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RESEARCH PAPER

Assessment of Environmental Parameters in Pre- and Post-Monsoons at Chabahar Bay, Gulf of Oman

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ABSTRACT: This study is the first investigation to assess the variations of physical and chemical characteristics and biodiversity of planktons in offshore water column and chlorophyll-a and b, during the two monsoons at Chabahar Bay, to evaluate the water quality. To this end, 27 surface water samples in pre-monsoon (May, 2012) and totally 60 surface and deep water samples in post-monsoon (December, 2012) were collected from 9 and 10 stations at depths between 3.8 to 13.6 m in Chabahar Bay, respectively. The results showed that water salinity and pH with low variations were relatively higher in post-monsoon. The average of water alkalinity levels in pre- (2.42±0.02 mmol H^+/kg) and post- (2.44±0.01 mmol/kg) monsoons were comparable to that of oceanic surface water (2-2.5 mmol H^+/kg). In this study, 66 phytoplankton genus and species belonging to 13 groups were identified in pre-monsoon. Results demonstrated that nutrients were at higher levels inside the Chabahar Bay. Moreover, the physicochemical parameters of water samples were investigated and compared with international standards and data from other marine ecosystems. The results indicated that the water quality falls within the stipulated range of acceptability and sampling area can be classified as a good, stable, and healthy aquatic ecosystem.

Keywords: Chabahar Bay, Gulf of Oman, Nutrients, Phytoplankton, Water Quality.

1. Introduction

It is well known that seawater resources are under threat by human activities (Salvi et al., 2014). Water quality in marine environment plays a very important role in human wellbeing, and has a prominent impact on metabolic pathways in marine organisms (Mearns et al., 2013). Therefore, minor variations in some parameters such as pH and nutrients might play key roles in growth and health of biota. Marine phytoplankton communities which contribute to primary productivity are largely dependent on nutrient availability, light penetration and quality of water column in coastal areas (Basu et al., 2018). Among various nutrients, nitrogen, phosphorous and silicon are considered to be more important than the others, due to being crucial for phytoplankton abundance, growth and metabolism (Shanthi et al., 2014). The Gulf of Oman is influenced by

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upwelling events that bring a great amount of nutrients into the upper ocean, hence enhancing primary productivity and ultimately the fisheries.

Physicochemical characteristics are indeed vital water quality parameters for monitoring due to their instability (Efe et al., 2005), since significant variations in physicochemical parameters affect the quality of water resources. Therefore, it would be impotent to monitor water quality of all marine sources.

In this study, total alkalinity of seawater, which is one of the required parameters to evaluate the carbonate chemistry of seawater, was investigated. The water quality of Chabahar Bay on the Makran coastline in Sistan and Baluchestan Province, Southeast of Iran, was studied. Chabahar Bay is a free port, industrial zone and an important shipping route for the oil-producing countries in Persian Gulf.

Little studies have focused on physicochemical data in Chabahar Bay, and hence it seems required to continue and perform further investigations to protect this valuable ecosystem. The main objectives of the present study were: 1) To determine water quality parameters (physicochemical characteristics, nutrients, alkalinity and chlorophylls) from the Chabahr Bay, Oman Sea; 2) To investigate the abundance and biodiversity of planktons in water column; 3) To discover the relationships between the abundance of phytoplankton and water physicochemical parameters and, 4) To compare the results from different studied stations with each other and with data from other marine ecosystems.

2. Materials and Methods

In recent years, Chabahar Bay has become more important, due to the increase in human population, urbanization and accelerated developmental activities. The special importance of Chabahar Bay is its Ω shape and the limited water circulation. The study area has humid climate, hot summers and moderate winters with maximum and average depths of 22 and 12 meter, respectively. Fishing and marine commerce are the main activities in the study area (Fazel, 2008).

We utilized glass/ reference electrode (Hach, IntelliCAL PHC 101), calibrated by NBS buffers (accuracy of +0.02, precision of +0.001) to measure surface water temperature and pH. Salinity was determined using a conductivity probe (Hach, IntelliCAL CDC401 with the precision of +0.1), calibrated by a certified seawater. Dissolved oxygen was measured using a calibrated dissolved oxygen optical sensor (HACH, IntelliCAL LDO101 luminescent/optical dissolved oxygen probe). In addition, CTD was used to obtain the physicochemical parameters of surface and deep water (temperature, salinity) at pre- and post-monsoons. Geographical characteristics of sampling locations were recorded by GPS (Geographic Positioning System). All sensors of the CTD were calibrated according to the guidelines of the related manufacturers, based on 1 sec. per data. In each station, CTD was sank 1 m/min to prepare water profile parameters (temperature, pH, turbidity, salinity, and dissolved oxygen). All data of the CTD was controlled and initially processed in excel to detect outliers. The clarity of water samples was measured using Secchi disc.

In order to detect the concentrations of different nutrients (nitrite, nitrate, phosphate and silicate), water organic carbon, alkalinity, phytoplankton species and chlorophyll-a and b, surface water samples were collected in pre- and post-monsoons from geographical situations located at 25º 15’ 33’’ to 25º 26’ 3’’ of latitudey, and 60º 15’ 21’’ to 60º 45’ 18’’ of longitude, in Chabahar Bay (Table 1). The sampling locations were: 1) Tiss; 2) Konarak; 3) Desalination plant; 4) Entrance of Chabahar Bay; 5) Posm and; 6) Ramin (Figure 1). The selected sampling sites represented the most important harbors, desalination plants, and industrial regions in the area.

Totally 27 surface water samples in pre-monsoon (May, 2012), 30 surface and 30 deep water samples in post-monsoon (December, 2012) were collected from 9 and 10 stations at depths between 3.8 to 13.6 m in Chabahar Bay, respectively (Figure 1). Jellyfish bloom at deeper parts of Ramin station in pre-monsoon limited the sampling and measurements of the physicochemical parameters at this station.

Triplicate surface water samples (collected from a depth of 1 m) in pre-monsoon as well as the surface and bottom water samples in post-monsoon were collected using Niskin bottle (2 L).

In order to determine the concentrations of the nutrients, an aliquot of each water sample (100 mL) was filtered using 0.45-µ cellulose acetate filter, collected in labeled polyethylene bottles, carried to the laboratory on ice, and analyzed during 24 h. Nitrite was detected based on pink diazo dye formation and its colorimetry. Nitrate was measured after its reduction to nitrite using cadmium powder. Phosphate was detected based on colorimetric determination by phosphomolybdate. Dissolved nutrients such as nitrate, nitrite, phosphate and silicate contents were measured using HACH spectrophotometer (Ray Light UV 9200, MOOPAM, and ROPME, 1999).

Water samples for determination of total alkalinity were collected in 500-mL glass bottles, and 100 µL of a saturated mercury (II) chloride ($HgCl_2$) solution was subsequently added to stop the biological activities (Dickson et al., 2007). Samples were stored at 4 °C until laboratory analysis. Total alkalinity was determined by potentiometric open-cell titration (Dickson et al., 2007, SOP03b) using a digital 715 Dosimat titrator (Hydro-bios). For pH measurements, a Sartorius pH meter (with precision of ± 0.01) was used.

Total organic carbon in water samples was analyzed using TOC Analyzer (SGE, ANATOC Seri II Australia; Agah et al., 2014). Detection limit of TOC analyzer was 50 ppb. The concentrations of TOC in all samples were higher than detection limit. The recovery of methodology was 97±2%.

