed for the identification of toxic microalgal species. The organisms of interest were isolated using Pasteur pipette and serially transferred to cavity slides containing sterile sea water for pure isolates for culturing.

Culturing of isolates

The marine microalgae samples were cultivated using F/2 medium,[22] providing an artificial light source with a light: dark cycle interval of 12:12 at 20°C for a week period.

Preservation of the sample

Samples for qualitative and quantitative analysis were fixed using 10% formalin (equivalent to 4% commercial formaldehyde) with hexamethylene diamin (Hexamin) for further analysis.

Quantitative microalgae analysis

The sampling for quantitative microalgae analysis was done by filtering 100 litres of sea

Table 1. Diatom species identified during the study

No.	Name of the Diatom Species
1	*Paralia sulcata* (Ehrenberg) Kutzing
2	*Stephanopyxis turris* (Grev. et.al) Ralfs
3	*Stephanopyxis palmeriana* (Greville) Grunow
4	*Skeletonema costatum* (Greville) Cleve
5	*Thalassiosira.subtilis* (Ostenfeld)(Gran)
6	*Cyclotella meneghiniana* Kutzing
7	*Cyclotella striata* (Kutzing) Grunow
8	*Thalassiosira eccentrica* Ehrenberg
9	*Coscinodiscus gigas* Ehrenberg
10	*Planktoniella* sol (Wallich) schutt
11	*Actinoptychus undulatus* (Bailey) Ralfs
12	*Asterompalus flabellatus* (Brebisson) Greville
13	*Auliscus sculptus* (W. Smith) Ralls
14	*Corethron hystrix* Hensen
15	*Leptocylindrus minimus* Gran
16	*Detonula delicatula* (Peragallo) Pavillard
17	*Lauderia minimus* Gran
19	*Rhizosolenia cylindrus* Cleve
20	*Rhizosolenia.stolterfothii* H.Peragallo
21	*Rhizosolenia robusta* Norman
22	*Rhizosoleni imbricata* Brighhtwell
23	*Rhizosolenia styliformis* Brightwell
24	*Leptocylindrus danicus*
25	*Bacteriastrum hyalinum* Lauder
26	*Bacteriastrum varians* Lauder
27	*Chaetoceros peruvianus* Brightwell
28	*Chaetoceros lorenzianus* Grunow
29	*Chaetoceros didymus* Ehrenberg
30	*Eucampia zoodiacus* Ehrenberg
31	*Eucampia cornuta* (cleve) Grunow
32	*Bellerochea malleus* (Brightwell) Van Heurck
33	*Ditylum brighwellii* (West) Grunow
34	*Ditylum* sol Grunow
35	*Triceratium favus* Ehrenberg
36	*Triceratium.roberisianum* Greville
27	*Triceratium reticulatum* Ehrenberg
28	*Odontella sinensis* Greville
39	*Odontella mobiliensis* Bailey
40	*Biddulphia heteroceros* Grunow
41	*Hemiaulus sinensis* Greville
42	*Hemidiscus hardmannianus* (Greville) Mann
43	*Rhabdonema mirificum* W.Smith
44	*Grammatophora undulata* Ehrenberg
45	*Climacosphenia moniligera* Ehrenberg
46	*Climacosphenia elongata* Bailey
47	*Rhaphoneis amphiceros* Ehrenberg
48	*Rhaphoneis discoides* Subramanyan
49	*Thalassionema nitzschioides* Grunow
50	*Thalassiothrix longissima* Cleve and Grunow
51	*Thalassionema frauenfildii* Grunow
52	*Cocconeis littoralis* Subrahmanyan
53	*Achnanthes stromii* Hustedt

Table 2. Dinoflagellate species identified during the study

No.	Name of the Dinoflagellate Species
1	*Prorocentrum micans* Ehrenberg
2	*Prorocentrum lima* Stein
3	*Prorocentrum maximum* Schiller
4	*Exuviaella* Cienkowski
5	*Prorocentrum compressum* Barley and Ostenfeld
6	*Gonyaulax spinifera*
7	*Tripos cephalotus* (Lemmermann)
8	*Tripos furca* (Ehrenberg) Claparede and Lachmann
9	*Oxytoxum turbo* Kofoid
10	*Dinophysis caudate*
11	*Noctiluca scintillans*
12	*Guinardia flaccida*
13	*Protoperidinium* species
14	*Gymnodinium* species
15	*Cochlodinium* species
16	*Protoperidinium* species
17	*Pyrocystis* species
18	*Oxytoxum* species

surface water through the standard plankton net. The filtrate collected in the collecting bucket was taken for counting of both living and preserved the cells using a Sedgwick Rafter Cell.[23]

