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Phytoplankton Community and Physical-Chemical Characteristics of Seawater in the Bandar Abbas Coastal Water, Persian Gulf: An Environmental and Process Perspective

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Abstract

Seawater ecosystems are controlled by multitude various abiotic and biotic factors. These factors also affect the activities of coastal human communities and installations including coastal desalination plants. This research investigated a point environmental (physical and chemical) and biological (phytoplankton) parameters of Bandar Abbas coastal water in 3 depth layers of 1, 5 and 10 m carried out in September, 2015 and March, 2016. The obtained experimental results were analyzed using principal component analysis (PCA) method. Thirty four species belonging to 5 classes of Bacillariophyceae, Dinophyceae, Cyanophyceae, Euglenophyceae and Chrysophyceae were identified. The most representative class in terms of species richness was Bacillariophyceae represented by 21 species and dominated by *Cyclotella* sp., *Nitzschia* sp. and *Navicula* sp. *Dinophyceae* was represented by species with the dominant of *Gymnodinium* sp. in two seasons and all waters layers. The group cyanobacteria was represented by species of diverse morphological characteristics and the dominance of Anabaena. The other dominant class of Euglenophyceae and Chrysophyceae were represented by Eutreptia and Dictyocha, respectively. The coastal water exhibits high electrical conductivity (67,000 µS/cm), alkaline pH (8.26-8.29) and mean temperature of 22.2 - 22.8 °C, with no significant differences during sampling periods. The mean Shannon index value of the site sample was found to be 0.798. Two principal components were recognized which indicate that the coastal waters are mainly affected by parameters of pH, EC, nitrogen and phosphorus nutrients, and chlorophyll in the first principal component represented by high factors loading and gas solubility capacity with high factor loading of temperature and dissolved oxygen in the second principal component. These results may be useful to select required pretreatment systems to establish desalination plants in the Hormozgan province.

Keywords: *Phytoplankton Biodiversity; Open Seawater Intake; Biotic Communities; Desalination; Persian Gulf.*

1. Introduction

The number of desalination installations is growing in the Persian Gulf area, using open costal seawater, to cope with high demands of fresh water in the region. Seawater reverse osmosis (SWRO) desalination facilities are commonly include the

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main units of intake, pretreatment and reverse osmosis (Figure 1).

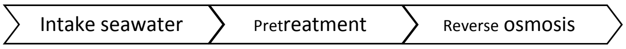

Fig. 1: A schematic flowchart perspective in desalination plant operations.

Seawater phytoplankton particles and organic matter released into seawater by phytoplankton especially during algal bloom periods can seriously deteriorate the performance of SWRO systems. Therefore, pretreatment systems are generally installed upstream of the SWRO membranes (Schneider et al., 2005; Petry et al., 2007; Caron et al., 2010; Tabatabai, 2014; Ahmad et al., 2015). In general, pretreatment systems have to be installed to improve the poor quality and variation in quality of the raw water supplied by the open intake system to avoid membrane biofouling. Pretreatment normally involves a form of filtration and other physical-chemical processes to remove suspended solids, particularly removal of solid particles (Hakizimana et al., 2016). From the process perspectives, seawater quality and its seasonal variations are the basis for designing desalination pretreatment unit and maintenance (Schneider et al., 2005).

From the environmental perspectives, the intake seawater, affects the phytoplankton population and ecology (impingement and entrainment). Regardless of the desalination plants location, the technical and environmental challenges, can be adversely affected by phytoplankton communities and seawater quality. Therefore, it is important to establish a robust/routine monitoring program to measure potential impact of biotic and abiotic parameters and to assess their effectiveness of the engineered pretreatment system on the development of desalination plants (Tabatabai, 2014; Villacorte et al., 2015).