In order to determine the concentrations of chlorophylls, one liter of post-monsoon surface and bottom water samples were filtered through 47 mm glass fiber filters. According to the Standard Method (10200 H), chlorophyll-a and b were extracted and measured by HPLC using UV (absorption wavelength of 440 nm) and fluorescence (excitation and emission wavelengths of 430 and 600 nm) detectors, respectively.

Surface (n = 27 and 30) and sea bottom water samples (n = 30, ~1 m depth from bed) in pre- and post-monsoon sampling periods were transferred to dark bottles, preserved in Lugol's iodine, followed by storage. Identification of phytoplanktons and their abundance was performed using an inverted microscope (Axiostar S100, Ziess) with 40X objectives (Sedgwick-Rafter Method) and various taxonomic keys (Al-Kandari et al., 2009; Xiang et al., 2019; ROPME, 2012, Karlson, 2010; AlgaeBase).

Results were reported as the average of triplicate analyses and their corresponding standard deviations. Statistical analysis was performed using SPSS (version 2017) software. The Pearson correlation matrix was carried out using SPSS statistical software (Version 16.0 for Windows). A Kolmogorov-Smirnov test was performed to evaluate the normality of data distribution. In addition, one-way ANOVA was used to assess significant differences between the mean levels of the elements at different sampling stations. A P-value equal or lower than 5% indicated that significant relationship between the corresponding variables exists.

The Mann-Whitney analysis was used to evaluate the significant differences in phytoplankton density at the studied stations using SPSS statistics, version 21 software.

3. Results and Discussion

Water quality of Chabahar Bay, the main Iranian omega shape gulf in the Makran zone, Gulf of Oman with high transport and trade potential, has been affected by several factors in last decades, as a result of anthropogenic activities (Burt et al., 2016; Agah, 2018). Hence, studying the water physicochemical characteristics of the gulf can guide us to protect this ecosystem during its developing programs.

Temperature (or its changes) as a basic property of water is important in regulation of many physiological processes in marine organisms and is therefore one of the most important water quality attributes in aquaculture (IEPA, 2001); it controls water metabolism and specifies the habitat area for aquatic life (Ding and Elmore, 2015).

Owing to the high level of natural variability in pH, salinity and DO in coastal marine waters both temporally and geographically, it is not possible to provide fixed guideline values for temperature. The temperature values of the surface water (Figure 2) at all stations were comparable throughout the study period, varying from 26 (Posm) to 28.6 (Tiss) ºC and from 24.3 (Konarak) to 26.4 (Ramin) ºC in pre- and post-monsoons, with average of 26.6 and 25.5 ºC, respectively.

Variation of surface water temperature in pre- and post-monsoons inside Chabahar Bay were relatively higher than that of other stations, which could be related to less water exchange from inside the semi-closed bay. Average of deep layer water temperature was 25.1 °C in post-monsoon. According to NOAA Coral Reef Watch (2019), the annual minimum and maximum sea surface temperature variation in Chabahar Bay at 2017 was belonged to February (22.8 ˚C) and June (30.3 ˚C) with average value of 27.5 ˚C. Results revealed that sea surface temperature in all the studied stations was within the range of the area.

Salinity, pH and temperature of the surface water were uniform at all the stations and exhibited only a narrow variation. The range and average values of pH and salinity of surface water in pre-monsoon were 8.03 (Posm)-8.15 (Desalination plant) (8.12±0.04) and 36 (Posm)-37.3 (Tiss) (36.6±0.37) ‰, and in post-monsoon were 8.13 (Posm)-8.21 (Ramin) (8.18±0.04) and 36.3 (Ramin)-37 (Posm) (36.7±0.36) ‰ (Table 2).

Table 1. Sampling geographical locations in the Chabahar Bay (May and December 2012)

Seasons		Stations	Depth (m)	Geographical locations
Post-monsoon December, 2012	Pre-monsoon May, 2012	Posm 1	6.0	25º22’54’’ N 60º15’21’’ E
		Posm 2	12.10	25º19’58’’ N 60º15’44’’ E
		Konarak 1	5.0	25º19’58’’ N 60º15’44’’ E
		Konarak 2	10.5	25º22’23’’ N 60º28’30’’ E
		Desalination plant	5.8	25º26’3’’ N 60º30’14’’ E
		Tiss 1	3.8	25º21’46’’ N 60º35’40’’ E
		Tiss 2	9.0	25º22’50’’ N 60º33’59’’ E
		Entrance of the Chabahar Bay	13.6	25º17’44’’ N 60º32’12’’ E
		Ramin 1	4.5	25º15’42’’ N 60º46’18’’ E
		Ramin 2	13.2	25º15’33’’ N 60º46’14’’ E

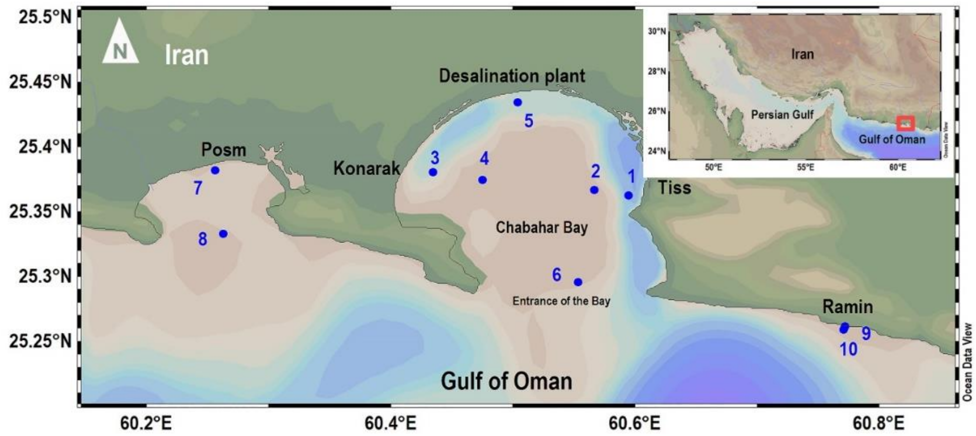
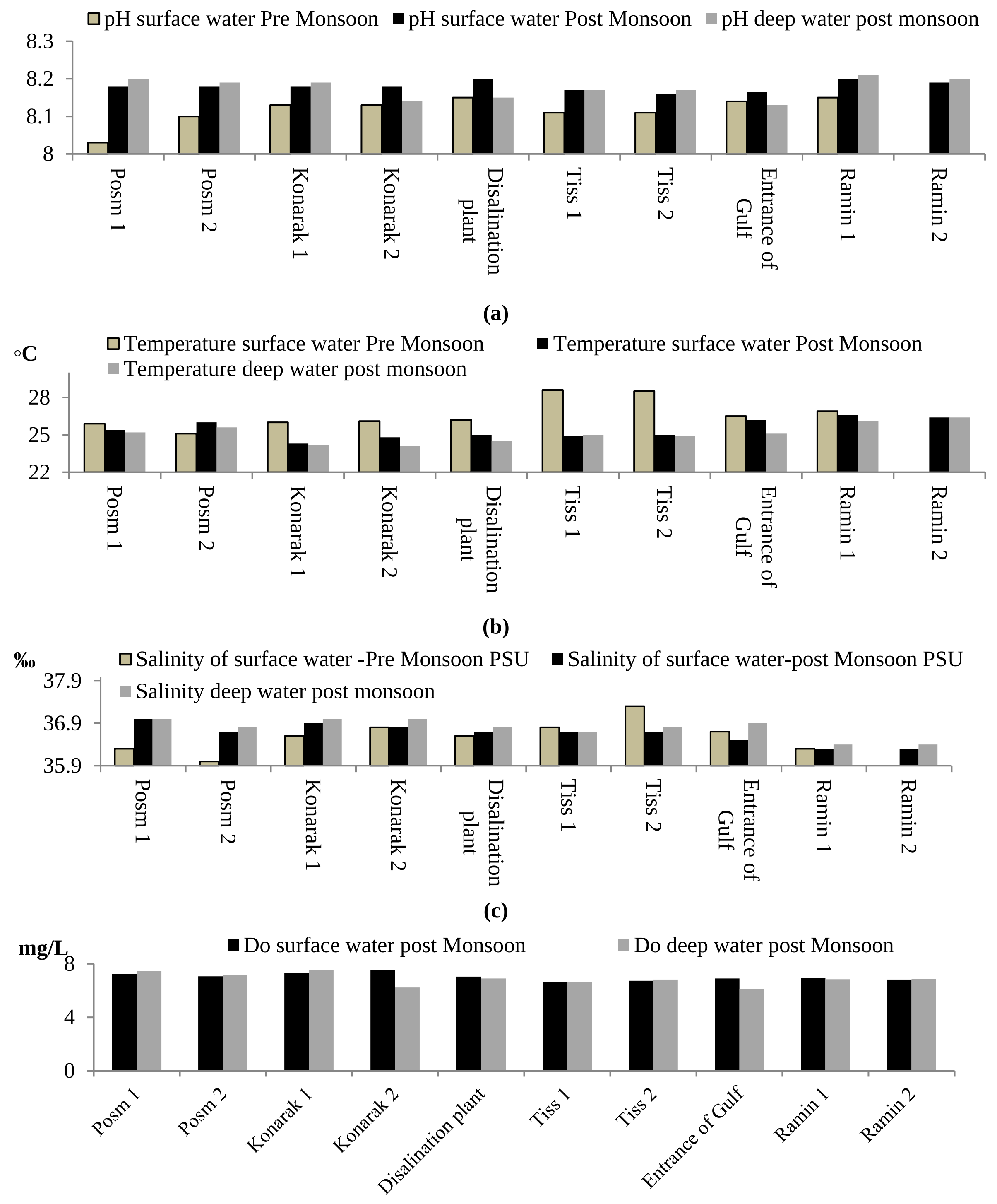