Sampling for physicochemical parameter analysis

For the analysis of different physicochemical parameters, the samples were collected from the study site, 2 km away from the shore. The samples were analysed immediately for physicochemical parameters. The parameters such as temperature, salinity and pH were analysed at the site itself using a multi-parameter portable meter (Orion Star, USA) and the oxygen content analysed in the laboratory immediately after sampling. The chemical parameters (Nitrite, Inorganic Phosphate, Reactive Silicate, Nitrate, Total Nitrogen and Total phosphorus) were analysed in the laboratory immediately.

Statistical analysis

Statistical analysis was performed using SPSS software version 25.0. Pearson correlation was carried out to see the correlation of physicochemical parameters with total microalgae count. All tests are double-tailed and P-value of less than 0.05 was considered statistically significant.

RESULTS AND DISCUSSION

Microalgae species diversity analysis

A total of 53 diatom species were collected and identified during the study period belonging to different families like *Coscinodiscaceae, Actinodiscaceae, Eupodiscaceae, Rhizosoleniaceae, Chaetoceraceae, Biddulphiaceae, Euodieae, Hemiauliniae, Fragilarioidaceae, Achnanthoidaceae* and *Naviculoidaceae* (Table 1). A total of 15 different genera of dinoflagellates were also identified (Table 2). The maximum number of dinoflagellate cells was recorded in the month of May (3,356 cells/litre) and the minimum number of cells in the month of December (634 cells/l). The maximum number of diatom cells was recorded in the month of April (16,304 cells/L) and the minimum in the month of December (7,198 cells/L). At the month of April, the total microalgal count was found to be higher (18591 cells/L) than other months (Table 3; Fig. 2).

Identification of toxic species

The population of the predominant toxic species was shown in the Fig. 3. Counts of *Tripos furca* ranged between 56cells/L to 269 cells/L, *Prorocentrum lima* between 64 cells/L to 230 cells/L, *Noctiluca scintillans* between 64 cells/L to 308 cells/L and *Dinophysis caudata* between 82 to 368. The total toxic microalgae species were found to be higher on April (1171 cells/L) and lower on December (288 cells/L).

Physical parameters

Physical parameters like temperature, salinity and pH were observed on the study area during October to May and are presented in Table 4. The temperature was found to be higher (29.1°C) during the month of March and lower (26.1°C) in the month of December. The pH showed an early morning (9-10 am) maximum of 8. 00 during November and a minimum of 7.44 in February. The salinity ranged between 33.3 ppt during May and 29.9 ppt in the month of December.

Chemical parameters

Chemical parameters such as levels of oxygen, nitrite, nitrate, total nitrogen, inorganic phosphate, and reactive silicate were analysed (Table 5). The oxygen content showed a maximum (6.30 mg/L) during the month of November and minimum (3.41 mg/L) in the months October and January. The inorganic phosphate ranged between

1.9821 µ-mol/L and 0.991 µ-mol/L at December and February. Higher levels of reactive silicate (5.8122 µ mol/L) were observed during March and lower levels (3.121 µ-mol/L) in February. The nitrate showed a maximum (4.4212 µ-mol/L) during the month of October and minimum (2.0020 µ-mol/L) in the month of December. The total nitrogen level was higher (20.42 µ-mol/L) in October and lower (6.28 µ-mol/L) in January. The total phosphorus showed a maximum (5.1293 µ-mol/L) during the month of May and minimum (3.41 µ-mol/L) in the month May.