Biotic and abiotic variation in coastal water bodies such as phytoplankton communities depend on various interrelated physical, chemical and biological factors (Câmara et al., 2015). The temporal and spatial variations may be of natural origin, such as precipitation, water flow regimes, wind and the influx of the water stream, or as a consequence of human being activities on the environment such as wastewater discharges. Therefore, the phytoplankton communities display a potential for change that may lead to the substitution, removal or addition of species and intake water characteristics. Alterations in species richness are mainly due to the variability of abiotic factors, such as climactic tendencies or short-term climatic variations (Câmara et al., 2015). The studies of water phytoplankton communities are commonly performed in the gulfs, reservoirs, sea shoreline, natural lakes, coastal lagoons, floodplain lakes, rivers and fish ponds. Nearly most of the studies in the Persian Gulf come from the south and southwestern coastal regions of Iran based on both descriptive and experimental approaches following local red tide event in 2008-2009 (Hamzehei et al., 2013; Zarshenas et al., 2015; Pouladi et al., 2017). The most important contributions are based on the general phytoplankton structure, diversity to cyanobacterial dominance and their toxin producing capacity and concentrations associated with eutrophic conditions (Kim, 1999; Chellappa et al., 2008). However, still relatively few studies have been conducted in the coastal area of Bandar Abbas which is important for its environmental and economic values (Saeedi, 2012).

The aims of this study are: i) to analyze phytoplankton and water physical-chemical parameters of the Bandar Abbas coastal water in 3 depth layers of 1, 5 and 10 m; ii) to find out compositions of phytoplankton community structure, diversity; and iii) the inter-relationship of physical-chemical parameters to phytoplankton abundance.

2. Materials and Methods

The sampling site is located in the shoreline of Bandar Abbas coastal area in the southwest region of

Hormozgan province (geographic coordinates: latitude 27.05555°N and longitude 55.98699°E) (Figure 2). This site is designated for the establishment of local desalination plant and the artificial channel start point for national seawater transfer project to the center of country mainland.

Samples were collected in September, 2015 and March, 2016 at a fixed collection station with a Van Dorn bottle (5 L) at three water depth layers: surface (1 m), middle (5 m) and bottom depth (10 m). The samples were preserved in formalin solution before being transferred to the laboratory. For qualitative analysis of phytoplankton, samples were examined using an inverted microscope (Nikon, Japan). Identification of the algae species was carried out on the basis of the orphological criteria of the free cell features (Golterman et al., 1978; Wehr and Sheath, 2003; Huynh and Serediak, 2006; Rice et al., 2012). The nomenclature and quantitative measurements of phytoplankton individuals of the species was cited following standard references (Wehr and Sheath, 2003; Huynh and Serediak, 2006; Rice et al., 2012). The water parameters of pH, and dissolved oxygen were measured with multi-parameter meter (WTW Multiparameter Multi 340i). Temperature and turbidity were measured with thermometer and turbidity meter (TU-2016, Lutron, Taiwan), respectively. Nutrient analyses such as nitrate, orthophosphate (Rice et al., 2012), ammonium and phosphate concentrations (phosphate concentration is calculated by phosphorous concentration) (Golterman et al., 1978) were conducted in the laboratory using spectrophotometer (DU 530, Beckman, USA). Concentration of chlorophyll was determined following filtration and extraction with acetone, and measured using a fluorescence spectrophotometer (Cary Eclipse, Varian) (Li et al., 2012). Conductivity (normalized to 25°C) of all samples were measured with a conductivity meter following calibration with standard calibration solution.