Fig. 1. The location of the sampling site in the Chabahr Bay

Table 2. Physico-chemical parameters of water samples in different station in pre and post Monsoon (May and December 2012)

Station	Depth (m)		Temperature ◦C			pH			Salinity ‰			DO (mg/L)		TOC (ppm)	Clarity Secchi disc (m)	
	Pre	Post	Pre Surface	Post Surface	post Bottom	Pre Surface	Post Surface	post Bottom	Pre Surface	post Surface	post Bottom	post Surface	post Bottom	Pre Surface	Pre	Post
Posm 1	6	4.8	25.9	25.4	25.2	8.03	8.18	8.2	36.3	37	37	7.23	7.46	1.41	3	2.5
Posm 2	12.1	10.6	25.1	26	25.6	8.1	8.18	8.19	36.0	36.7	36.8	7.06	7.15	1.50	1.3	6
Konarak 1	5	4.6	26	24.3	24.2	8.13	8.18	8.19	36.6	36.9	37	7.33	7.54	2.56	1.5	4
Konarak 2	10.5	10	26.1	24.8	24.1	8.13	8.18	8.14	36.8	36.8	37	7.54	6.23	1.04	1.2	3
Desalination plant	5.8	4.7	26.2	25	24.5	8.15	8.2	8.15	36.6	36.7	36.8	7.04	6.9	1.51	1.75	3.5
Tiss 1	3.8	3.1	28.6	24.9	25	8.11	8.17	8.17	36.8	36.7	36.7	6.62	6.61	2.78	0.9	3.1
Tiss 2	9	8.2	28.5	25	24.9	8.11	8.16	8.17	37.3	36.7	36.8	6.73	6.82	1.5	1.2	8.2
Entrance of Chabahar Bay	13.6	14.3	26.5	26.2	25.1	8.14	8.16	8.13	36.7	36.5	36.9	6.9	6.13	1.68	2.7	8.5
Ramin 1	4.5	4.5	26.9	26.6	26.1	8.15	8.2	8.21	36.3	36.3	36.4	6.96	6.84	1.41	3.5	4.5
Ramin 2	-	13.3	-	26.4	26.4	-	8.19	8.2	-	36.3	36.4	6.82	6.85		4.5	8.5
Average			26.6±1.2	25.5± 0.8	25.1± 0.8	8.1± 0.04	8.18±0.01	8.18± 0.03	36.6± 0.4	36.7±0.2	36.8±0.2	7.0±0.3	6.8±0.5	1.7± 0.57	189.4±93	5.18±2.4

(Pre: Pre Monsoon and Post: Post Monsoon)



(d)

Fig. 2. a) pH; b) Temperature; c) Salinity and; d) Dissolved oxygen of surface and deep layer at pre and post Monsoons in Chabahar Bay (May and December 2012)

Although the salinity of surface waters relatively varied at different stations during two monsoons, their average values (36.6 and 36.7 ‰) were comparable ($P > 0.05$). In an investigation, Fazeli et al. (2010) assessed seasonal variations of Copepoda in Chabahar Bay. In this study, water sanity was reported to be within the range of 36.7 to 36.9 ‰, which was comparable to that of the present study during the two monsoons. Ibrahim (2010) investigated water quality parameters at southern parts of the Gulf of Oman on February-March 1987, and reported a mean water salinity of 36.70. Comparing the results of this study with those of the present work demonstrated that water salinity values in pre-monsoon were comparable over the last two decades (Ibrahim, 2010).

Average values of pH and salinity for bottom water in post-monsoon were 8.18 and 36.8±0.2 ‰, respectively. Low variations in pH within the sampling area (Figure 2) during pre- and post-monsoons represented the water homogeneity.

Results demonstrated that the average value of pH in the sampling area was within the range of the surface ocean pH (Raven et al., 2005), producing appropriate conditions for coral reefs (which are very sensitive to any changes in pH) (Omer, 2010).

Obtained results indicated that pH of the surface water in post-monsoon were slightly higher than that at pre-monsoon. Seasonal variations of atmospheric carbon dioxide and phytoplankton activities can influence pH variations in different seasons.

Concentrations of 5.0 mg/L or higher for dissolved oxygen are desirable for fish survival. Low levels of dissolved oxygen are known to be one of the major problems for faunal and floral survival in aquatic environment (Friedrich et al., 2014). When the base DO level is less than the recommended level, that concentration should become the interim guideline at that time (CCME, 2003). The range and average values of dissolved oxygen of surface and deep layer water in post-monsoon varied from 6.6 (Tiss1) to 7.5 (Konarak2) (7.0±0.3) and from 6.13 (Entrance of Chabahar Bay) to 7.54 (Konarak) (6.9±0.5) mg/L, respectively. Hence, the dissolved oxygen levels measured in the present study were considered to be moderate to sustain the aquatic biodiversity. Generally organic wastes and other nutrient inputs from sewage and industrial discharges, agricultural, and urban runoff can result in decreased oxygen levels in some stations (Nasir Khan and Mohammad, 2014).