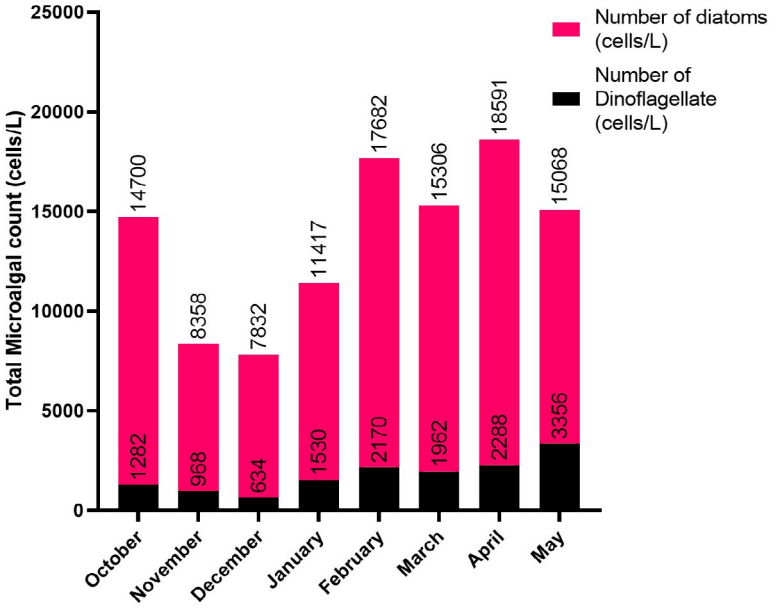

Fig. 2. Total diatoms and dinoflagellate cells observed in the study.

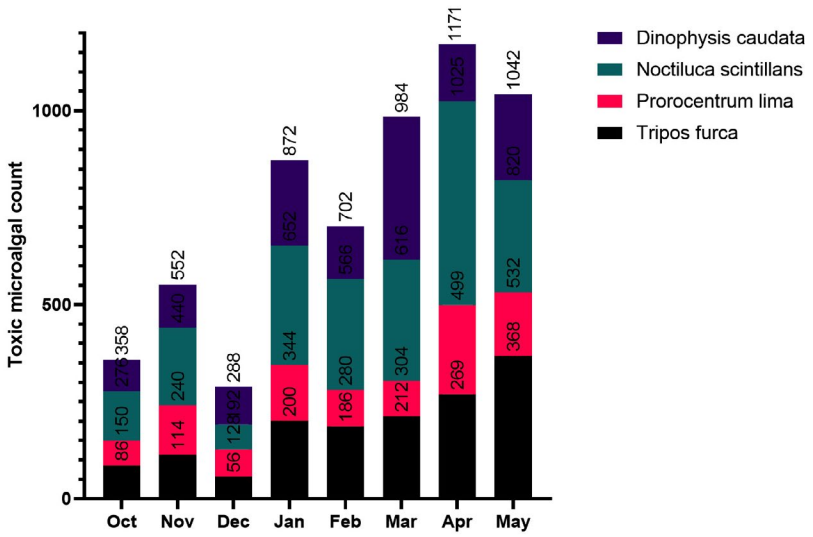

Fig. 3. Variation in population of the predominant dinoflagellate species.

Correlation of total microalgae count with physicochemical properties

Correlation analysis between microalgal counts and physical parameters are presented in Table 6. Dinoflagellates showed a positive correlation with salinity (r = 0.848; p = 0.008), Diatoms showed positive correlation with temperature (r = 0.804; p = 0.016) and total microalgal densities were positively correlated with temperature (r = 0.825; p = 0.012). Scatterplot matrices showing correlation with physical parameters are shown in Fig. 4. Correlation analysis of microalgae count with oxygen, nitrite, nitrate, reactive silicate, total nitrogen and total phosphorus are presented in Table 7 and shown in Fig. 5. Dinoflagellates showed a positive correlation with nitrite (r = 0.752; p = 0.032) and total phosphorus (r = 0.734, p = 0.038). Diatoms showed a positive correlation with nitrate (r = 0.774, p = 0.024) and total microalgae population densities were positively correlated with nitrate concentration (r = 0.811, p = 0.15).