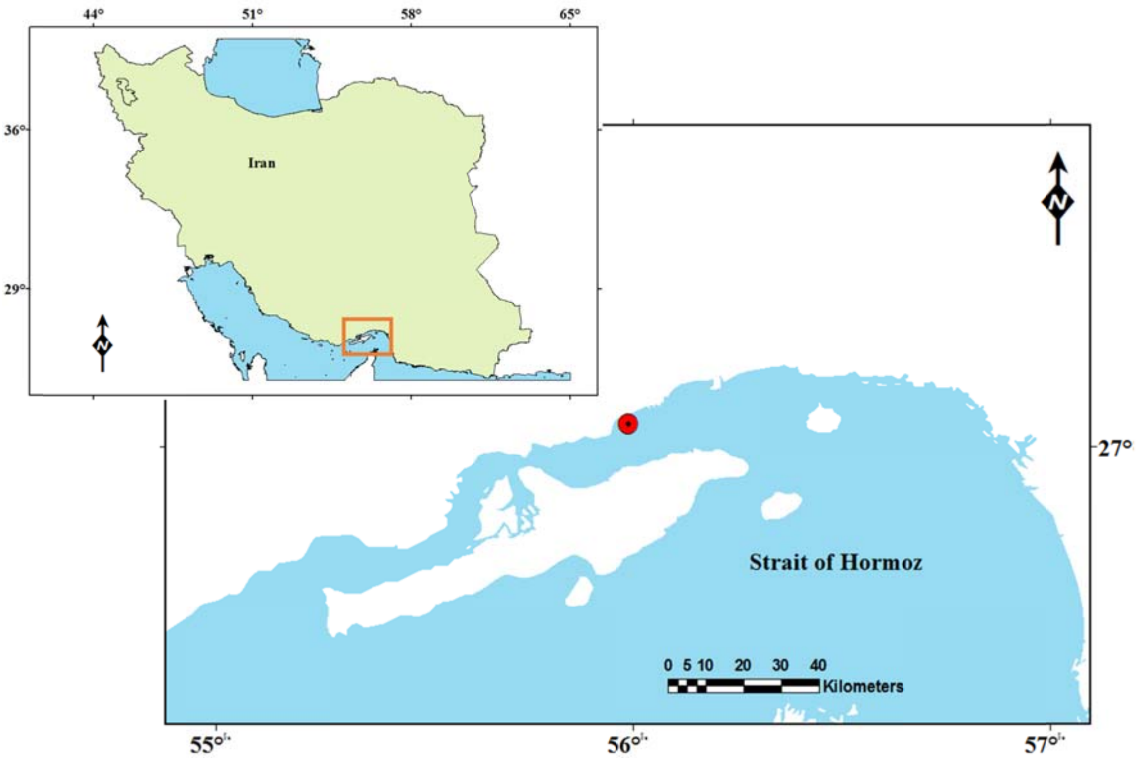

Fig. 2: Experimental site location in the Bandar Abbas, Hormozgan province.

The effects of physicochemical characteristics of seawater at various depth layers in two seasons were assessed in a randomized complete block design with three replications. The physicochemical resulting data matrix were analyzed using principal component analysis (PCA) to represent the similarities and dissimilarities between objects (3 depths and 2 seasons). PCA analysis is based on values of associated multiple variables of water physicochemical variables by reducing the high dimensionality of the data to a low dimensional approximation. As each of the original variables was measured on different scales, PCA was performed on the correlation matrix. Significant principal components were selected by plotting the eigenvalues against the components, to detect when the amount of specific and error variance begin to dominate the shared variance among variables. The zone where the slope of the curve begins to flatten indicates the maximum number of components to extract. The selected components were then rotated by varimax rotation, which redistributed variance from earlier to subsequent factors. This technique is generally used to facilitate the interpretation of the component pattern. Statistical analysis were performed using the software IBM-SPSS Statistics (version 22, IBM, USA). The Shannon diversity index (H) was used to analyses the diversity of phytoplankton at the study sites (Zhang et al., 2016).

3. Results

Physical, chemical and biological seawater parameters varied in Bandar Abbas samples as (Tables 1, and 3). Mean turbidity values during the September and March sampling were 5.19 and 31.9 NTU, respectively (Table 1). Temperature ranged between 22.0°C to 22.4°C in the examined samples, with the highest value of 22.4 in the September surface water and the lowest value of 22.0°C in the March depth water. It shows weak seasonal and depth variations, with the range of 0.4°C. The mean concentration of dissolved oxygen in the collected samples oscillated between 4.83 mg/L in September and 4.93 mg/L in March (Table 1). The lowest electrical conductivity values were observed in September (67,000 µS/cm) and depth of 1 m, and the highest conductivity value was registered in the lowest of 10 m the water depth in March (68000 µS/cm). The mean was 67550 µS/cm in September and 67770 µS/cm in March. The variation in seawater electrical conductivity, a fact often observed in Bandar Abbas coastal area in the semi-arid regions of north of Persian Gulf, may happen by seawater buffering systems (Michael Reynolds, 1993; Lee et al., 2009). The pH had a mean value of 8.28 in the depth of 1 m, 8.29 in the depth of 5 m, and 8.26 in the depth of 10 m (Table 1).