The pH of an aquatic ecosystem is an important indicator of the water quality. The ideal pH for biological productivity ranges between 6.8 to 8.5 (CCME, 2003; EPA, 1970), while pH values lower than 4 are detrimental to aquatic life (Abowei, 2010) and also allow toxic elements and compounds such as heavy metals to become mobile to aquatic life (APHA, 1995). Waters with pH values from 6.5 to 9.0 would be best for fish production (Olatayo, 2014). The recorded pH values in the present study ranged from 8.1 to 8.28 by a mean value of 8.18 (Table 2), which was within the range of the sea waters (6.5-8.4**)** (Olatayo, 2014), and was appropriate for aquatic life.

In pre-monsoon, pH value (8.03) and salinity (36.0 ‰) were relatively lower at Posm, as a closed bay ($p > 0.05$), compared to the other stations (Figure 2), which might be affected by rain fall one day before sampling. This finding could be confirmed by comparison of temperature at different stations.

Figure 3 illustrates the profiles of water temperature and salinity in pre-monsoon as typical measurments by CTD within the studied area (May 2012).

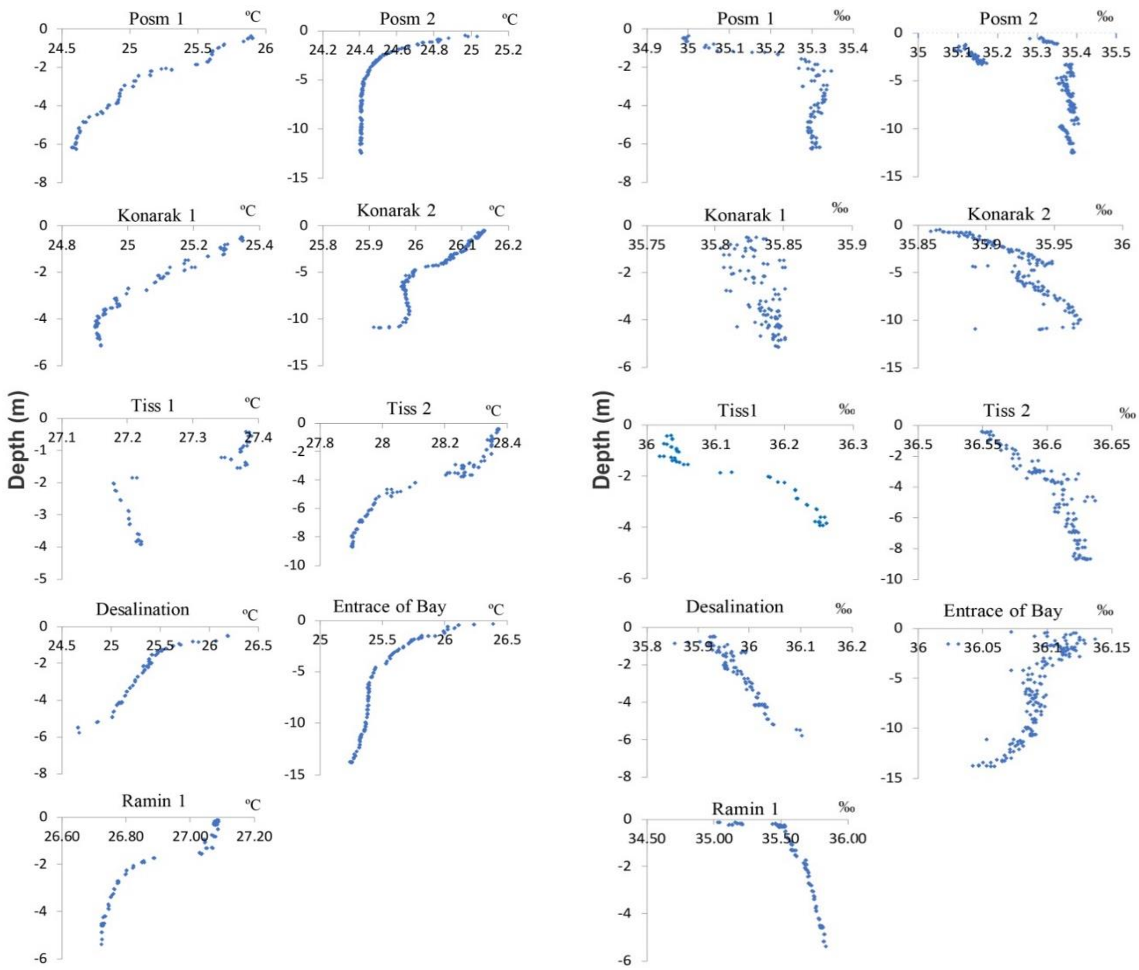
The range and average values of organic carbon at pre-monsoon were 1.04 (Konarak) -2.78 (Coastal parts of Tiss) and (1.7±0.56) ppm, respectively (Table 2).

Surface waters of some stations (Posm, Konarak, Tiss, and Ramin) were analyzed to determine total alkalinity in both pre- and post-monsoons. The averages of surface total alkalinity in pre- and post-monsoons were 2.422 ± 0.02 mmol/Kg and 2.439 ± 0.01 mmol/Kg (Figure 4), which were within the range of oceanic surface water (2-2.5 mmol/Kg), and slightly higher than data available from GLODAPv2.2020 (Olsen et al., 2020) in the offshore Oman Sea (2.409 ± 0.01, surface water, August 1995). Recently, Saleh et al. (2020) reported total alkalinity of surface waters within the range of 2.413 to 2.425 mmol/Kg for seawater samples from intertidal rocky shores of the Chabahar Bay and Makran Sea (northern Oman Sea) (Saleh et al., 2020).

Results of post-monsoon sampling indicated that total alkalinity of the surface and near-bottom layers in shallower stations (stations of inner Chabahar Bay with depths of less than 5 m) did not show significant differences (P > 0.05), probably due to mixing process forced by tidal currents. Low values of positive correlation coefficients between total alkalinity as a conservative seawater characteristic and salinity ($r^2 = 0.2$, $p > 0.05$), might be related to biological activities (such as bio-calcification and photosynthesis), and fresh water input (surface seasonal floods and groundwater inflows) (Xue and Cai , 2020).

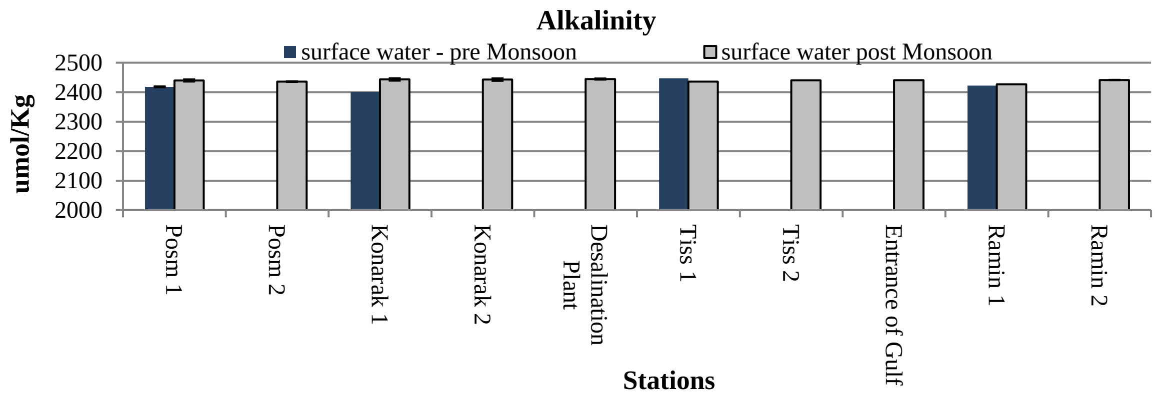
Nutrient input often leads to excessive algal growth; when the algae die, the organic matter is decomposed by bacteria, a process which consumes a great deal of oxygen that could lead to a decrease in water quality and increases the threat to ecological life. Nitrite as an indicator of bacterial activity (Mahanta et al., 2014), ranged from 2.1 (coastal parts of Posm) to 13 (coastal parts of Ramin) µg/L in pre-monsoon, and from 4.4 to 9.6 µg/L (coastal parts of Konarak and entrance of Chabahar Bay) in post-monsoon, respectively (Figure 5).