Harmful Algal Bloom (HAB) is found to be natural phenomena that have appeared

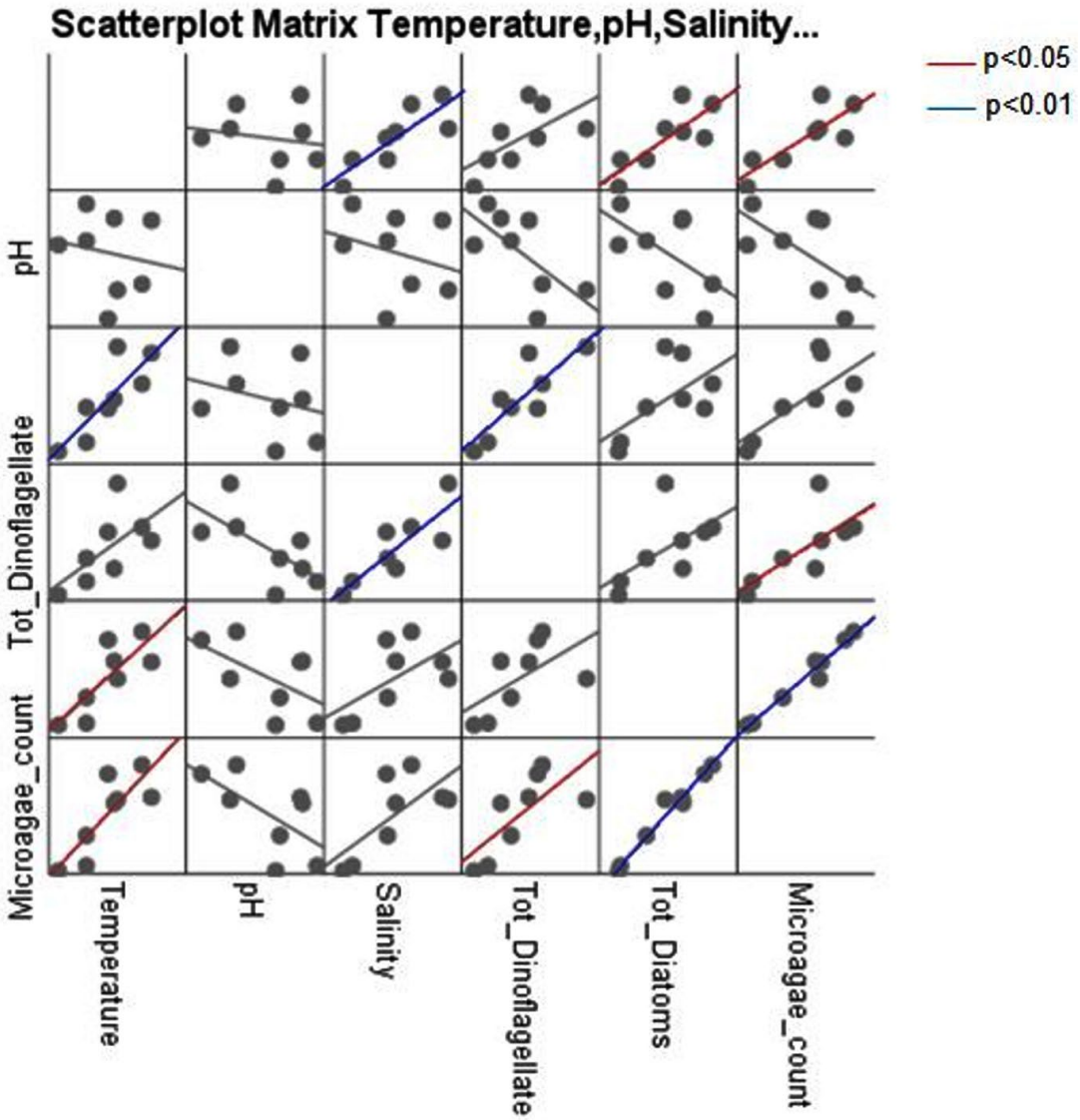

Fig. 4. Scatter plot between microalgal count and physical parameters of seawater.

throughout history. Due to factors like pollution with nutrients and climate change,[24] the HAB events have been drastically increased in intensity, frequency, and geographic distribution, resulting in severe public health and economic impact. Recurrent global occurrence of HAB has greater impacts on fishery sources and the marine environments. The present study focuses on determining the microalgal diversity and blooms during Southwest and Northeast monsoon at Malabar Coast, Kerala, India. The Malabar Coast has two monsoons – South West during May/ June to September and North East – November/ December with a hot dry weather in between. A strong upwelling is regularly observed here during the summer.[25] There are about half a million people involved with fisheries and the sea food industry directly and indirectly in the area. The annual fish harvest in the area has been estimated as 900 tones. There are more than 2000 coastal families directly depend on marine mussel culture which depends upon phytoplankton giving 1900 tons of farmed bivalves per annum.[26]