Table 1: Bandar Abbas coastal water physical characteristics in various depths of 1, 5 and 10 m.

		Winter			**Summer**		
	Unit	1 m	5 m	10 m	1 m	5 m	10 m
Water temperature	°C	22.8	22.4	22.2	22.4	22.2	22.0
Turbidity	NTU	19.5	20.7	55.4	5.23	5.64	4.68
TSS	mg/L	8	9	18	2	2	2
pH	-	8.28	8.29	8.26	8.22	8.24	8.20
Electrical conductivity	µS/cm	67000	67100	68000	66900	69100	68100
Dissolved oxygen	mg/L O_2	5.2	4.9	4.7	5.0	4.8	4.7

Analysis of variance for water physical characteristics reveals that there are significant differences in temperature and dissolved oxygen at 0.05 (Table 2).

Concentration of chlorophyll varied from 1.34 µg/L at the bottom depth in September to 1.26 µg/L at middle depth (5 m) in March. The greatest concentration of chlorophyll were generally observed at water surface. Mean chlorophyll concentration was greater during September.

In this study, 34 taxa of algae were identified belonging to 5 classes of Bacillariophyceae, Dinophyceae, Cyanophyceae, Euglenophyceae and Chrysophyceae (Table 3). The most representative class in terms of species richness was Bacillariophyceae (21 species, with 19 in the September and 5 in the March), followed by Dinophyceae (7 species, with 7 in the September and 1 in the March), followed by Cyanophyceae (4 species in the September), followed by Euglenophyceae (1 species in the September) and followed by Chrysophyceae (1 species in the September). Table 3 present detailed qualitative and quantitative data on species, their relative abundance in September and March months, and the frequency of occurrence of phytoplankton in Bandar Abbas coastal open waters during the 2015-2016. The highest number of taxa was found in the March in all of the depth layers. Bacillariophyceae dominated the surface during the entire study. Dinophyceae dominance at the surface was followed by Bacillariophyceae with a relative abundance of 14.69%. During this study Dinophyceae was followed by Cyanophyceae with a relative abundance of 4.32%, followed by Euglenaphyceae dominance (1.80%). Chrysophyceae with a relative abundance of 0.34% was less than others. Table 3 presents different genus of phytoplankton.

Table 4 shows a comparison of the statistical results of mean, SE, minimum value, maximum value and variance related to phytoplankton population in two seasons and three different water depth layers.

Significant correlation between environmental parameters and phytoplankton variables on the spatial-temporal scale are shown (Table 5). A high positive correlation was established for water temperature, dissolved oxygen concentration and nitrate. pH correlated positively to water EC, chlorophyll, nitrite, ammonium and phosphate. Chlorophyll concentration positively correlated to nitrite, ammonium and phosphate. Species diversity index of Shannon-Wiener were calculated for the phytoplankton community of the Bandar Abbas coastal water at the surface (1 m) (0.874), mid-depth (5 m) (0.868) and bottom (0.653). Phytoplankton species diversity is addressed in relation to two periods for each sample which reflects the level of organization of the phytoplankton community of Bandar Abbas coastal open waters.

Table 2: Analysis of variance (mean squares values) for physical characteristics of Bandar Abbas coastal water

Source of variation (S.O.V)	Temperature	Turbidity	pH	EC	Dissolved oxygen
Repeat	0.107^{ns}	1068.00^{ns}	0.004800^{*}	4166666.67^{ns}	0.015^{ns}
Depth	0.127^{*}	199.21^{ns}	0.000620^{*}	95000.00^{ns}	0.082*
Error	0.007	216.74	0.000017	1021666.67	0.005

* Significant at the 0.05 level of probability, ** significant at the 0.01 level of probability and ns = non-significant

Table 3: Biotic characteristics of coastal water in various depth layers of 1, 5 and 10 m