Since few studies for nitrogen toxicity in environments of marine estuarine are available, the marine guideline is the same as the interim guideline proposed by CCME (2003). The 30-day average concentration of nitrate (as N), to protect freshwater aquatic life is 3.0 mg/L and its maximum concentration is 32.8 mg/L. The 30-day average concentration of nitrate (as N) to protect marine aquatic life is 3.7 mg/L. Minimum concentrations of nitrate in pre- (2.2 µg/L) and post-monsoons (2.1 µg/L) were related to coastal parts of Tiss and deeper parts of Ramin, while its maximum values in pre- (25 µg/L) and post-monsoons (15.3 µg/L) were detected at deeper parts of Ramin and entrance of Chabahar Bay, respectively (Figure 5).

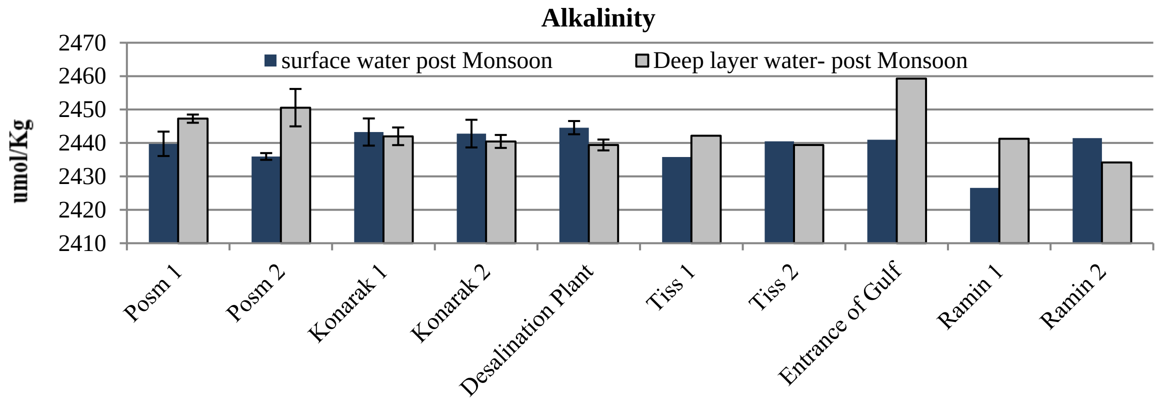


(a) **(b)**

Fig. 3. Profiles of: a) Water temperature; b) Salinity; in pre Monsoon at the study area (May 2012)



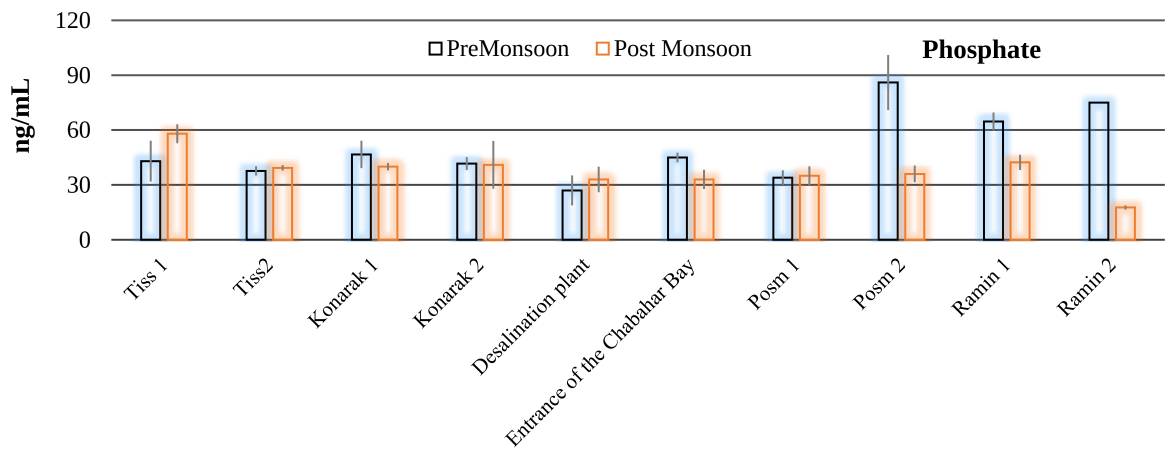
(a)



(b)

Fig. 4. Levels of Alkalinity: a) surface seawater in pre and post monsoon and; b) surface and near-bottom water in post monsoon (μmol/kg)

Nutrient concentration is highly variable in marine environment. In many cases, it shows a wide range of spatio-temporal variations depending on physical and biogeochemical processes. Based on Glodap2020 data, in the Gulf of Oman, NO_3 ranged from 0 at the surface to more than 35 umol/Kg (or 2100 ug/L at 1000 m), NO_2 ranged from 0 at surface to 0.75 umol/Kg (or 34 ug/L), PO_4 ranged from 0 at surface to 3 umol/Kg (or 285 ug/L at 1000 m), and Si ranged from 2 umol/Kg at surface to 150 umol/Kg at 3000 (56 to 4200 ug/L). Therefore, having values of near-zero for nutrients in surface samples is not unusual in this region; however, higher values of nutrients at the surface are expected during early winter in the northern Arabian Sea, due to winter convective mixing.



