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Research Article

Evaluation of biodiversity of phytoplankton and determination of biological health quality of Arvand River (south west of Iran) using Trophic Diatom Index (TDI)

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Abstract

Phytoplankton is considered the primary producer of any ecosystem and is sensitive to environmental changes. Therefore, phytoplankton is a suitable indicator for evaluating river water quality. Change of the environment leads to changes in abundance, diversity, and dominance of phytoplankton communities. Six stations were selected from beginning of Arvand River (the point of tributary from Karun River, station 1) to the sea estuary (in Arvand Kenar, station (2015-2016). Phytoplankton sampling was conducted using a plankton net with 30-µm mesh size, with three replications in each station. Meanwhile, temperature, salinity, pH, dissolved oxygen (in field operations), nitrate and phosphate were measured in the laboratory with three replications. The results showed that 43 phytoplankton species were present in the sampling area. Ochrophyta division was most abundant with 32 species, followed by four divisions Chlorophyta (5 species), Cyanobacteria (3 species), Myzozoa (2 species), and Charophyta (1 species). The most dominant species in different seasons were *Coscinodiscus marginatus* from Bacillariophyceae, followed by *Oscillatoria* sp. from Cyanophyceae and *Ulothrix aequalis* from Chlorophyta. Mean total value of diatom trophic index was calculated to be 62.31+3.09 during the study period, indicating poor quality of the ecosystem and eutrophic condition. According to the results of correlation analysis (PCA), phosphate content was one of the most important factors affecting abundance and diversity of phytoplankton.

Keywords: Phytoplankton, Biodiversity, Trophic Diatom Index, Arvand River

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Introduction

Coastal and estuarine ecosystems are vital components of aquatic systems. They are significant sources for economic and social activities, such as aquaculture, fishing, and tourism (Boudaghpour *et al*., 2020). Time- and space-dependent changes in phytoplankton community (species composition, biomass and abundance) are resulted from complex interactions of physical, chemical, and biological processes (Kulk *et al*., 2021). Therefore, examining their temporal and spatial interactions with environmental factors and interpreting the processes that control them have a fundamental role in performance and efficiency of aquatic ecosystems (Jaccod *et al*., 2021).

Water quality can be calculated through organisms, such as diatoms and zooplankton, response to environmental changes. Also, Water Quality Index (WQI), based on physical and chemical factors, can be used to determine water quality (Almeida *et al*., 2014).

Diatom index is increasingly used to assess the condition of rivers (Chen *et al*., 2016). For this reason, it is often used as an indicator of water and environmental health (Karpinsky, 2010). Water pollution is a potential threat to primary producers such as diatoms and affects them; thus, diatoms can be used as a pollution indicator. Since diatoms are present in most waters, rapid changes in environmental conditions can be measured through them (Bellinger and Sigee, 2010). Diatoms are widely used as water quality indicators, especially in Europe, North America, and Australia. Similar results were also obtained by Nygaard-Palmer and Saprobic indices for Bahmanshir River health (Sakhaei *et al*., 2018), and use of microalgae as a source of omega-3 (Gorjzdadeh *et al*., 2016). The researchers evaluated the water organic pollution of Bahmanshir River based on saprobic index and reported the condition of the river as alpha-mesosaprobic. They also reported resistant phytoplankton to organic pollution in the river, which is a dangerous sign for reducing river water quality.

Panich-pat *et al*. (2009) reported that among phytoplankton collected in Chadeebucha Canal, Nakhon Pathom Province, 3 divisions, 56 genera, 96 species, the 4 dominant genera, *Oscillatoria*, *Euglena*, *Scenedesmus*, and *Phacus*, indicate low water quality, especially *Oscillatoria limosa, O. tenuis*, and *Desmodesmus communis* as top five species indicating wastewater containing organic substances in water resources.