	March			September		
Family	**1 m No./mL**	**5 m No./mL**	**10 m No./mL**	**1 m No./mL**	**5 m No./mL**	**10 m No./mL**
Bacillariophyceae						
Amphora	50	40	30	0	0	0
Amphiprora	40	30	20	0	0	0
Biddulphia	20	20	15	0	0	0
Bellerochea	20	15	10	0	0	0
Bacteriastrum	30	30	10	0	0	0
Campylodiscus	10	5	0	0	0	0
Cerataulina	10	0	0	0	0	0
Cyclotella sp.	500	360	300	750	500	250
Dactyliosolen	10	15	10	0	0	0
Diploneis	10	10	10	0	0	0
Eucampia	10	5	0	0	0	0
Lauderia	15	10	10	0	0	0
Melosira sp.	50	40	20	0	0	0
Navicula sp.	300	230	200	310	140	50
Nitzschia sp.	300	200	150	280	140	80
Pinnulria	50	40	30	0	0	0
Rhizosoleniasetigera	10	15	5	0	0	0
Skeletonem	0	0	0	300	160	40
Streptothca	0	0	0	270	130	100
Stephinophyxis	0	5	5	0	0	0
Thalassionema	10	5	0	0	0	0
Chrysophyceae						
Dictyocha	15	5	0	0	0	0
Cyanophyceae						
Anabaena	50	30	10	0	0	0
Phormidium	30	30	20	0	0	0
Spirullina sp.	40	35	20	0	0	0
Oscillatoria sp.	30	15	0	0	0	0
Dinophyceae						
Alexandrium	0	10	0	0	0	0
Ceratium	0	0	5	0	0	0
Dinophysis	20	10	5	0	0	0
Gymnodinium sp.	300	230	60	320	147	33
Oxytoxum	0	5	0	0	0	0
Protoperidinium	60	40	20	0	0	0
Scripciella	0	0	10	0	0	0
Euglenaphyceae						
Eutreptia	50	40	30	0	0	0

Table 4: Comparison of the phytoplankton population in Bandar Abbas coastal water.

Parameters	**Bacillariophyceae**	**Dinophyceae**	**Cyanophyceae**	**Euglenophyceae**	**Chrysophyceae**
Mean	1140.80	5.00	62.50	212.50	26.00
Standard error (S.E)	485.52	6.32	57.07	38.26	17.20
Minimum value	52.00	0.00	5.00	33.00	6.00
Maximum value	1910.00	15.00	150.00	380.00	50.00

Table 5: Correlation matrix between water abiotic and biotic parameters.

	Temp.	DO	pH	EC	Chl.	NO_2	NO_3	NH_4	SiO_3	PO_4	G1	G2	G3	G4	G5
Temp.	1.00														
DO	0.96	1.00													
pH	-0.50	-0.24	1.00												
EC	0.01	0.26	0.83	1.00											
Chl.	-0.51	-0.25	0.99	0.79	1.00										
NO_2	-0.42	-0.17	0.98	0.90	0.95	1.00									
NO_3	0.89	0.79	-0.71	-0.35	-0.70	-0.68	1.00								
NH_4	-0.54	-0.29	1.00	0.81	0.99	0.98	-0.75	1.00							
SiO_3	0.58	0.33	-0.99	-0.78	-0.99	-0.97	0.77	-0.99	1.00						
PO_4	-0.58	-0.33	1.00	0.78	0.99	0.97	-0.77	1.00	-0.99	1.00					
G1	0.67	0.77	0.10	0.62	0.02	0.26	0.36	0.06	-0.02	0.01	1.00				
G2	0.93	0.98	-0.25	0.24	-0.26	-0.17	0.75	-0.30	0.34	-0.33	0.78	1.00			
G3	0.91	0.80	-0.76	-0.36	-0.76	-0.71	0.98	-0.79	0.82	-0.81	0.41	0.79	1.00		
G4	0.92	0.94	-0.32	0.20	-0.36	-0.21	0.81	-0.37	0.41	-0.41	0.83	0.92	0.82	1.00	
G5	0.85	0.68	-0.87	-0.49	-0.88	-0.81	0.94	-0.90	0.91	-0.91	0.34	0.68	0.97	0.73	1.00

G1: Bacillariophyceae; G2: Dinophyceae; G3: Cyanophyceae; G4: Euglenophyceae; G5: Chrysophyceae.