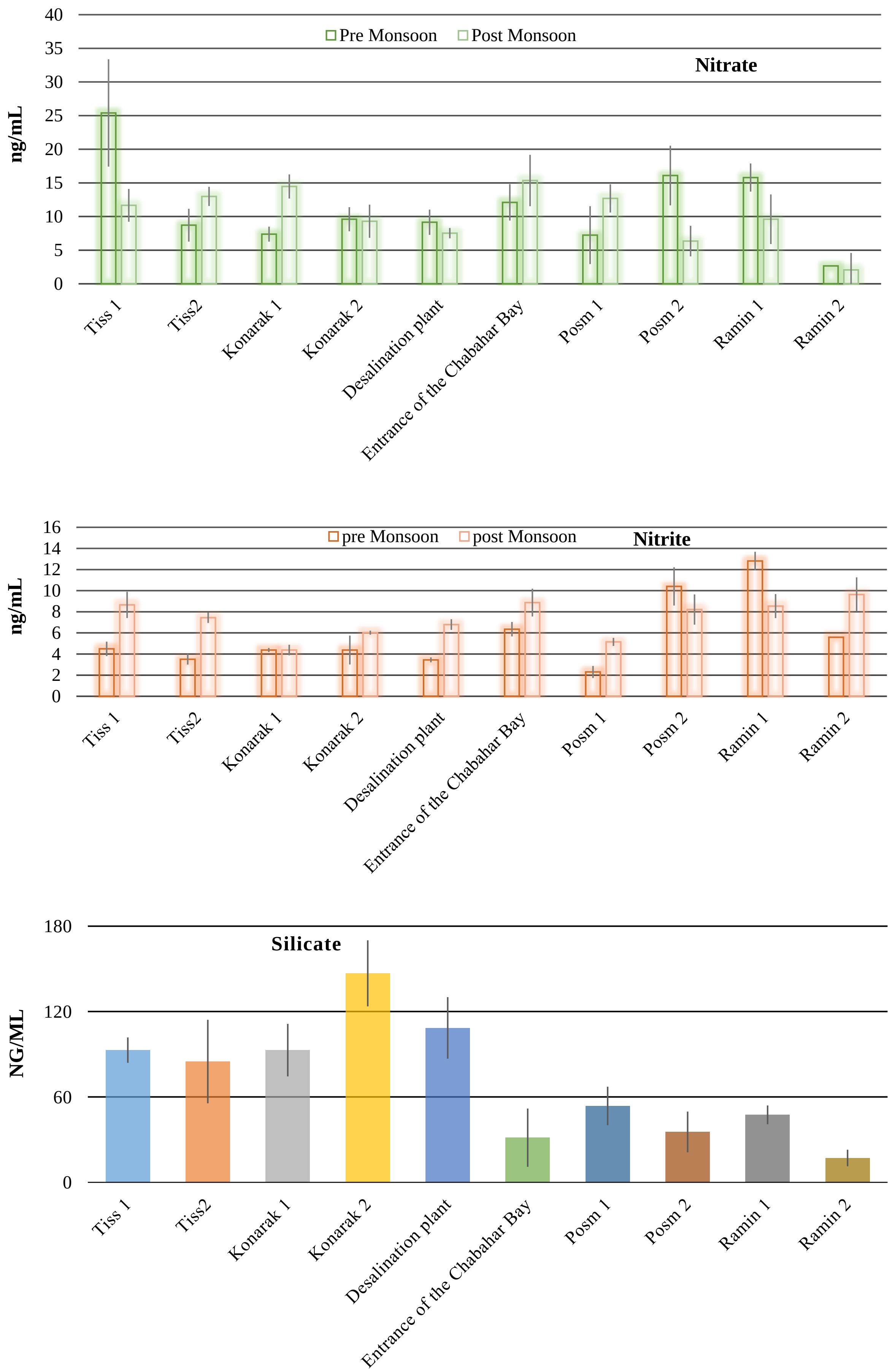


Fig. 5. The concentrations of nitrate, nitrite, phosphate and silicate at pre and post Monsoon

The concentrations of phosphate ranged from 27 (Desalination) to 86 (Posm), and from 17.7 (Ramin) to 58 (Tiss) µg/L in pre- and post-monsoons, respectively (Figure 5).

For Si, the mean value was significantly higher (P = 0.015) within the Bay, which could be the result of shallower environment inside the Bay. Probably, tidal currents could re-suspend bottom sediments in the shallow area, and release dissolved Si previously being trapped in sediments. The dilution effect in open sea stations could reduce this effect.

Average values of the nutrients in the present study were comparable to those reported in Gulf of Oman (nitrite: 2-26 and phosphate: 8-15 µg/L) (Fazeli, 2010), and Persian Gulf at Strait of Hormoz (nitrite: 0.8-39.3, nitrate: 0-30 and phosphate: 0.5-55 µg/L) (Sanjani, 2009).

The concentrations of chlorophyll-a and b in surface and bottom waters were determined at post-monsoon. The maximum chlorophyll-a in surface (0.64 µg/L) and bottom water (1.20 µg/L) were detected at Posm, while it was not detected at the stations inside Chabahar Bay. The maximum chlorophyll-b in surface (3.22 µg/L) and bottom water (2.92 µg/L) were related to deeper parts of Konarak (Figure 6).

Obtained results demonstrated that there were significant correlations between chlorophyll-a ($r_2 = 1$, $p < 0.01$) in surface and deep layer water, as well as chlorophyll-b ($r_2 = 0.92$, $p < 0.01$), but there were no correlations between chlorophyll-a and b in surface or deep layer waters (Table 3). It was revealed from statistical analysis that there were positive strong significant correlations between chlorophylls and dissolved oxygen content. Although pH variation within the studied area was 0.26, low pH variations inversely correlated with chlorophyll-a ($p < 0.05$) in surface water.

It might be necessary to conduct more investigations in a vast area during a longer period to be able to have an ecological justification on pH and chlorophyll variations. Chlorophyll-a was inversely correlated with temperature and positively correlated with salinity and dissolved oxygen (Table 3), which was in accordance with the results of Nurdin et al. (2013), who reported a negative correlation between temperature and chlorophylls.

Turbidity is an important operational parameter affecting the process of photosynthesis for algal growth (IEPA, 2001). Low levels of turbidity could be attributed to low wave actions and minimal turbulence, while high turbidity might be observed due to rainfall, riverine sediment loads, discharges of sewage and industrial waste or the presence of a large number of microorganisms (Olatayo, 2014). High turbidity reduces the light penetration, hence adversely influencing the primary, secondary and tertiary biological productions (Olatayo, 2014). Water clarity in pre- and post-monsoons were 0.9 (Tiss) - 4.5 (Ramin) and 2.5 (Posm) -8.5 (Ramin) m, respectively. The clarity of water samples in pre- and post-monsoons varied from 0.9 (Tiss) to 4.5 (Ramin), and from 2.5 (Posm) to 8.5 (Ramin) m, respectively. Higher water clarity in post-monsoon could be related to its higher rain fall.

In this study, 66 phytoplankton genus and species belonging to 13 groups (Bacillarophyceae, Dinophyceae, Cyanophyceae, Alphaproteobacteria, Prymnesiophyceae, Zygnemophyceae and Chlorophyceae) were identified in pre-monsoon (Table 4).

The most dominant phytoplankton groups were Dinophyceae (73.30%) and Bacillariophyceae (22.30%). The maximum and minimum abundances of phytoplankton communities were detected at Tiss and Ramin stations, respectively. In post-monsoon, total phytoplankton abundance was 1944333 ± 5271 (Cell L^{-1}) and 994000 ± 4475 (Cell L^{-1}) in surface and depth (7 m) waters. In this survey, 66 species were identified; Bacillariophyceae (49.4%) and Dinophyceae (44.5%) were the most dominant phytoplankton groups, respectively.

In this survey, no significant correlation (p > 0.05) was found between phytoplankton abundance, temperature and salinity (Table 5). The Mann-Whitney analysis showed that there was significant difference in phytoplankton density among different stations. Obtained results demonstrated that Tiss had higher distribution of phytoplankton compared to other sampling stations. Nutrient levels especially silicate and nitrate concentrations (Barcelos e Ramos et al., 2017; Mirzaei et al., 2017), originated from fishing and recreational beach as well as municipal sewers, might affect the higher phytoplankton abundance in this station.

4. Conclusions

In addition to receiving marine pollution from eastern and western neighborhoods (in pre- and post-monsoons), Chabahar Bay receives domestic, industrial, and in some cases, agricultural wastewater from its coastal areas, which can influence the quality of the water. In order to study the effect of anthropogenic influence on this ecosystem, in the present study, 10 stations were selected to assess the water quality. Results indicated that water salinity and pH (with narrow variation) were relatively higher in post-monsoon, especially in the stations inside the Chabahar Bay. Obtained results revealed that there was no significant change in pH values during two monitoring periods, pre- and post-monsoons. The pH values were within the range of 8.03 to 8.21, which was in accordance with Indian standards for sensitive ecological areas for coastal waters, such as Arabian Sea (Salvi et al., 2014). Appropriate pH and dissolved oxygen levels could express that the sampling area was suitable for marine life.

Temperature is one of the most important parameters for growth and survival of corals in marine water. Although temperature showed a temporal variation in accordance to the atmospheric variation and followed a seasonal trend, in the present study, the temperature was in appropriate range for corals as well as other marine diversity.