Their results showed that eutrophic regions include communities with larger cells and more accumulation of phytoplankton biomass, while smaller cells are found in oligotrophic systems. Jiang *et al*. (2015) investigated the effect of physical and chemical factors on density of phytoplankton in Chang Jiang River estuary in China. Their results showed that diatoms and dinoflagellates were affected by upwelling and coastal currents, while cyanophytes and cryptophytes were more present in coastal warm and oligotrophic waters. Prasertsin and Peerapornpisal (2015)

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monitored water using phytoplankton in Lake Rama in Pathumthani, Thailand. These researchers found that through the factors affecting phytoplankton and based on composition of phytoplankton species and other measured parameters, it was determined that this lake is clean and has a mesotrophic status.

This study aimed to investigate changes in biodiversity and phytoplankton species composition in Arvand River and determine water quality of this river based on Trophic Diatom Index (TDI) as an indicator of river water pollution.

Materials and methods

Study area

Arvand River is one of Iran-Iraq Border Rivers, which is located in Khorramshahr and Abadan. The length of its border is 84 kilometers. Arvand River constitutes the meeting Karun River with Tigris and Euphrates rivers in al-Qurnah, which is 110 km north of Abadan. Seasonal sampling was done in 6 stations (from the beginning of Arvand River to the refinery and the estuary (Arvand Kenar city) from winter 2015 to autumn 2016. Geographical location of each station is shown in Figure 1 and Table 1.

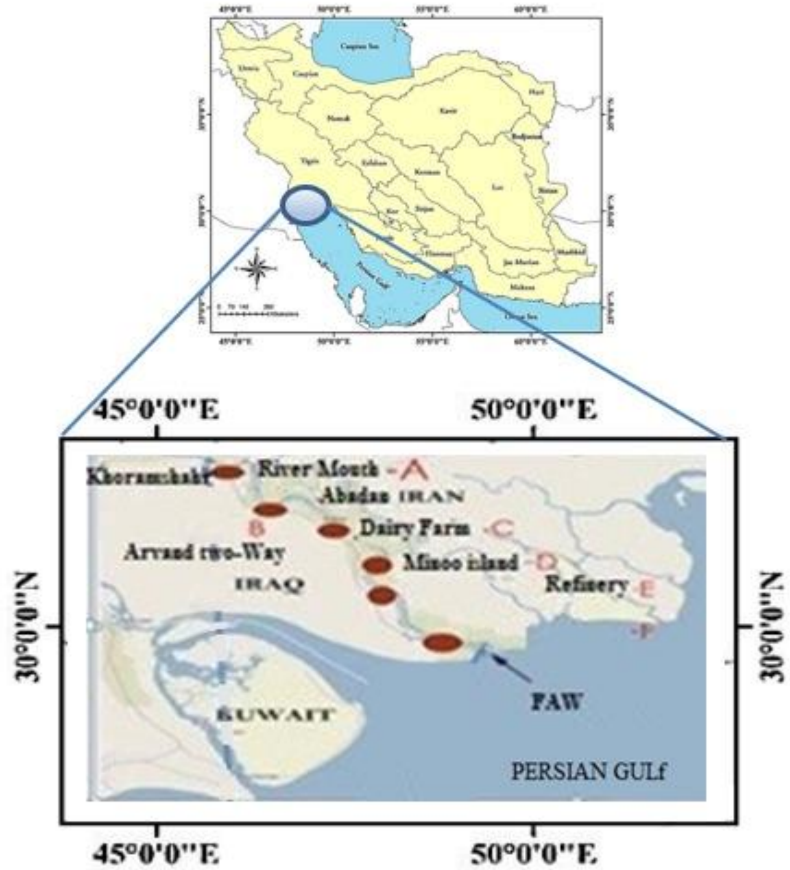

Figure 1: Study area in Arvand River

Table 1: The geographical location of studied stations in Arvand River, winter 2015 to autumn 2016.