The phytoplankton and physical-chemical data parameters through PCA are indicated in Figures 3 and 4. The Scree plot derived from 15 variables is shown in Figure 3. Based on the Scree plot, two principal components (PCs) were considered. Figure 4 reflects the plot of principle components 1 (PC1) and 2 (PC2) of the principle components analysis (PCA) results obtained from data of seawater in the Bandar Abbas coastal water, Persian Gulf. The results reflected in the plot 4 shows that there is positive correlation between pH, EC, nitrogen and phosphorus nutrients, and chlorophyll in the first principal component. PCA identifies the two directions (PC1 and PC2) along which the data have the largest spread. The first and second principal components explains about 67.0% and 29.5% of the variation, respectively. These two components accounted for 96.5% of the total variation recorded. Figure 4 shows that 8 variables have negative projection on the first component. This means that there is a negative correlation between Dinophyceae, Cyanophyceae, Euglenophyceae, Chrysophyceae, temperature, DO, NO3, SiO_3 and other variables. In the second compartment, 5 variables have negative projection on the second component. In the second component, pH, chlorophyll, NO_2, NH_4 and PO_4 variables have negative correlation with other variables. This axis separates chlorophyll, pH, and phosphate from other variables. The variables with the lowest value of the first and second components are Bacillariophyceae, and SiO_3, respectively. Similarly, the highest values of the first and second compartments are pH, and DO respectively

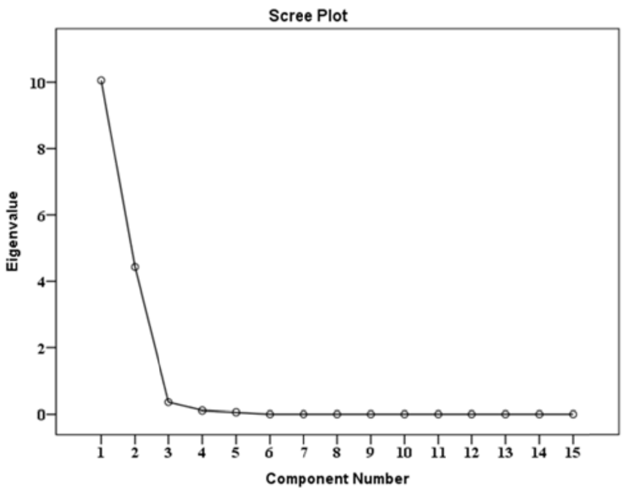

Fig. 3: Scree plot derived from 10 various variables of seawater in the Bandar Abbas coastal water, Persian Gulf indicating two principle components.

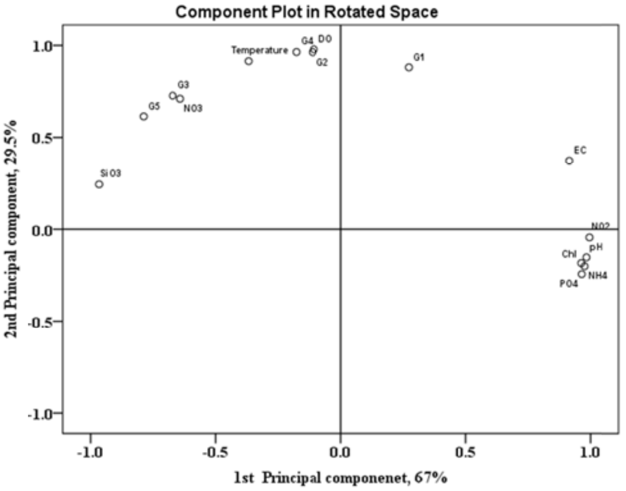

Fig. 4: Plot of 1st and 2nd principle components of the principle components analysis (PCA) results obtained from phytoplankton and physical-chemical data of seawater in the Bandar Abbas coastal water. The horizontal axis shows projections on to the first principal component and the vertical axis shows the projections on to the second component. Variable names are written at their projections on to the components. (NH_4= ammonium; PO_4= phosphate; Chl.= chlorophyll; NO_2= nitrate; EC= electrical conductivity; DO= dissolved oxygen; NO_3= nitrate; SiO_3= silicate). G1, Bacillariophyceae; G2, Dinophyceae; G3, Cyanophyceae; G4, Euglenophyceae; G5, Chrysophyceae

4. Discussion

The effective biotic and abiotic parameters of Bandar Abbas shoreline open seawater were investigated. The purpose of investigation was to evaluate biotic and abiotic parameters which providing insights for seawater intake and pretreatment process design of desalination plant and environmental protection.