Moreover, results indicated that in pre-monsoon, minimum (0.03) and maximum (0.55) Shanoon indices for phytoplankton diversity were determined at Ramin and Tiss stations, respectively (Figure 7a). In post-monsoon, the minimum and maximum values of Shannon index were observed at Tiss and Konarak by 4.5 and 1.37, respectively (Figure 7b).

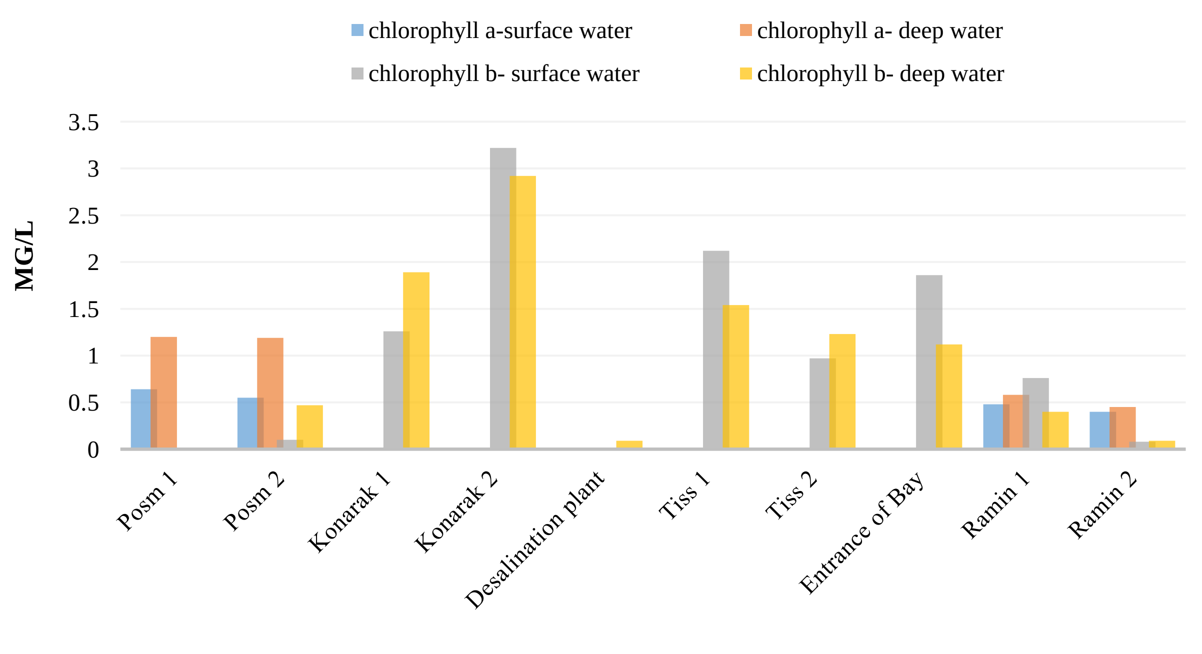


Fig. 6. Comparing chlorophyll a and b in surface and deep layer water at different stations in Post Monsoon

Table 3. Correlation between Chlorophylls and some environmental factors

Chlorophylls and some environmental factors	Chlorophyll-a Surface water	Chlorophyll-a Bottom water	Chlorophyll-b Surface water	Chlorophyll-b Bottom water
Chlorophyll-a surface water	1.00			
Chlorophyll-a deep layer water	1.00**	1.00		
Chlorophyll-b surface water	-0.40	-0.40	1.00	
Chlorophyll-b bottom water	-0.20	-0.20	0.92**	1.00
PH surface water	-0.74*	-0.74	-0.53	-0.51
PH deep layer water	-0.32	-0.32	-0.56	-0.50
Temperature surface water	-0.80**	-0.80**	-0.46	-0.67
Temperature deep layer water	-1.00**	-1.00**	-0.50	-0.67
Salinity surface water	0.95**	0.95**	0.03	0.25
Salinity deep layer water	0.95**	0.95**	0.18	0.32
Dissolved Oxygen surface water	1.00**	1.00**	-0.06	0.12
Dissolved Oxygen deep layer water	0.80**	0.80**	-0.67	-0.40

*: Significant at $p < 0.05$ and **: $P < 0.01$ levels

Table 4. The identified phytoplanktons

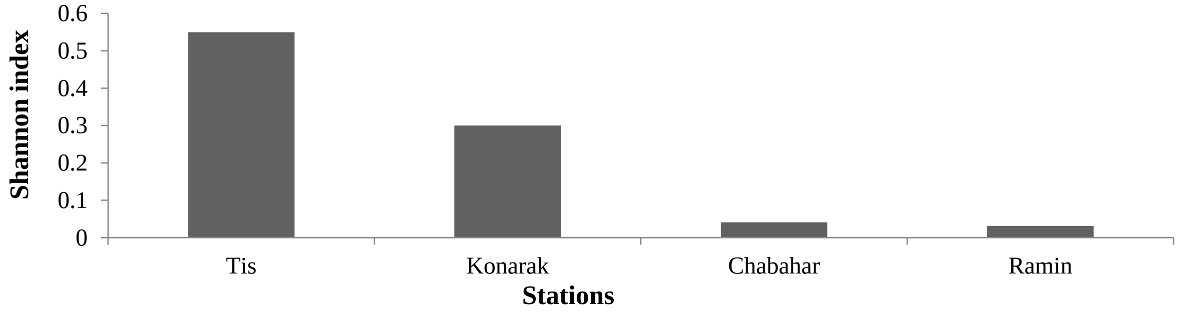
Class	Family	Genus	Pre (Abundance±SE)	Post (Abundance±SE)	Class	Family	Genus	Pre (Abundance±SE)	Post (Abundance±SE)
Dinophyceae	Prorocentraceae	*Prorocentrum*	11000±402	9083±208	Bacillariophyceae	Achnanthaceae	*Achnanthes*	0	317±24
Dinophyceae	Ceratiaceae	*Ceratium* spp.	3250±262	7833±410	Bacillariophyceae	Catenulaceae	*Amphora*	583±25	2733±60
Dinophyceae	Protoperidiniaceae	*Protoperidinium*	9917±493	8950±258	Bacillariophyceae	Melosiraceae	*Melosira*	0	2717±226
Dinophyceae	Dinophysiaceae	*Dinophysis spp.*	167±9	783±23	Bacillariophyceae	Asterolampraceae	*Asterolampra*	0	550±18
Dinophyceae	Kolkwitziellaceae	*Preperidinium*	385500±2360	10850±311	Bacillariophyceae	Climacospheniaceae	*Climacosphenia*	0	67±4
Dinophyceae	Gymnodiniaceae	*Cochlodinium*	0	133±13	Bacillariophyceae	Auriculaceae	*Auricula*	0	67±6
Dinophyceae	Amphisoleniaceae	*Amphisolenia*	0	133± 8	Bacillariophyceae	Fragilariaceae	*Synedra*	0	4100±119
Dinophyceae	Noctilucaceae	*Noctiluca*	250±25	1467±34	Bacillariophyceae	Thalassionemataceae	*Thalassionema*	917±59	2633±246
Dinophyceae	Calciodinellaceae	*Scrippsiella*	0	5100±151	Bacillariophyceae	Lauderiaceae	*Lauderia*	0	300±15
Dinophyceae	Gymnodiniaceae	*Gyrodinium*	167±16	10683±262	Bacillariophyceae	Thalassiosiraceae	*Thalasiosira*	917±56	233±19
Dinophyceae	Gonyaulacaceae	*Gonyaulax*	0	67±4	Bacillariophyceae	Biddulphiaceae	*Biddulphia*	0	83±6
Dinophyceae	Gonyaulacaceae	*Lingulodinium*	1000±79	0	Bacillariophyceae	Triceratiaceae	*Lampriscus*	0	150±15
Dinophyceae	Gonyaulacaceae	*Alexandrium*	0	50±3	Bacillariophyceae	Plagiotropidaceae	*Plagiotropis*	0	533±28
Dinophyceae	Dinotrichaceae	*Gymnodinium*	0	250±23	Bacillariophyceae	Hemiaulaceae	*Hemiaulus*	0	167±11
Dinophyceae	Gymnodiniaceae	*Amphidinium*	0	1100±70	Bacillariophyceae	Pinnulariaceae	*Pinnularia*	0	300±20
Dinophyceae	Pyrophacaceae	*Pyrophacus*	1833±133	0	Bacillariophyceae	Hemiaulaceae	*Hemidiscus*	0	150±13
Bacillariophyceae	Naviculaceae	*Navicula* spp.	4000±212	6400±217	Bacillariophyceae	Lithodesmiaceae	*Ditylum*	2667±159	300±30
Bacillariophyceae	Rhizosoleniaceae	*Rhizosolenia*	667±47	1517±32	Bacillariophyceae	Rhaphoneidaceae	*Rhaphoneis*	0	50±5
Bacillariophyceae	Bacillariaceae	*Pseudo-nitzschia*	917±62	3133±103	Bacillariophyceae	Bacillariaceae	*Cylindrotheca*	0	33±3
Bacillariophyceae	Fragilariaceae	*Striatella*	1750±95	17±1	Cyanophyceae	Phormidiaceae	*Trichodesmium*	0	283±18
Bacillariophyceae	Rhizosoleniaceae	*Guinardia*	1750±47	4083±165	Cyanophyceae	Oscillatoriaceae	*Oscillatoria*	750±75	500±32