A broad account of the occurrence, intensity, frequency, and geographical coverage of HAB in the exclusive economic zone (EEZ) of India were investigated by Padmakumar, Menon and Sanjeevan.[27] Potential toxic microalgae documented from the Indian waters were found to be *Dinophysis caudata, Prorocentrum lima, Coolia*

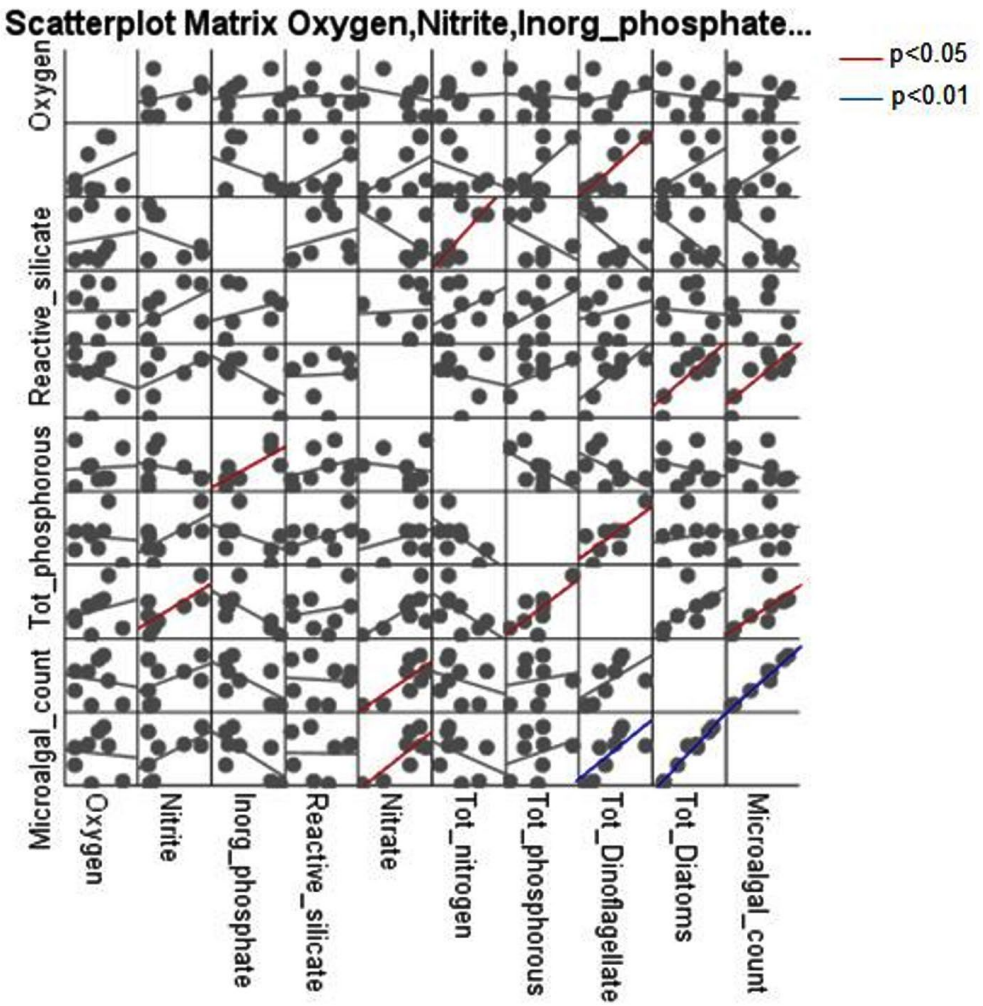

Fig. 5. Scatter plot between microalgal count and chemical parameters of seawater.

Table 3. Microalgal population densities at different months

Month	Number of Dinoflagellate cells/L	Number of Diatom cells/L	Total Number of Microalgal cells/L
October	1282	13418	14700
November	968	7390	8358
December	634	7198	7832
January	1530	9887	11418
February	2170	15512	17682
March	1962	13344	15306
April	2288	16303	18592
May	3356	11712	15068

Table 4. Physical parameters of the seawater

Month	Salinity (ppt)	pH	Temp. (°C)
October	31.6	7.93	27.9
November	30.2	8.00	27.0
December	29.9	7.8	26.1
January	31.33	7.82	27.0
February	31.3	7.44	27.7
March	33.1	7.92	29.1
April	32.1	7.61	28.8
May	33.3	7.58	28

monotis, Tripos furca spp. and *Gymnodinium* spp. These species were the bloom forming organisms identified from the Indian waters. The bloom occurring dinoflagellate *Noctiluca scintillans* was the predominant and recurrently occurring species in the South Eastern Arabian Sea (SEAS) during the summer monsoon and green *Noctiluca scintillans* in the North Eastern Arabian Sea (NEAS) during the winter cooling. These observations correspond with the results of the present study.