The physical water characteristics exhibited some minor increases in electrical conductivity and a decrease in pH during two seasons and at three depth layers, both of which have minimal impact on membrane treatment efficiency (Molelekwa et al., 2014). These variations may be due to local seasonal change and water evaporation. The turbidity was reduced significantly between seawater September and March samples. In addition, a slightly reduction in concentrations of phytoplankton population during two periods occurred.

Various types of phytoplankton with different densities were recognized in the water samples. Some phytoplankton are among toxin producers. The type of recognized phytoplankton are almost similar to other reported organisms in the Persian Gulf area (Rao and Al-Yamani, 1998; Al-Yamani et al., 2006; Villacorte et al., 2015; Polikarpov et al., 2016).

Season is the main parameter in the phytoplankton communities. It changes with a relatively regular and irregular patterns of seasons and events such as red tide phenomena. A previous reports found that in the research area, concentration of phytoplankton is highest in the August (Hamzehei et al., 2013). The concentration of phytoplankton obtained in this research was higher in the summer sampling compared to the winter samples, almost similar to published reports (Chellappa et al., 2008; Pouladi et al., 2017). Coastal open seawater are important in the development of Hormozgan province and are more vulnerable to human impact on phytoplankton dynamics and inland fisheries of the province (Afshar et al., 2014). The spatio-temporal distributions of major phytoplankton taxa were quantified to estimate the relative contribution to abundance, cyanobacteria bloom dynamics and chlorophyll biomass in the Bandar Abbas coastal seawater. Water depth influences phytoplankton communities and their suspension to water layers. Although, we did not measure the light penetration, light attenuation is one of the main parameter influencing phytoplankton communities in coastal shallow waters (Krause-Jensen and Sand-Jensen, 1998; Goela et al., 2015). Although, the light penetration varied on a seasonal basis, more favorable conditions in winter caused higher phytoplankton abundance with chlorophyll biomass linked to phytoplankton abundance. The present study indicates that the variation in temperature among the sampling site are relatively small and less than one degree. Bandar Abbas coastal water maintained a high phytoplankton species richness (34 taxons) during the 2015-2016 examined, which is very nearly similar to the report of Lababpour et al. 2013 on algal species in three sites in the Qeshm Island coastal water of Persian Gulf.

The results of this study demonstrate that density and population of phytoplankton changed during September and March sampling. Phytoplankton species diversity reflects important processes such as growth, sedimentation, possible grazing losses and nutrient assimilation, which varies markedly in relation to spatial heterogeneity and the dry/wet annual cycle (Pouladi et al., 2017).

5. Conclusions

The coastal water samples of Bandar Abbas exhibits great phytoplankton diversity with a total of 34 taxa distributed into 5 classes. The results obtained in the present study indicated that a diverse phytoplankton population is present in the Bandar Abbas coastal water in the following order of dominance: Bacillariophyceae> Dinophyceae> Cyanophyceae> Euglenophyceae> Chrysophyceae. Results demonstrated that species diversity index of phytoplankton is higher in the surface layer compared to other depth layers. These phytoplankton and abiotic factors affect the development of algal blooms which have subsequently affect the function of pretreatment unit systems. These conditions suggest a regulated technical and environmental management of intake seawater, would be required to prevent the risk of algal blooms which pose for presently working coastal desalination plants. The results may be useful as raw data in pretreatment process design prior to reverse osmosis desalination in order to mitigate significantly the reverse osmosis membrane fouling. In addition, may provide useful information in local desalination plants for pretreatment systems installations in local conditions. Further, provide insights to evaluate Bandar Abbas costal water from environmental and ecological sustainability prediction and modeling.

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