Bacillariophyceae	Bacillariaceae	*Nitzschia*	2000±78	13100±610	Cyanophyceae	Merismopediaceae	*Aphanocapsa*	1583±158	0
Bacillariophyceae	Fragilariaceae	*Licmophora*	0	283±26	Trebouxiophyceae	Chlorellaceae	*Closteriopsis*	0	4783±153
Bacillariophyceae	Coscinodiscaceae	*Coscinodoscus*	7667±335	1517±42	Actinobacteria	Micrococcuceae	*Microcrocis*	0	20033±767
Bacillariophyceae	Coscinodiscaceae	*Lennoxia*	333±23	0	Alphaproteobacteria	Sphingomonadaceae	*Rhizomonas*	500±50	0
Bacillariophyceae	Chaetocerotaceae	*Chaetoceros* spp.	0	5983±187	Chrysophyceae	Dinobryaceae	*Dinobryon*	0	300±8
Bacillariophyceae	Leptocylindraceae	*Leptocylindrus*	0	3150±83	Florideophyceae	Lemaneaceae	*Lemanea*	0	250±16
Bacillariophyceae	Amphioleuraceae	*Amphiprora*	0	833±55	Xanthophyceae	Heteropediaceae	*Heterococcus*	0	250±16
Bacillariophyceae	Skeletonemaceae	*Skeletonema*	0	1367±109	Zygnemophyceae	Closteriaceae	*Closterium*	250±25	0
Bacillariophyceae	Hemiaulaceae	*Eucampia*	167±96	467±30	Zygnemophyceae	Desmidiaceae	*Cosmarium*	417±41	0
Bacillariophyceae	Diploneidaceae	*Diploneis*	0	567±19	Chlorophyceae	Radiococcaceae	*Coenococcus*	2167±216	0
Bacillariophyceae	Naviculaceae	*Pleurosigma*	417±31	4067±213	Prymnesiophyceae	Rhabdosphaeraceae	*Coronosphaera*	1917±191	0
Bacillariophyceae	Hemiaulaceae	*Cerataulina*	0	750±38	Dictyochophyceae	Dictyochaceae	*Dichtyocha*	0	1033±29

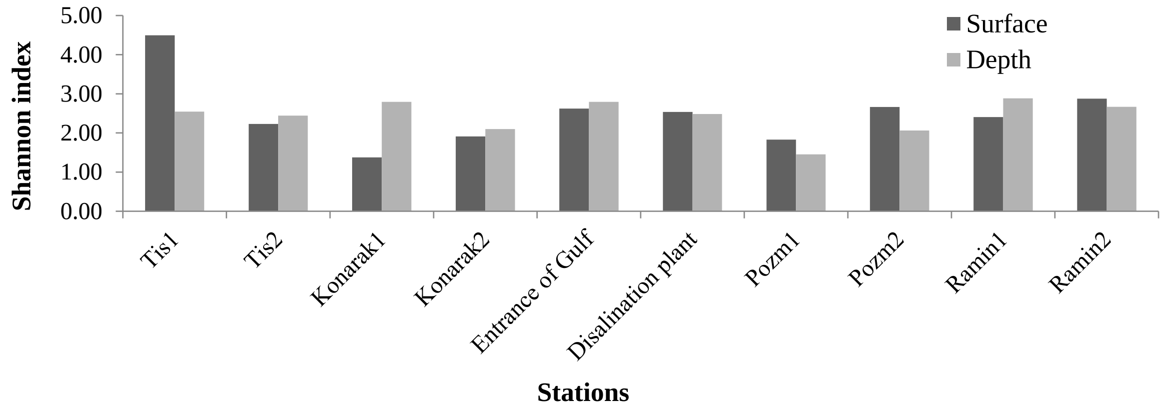
Table 5. Correlation coefficients between phytoplankton abundance and physic- chemical parameters in pre and post Monsoons

	Pre Monsoon			**Post Monsoon**			
Parameter	**Phytoplankton**	**Temperature**	**pH**	**Phytoplankton**	**Temperature**	**pH**	**Salinity**
Temperature	0.8			0.65			
pH	0	0.8		0.4	0.03		
Salinity	0.05	0.68	0.05	0.59		0.16	
DO	-	-	-	0.50	0.86	0.19	0.01 *

DO: Dissolved Oxygen; * Significant in $p < 0.05$



(a)



(b)

Fig. 7. Shannon index values in the sampling stations in: a) Pre Monsoon and; b) Post Monsoon

The higher levels of nutrients and subsequently phytoplankton abundance in surface water in post-monsoon could be due to strong wind currents, which mix surface and deep layer waters.

Excess phosphate level can accelerate the growth rate of algae and can result in death and decay of marine benthos and fishes, and might reduce water quality since it decreases the levels of dissolved oxygen. Phosphorous level higher than 1 mg/L can cause excessive plant growth and eutrophication (Ron Fleming, 1999). The average phosphorous level in the present study (0.09 µg/L) was much less than defined values in guidelines.

Low variations of water parameters, and low dissolved organic carbon (< 2 mg/L) have provided appropriate conditions to establish desalination plant in this area. In general, the physicochemical parameters of water samples from all stations indicated that water quality falls within the stipulated range of acceptability and sampling area can be classified as a good, stable and healthy aquatic ecosystem.

There should be a constant monitoring of the physicochemical parameters of the studied area in the future, due to the increase in anthropogenic activities around this area. For further investigations, it is recommended to assess the offshore physical, chemical, and biological parameters (> 50 m depth) for cage fish farming.

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