Physicochemical properties of the seawater samples were analysed during two different monsoons. Physical properties analysed were salinity, pH and temperature and the chemical properties were oxygen, nitrite, nitrate, and total nitrogen, and inorganic phosphate, total phosphorus and reactive silicate. All the physicochemical parameters varied in different months. Pearson correlation coefficients were evaluated to identify the correlation of diatoms, dinoflagellates and total microalgal count with physicochemical properties. P-values < 0.05 were considered to be significant. Among then physical parameters, dinoflagellates showed a positive correlation with salinity, diatoms showed positive correlation with temperature and total microalgal population were positively correlated with temperature. Chemical parameters analysis showed for dinoflagellates a positive correlation with nitrite and total phosphorous. Diatoms showed positive correlation with nitrate and total microalgae population was positively correlated with nitrate content.

Table 5. Chemical parameters of the seawater samples

Month	O_2 Content (mg/l)	Nitrite (µ mol/l)	Nitrate (µ mol/l) (µ mol/l)	Total Nitrogen (µ mol/l)	Inorganic Phosphate (µ mol/l)	Total Phosphorus (µ mol/l)	Reactive Silicate (µ mol/l)
October	3.41	0.3012	4.4212	20.42	1.8121	3.8121	5.0923
November	6.30	0.24138	2.8021	18.11	1.8121	3.41	4.1283
December	4.4	0.1939	2.0020	12.8138	1.9821	4.1816	4.8127
January	3.41	0.181	3.81	6.28	0.991	4.31	3.212
February	4.82	0.181	3.8121	8.531	0.991	3.856	3.121
March	4.21	0.6123	3.68621	12.31	1.0381	4.3313	5.8122
April	5.15	0.8311	4.1891	8.978	1.1180	4.3212	4.004
May	5.44	0.8190	4.2231	8.8702	1.2400	5.1293	5.7180

Table 6. Correlation of algal count with physical parameters

		Correlations					
		Temp.	pH	Salinity	Tot_ Dinoflagellate	Tot_ Diatoms	Microalgal_ count
Temperature	Pearson Correlation	1	-.171	.836**	.630	.804*	.825*
	Sig. (2-tailed)		.685	.010	.094	.016	.012
	N	8	8	8	8	8	8
pH	Pearson Correlation	-.171	1	-.275	-.665	-.561	-.624
	Sig. (2-tailed)	.685		.509	.072	.148	.098
	N	8	8	8	8	8	8
Salinity	Pearson Correlation	.836**	-.275	1	.848**	.605	.701
	Sig. (2-tailed)	.010	.509		.008	.112	.053
	N	8	8	8	8	8	8
Tot_ Dinoflagellate	Pearson Correlation	.630	-.665	.848**	1	.595	.725*
	Sig. (2-tailed)	.094	.072	.008		.119	.042
	N	8	8	8	8	8	8
Tot_Diatoms	Pearson Correlation	.804*	-.561	.605	.595	1	.985**
	Sig. (2-tailed)	.016	.148	.112	.119		.000
	N	8	8	8	8	8	8
Microalgal_ count	Pearson Correlation	.825*	-.624	.701	.725*	.985**	1
	Sig. (2-tailed)	.012	.098	.053	.042	.000	
	N	8	8	8	8	8	8

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Similarly, a zero dimensional numerical model was used by Zhou, Yu and Zhou,[28] to verify the progression of microalgal blooms based on the coastal waters adjoining the Changjiang River estuary. The model showed a significant dynamic of the diatoms and dinoflagellate blooms. Analysis was carried out under different scenarios to analyse the effect of temperature, light intensity and nutrient source on the occurrence of microalgal blooms. The results indicate that temperature and light have gradual effects on their occurrence. Phosphorus stress is the most critical parameter controlling the occurrence of the microalgae blooms and nitrate plays a vital role in affecting the ratio of dinoflagellate blooms. The functions of various environmental factors like temperature, light and nutrients were evaluated under different scenario. It was observed that phosphate is the most critical parameter for the decline of diatom blooms and the occurrence of dinoflagellate bloom. Reactive silicate is still higher in seawaters and not a major factor determining the growth of the local diatom blooms.[29]

CONCLUSION

This is the first study on microalgal diversity on the Malabar coast and determined the correlation between physicochemical parameters and microalgal counts. Samples were collected from October to December (southwest and northeast monsoon). Total diatoms, dinoflagellates and microalgal population were identified.

Prevalence of predominant toxic species *Dinophysis caudata, Noctiluca scintillans, Prorocentrum lima* and *Tripos furca* on different months were estimated. Microalgal count was found to be higher on April and lower on December. Physicochemical parameters

Table 7. Correlation of microalgal counts with chemical parameters

		Correlations									
		Oxygen	Nitrite	Inorg_ phosphate	Reactive_ silicate	Nitrate	Tot_ nitrogen	Tot_ phosphorous	Tot_ Dinoflagellate	Tot_ Diatoms	Microalgal_ count
Oxygen	Pearson Correlation	1	.300	.119	.010	-.247	.053	-.079	.226	-.151	-.081
	Sig. (2-tailed)		.470	.778	.981	.556	.902	.853	.591	.722	.849
	N	8	8	8	8	8	8	8	8	8	8
Nitrite	Pearson Correlation	.300	1	-.364	.524	.494	-.252	.682	.752*	.479	.572
	Sig. (2-tailed)	.470		.376	.182	.213	.548	.063	.032	.230	.139
	N	8	8	8	8	8	8	8	8	8	8
Inorg_phosphate	Pearson Correlation	.119	-.364	1	.270	-.574	.783*	-.427	-.678	-.626	-.682
	Sig. (2-tailed)	.778	.376		.517	.137	.022	.291	.064	.097	.062
	N	8	8	8	8	8	8	8	8	8	8
Reactive_silicate	Pearson Correlation	.010	.524	.270	1	.051	.365	.442	.213	-.072	-.016
	Sig. (2-tailed)	.981	.182	.517		.905	.374	.273	.613	.866	.970
	N	8	8	8	8	8	8	8	8	8	8
Nitrate	Pearson Correlation	-.247	.494	-.574	.051	1	-.172	.330	.687	.774*	.811*
	Sig. (2-tailed)	.556	.213	.137	.905		.683	.425	.060	.024	.015
	N	8	8	8	8	8	8	8	8	8	8
Tot_nitrogen	Pearson Correlation	.053	-.252	.783*	.365	-.172	1	-.612	-.547	-.266	-.345
	Sig. (2-tailed)	.902	.548	.022	.374	.683		.107	.160	.525	.402
	N	8	8	8	8	8	8	8	8	8	8
Tot_phosphorous	Pearson Correlation	-.079	.682	-.427	.442	.330	-.612	1	.734*	.174	.307
	Sig. (2-tailed)	.853	.063	.291	.273	.425	.107		.038	.680	.460
	N	8	8	8	8	8	8	8	8	8	8
Tot_Dinoflagellate	Pearson Correlation	.226	.752*	-.678	.213	.687	-.547	.734*	1	.595	.725*
	Sig. (2-tailed)	.591	.032	.064	.613	.060	.160	.038		.119	.042
	N	8	8	8	8	8	8	8	8	8	8
Tot_Diatoms	Pearson Correlation	-.151	.479	-.626	-.072	.774*	-.266	.174	.595	1	.985**
	Sig. (2-tailed)	.722	.230	.097	.866	.024	.525	.680	.119		.000
	N	8	8	8	8	8	8	8	8	8	8
Microalgal_count	Pearson Correlation	-.081	.572	-.682	-.016	.811*	-.345	.307	.725*	.985**	1
	Sig. (2-tailed)	.849	.139	.062	.970	.015	.402	.460	.042	.000	
	N	8	8	8	8	8	8	8	8	8	8

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

of the seawater samples were evaluated and their correlation with microalgae count was determined. Positive correlation was observed for temperature and nitrate content. This study brings better understanding of microalgal diversity and correlation of physicochemical properties on Malabar coastal areas.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

Not applicable.

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