Station Number	Station Name	Geographical location
1	The confluence of Karun River with Arvand River	30º 26´ 965″ N , 48º 7´ 267″ E
2	Two-way customs office	30º 55´ 552″ N , 48º 9´ 819″ E
3	Dairy Farm (Shipbuilding industry)	30º 22´ 584″ N , 48º 11´ 560″ E
4	Minoo Island (tourist area)	30º 22´ 011″ N , 48º 11´ 214″ E
5	Abadan Refinery	30º 20´ 333″ N , 48º 15´ 973″ E
6	Mouth of the estuary (Arvand-kenar - Faw estuary)	29º 58´ 108″ N , 48º 30´ 46″ E

Sampling and laboratory analyses

Phytoplankton samples were taken at half a meter below the surface at three stations using plankton net with mesh size with 30 µm, diameter 30 cm, and length 80 cm. The amount of filtered water in each replication was measured by rotating the flowmeter. The collected samples were transferred to storage containers and fixed with 4% formalin. The amount of filtered water in each replication was measured by rotating the flowmeter. Parameters such as salinity, dissolved oxygen (DO), electrical conductivity (EC), pH, and temperature were measured by salinity meter and Multi meter with three replications (Doane and Horwáth, 2003). Nitrate was measured by ultraviolet spectrophotometric screening method and Phosphate was measured by Ascorbic Acid method (APHA/AWWA/WEF, 2012). Nitrate was measured by a spectrophotometer with wavelengths of 230 and 210 nm, and phosphate by a spectrophotometer with 680 nm wavelength. After mixing the sample completely in a polyethylene container, 1 cc of the sample was used to fill the plankton chamber. The phytoplankton samples were identified using an Olympus TL2 inverted microscope and valid identification keys were used to identify phytoplankton genus and species (Cox, 1996; AL-Kandari *et al*., 2009; Bellinger and Sigee, 2010).

Data analysis

The following formulas (1 and 2) were used to calculate phytoplankton abundance in one cubic meter and in a liter of river water (APHA/AWWA/WEF, 2012):

$$D = (N \times v) / V \quad (1)$$

Where, D: Number of samples per cubic meter of water, N: Number of phytoplankton counted, V: The volume of water sampled, v: Sample volume of water that counted under a microscope.

$$N = \frac{C \times \acute{V}}{V \times V''} \quad (2)$$

Where N: Number of samples per cubic meter of water, C : Number of organisms counted under a microscope, V′: Volume of condensed water, V=Sample volume counted under a microscope, V'' =The volume of water measured by a flowmeter.

Shannon-Wiener diversity index (Jorgensen *et al*., 2005), Simpson dominance index (Ajmalkhan, 2004), and Hill biodiversity were calculated (Hill, 1973).

Using the Shannon-Wiener formula (3), biodiversity of phytoplankton was calculated as follows (Pettersson, 1998):

$$H' = -\sum_{i=1}^{s}\left[\frac{(ni)}{N}\ Ln\left(\frac{ni}{N}\right)\right] \quad (3)$$

Where ni: Relative abundance of an ith taxon in the sample, N: total number of taxa in the sample.

Trophic Diatom Index (TDI) was calculated by following formulas (4 and 5) (Kelly *et al.*, 2001):

TDI = (WMS. 25) - 25 (4)

WMS=n∑j=1Aj.Ij Vj/ n∑j=1Aj .Vj (5)

Where WMS is the weighed mean sensitivity of the taxa present in the sample, Aj: abundance (proportion) of species in sample, Vj: indicator value (1-3), Ij = pollution sensitivity (1-5) of species j.

WMS values ranged from 1 (for sites with very low nutrient concentrations) to 5 (for sites with very high nutrient concentrations) while TDI values ranged from 0-100 which illustrated below with their corresponding ecological states: The range of this index is from zero (low concentration of nutrients) to 100 (very high concentration of nutrients) (Table 1).

Results

In this study 47 taxa belonging to five phyla, including 25 families, 34 genera were identified. Identification was done to species level for 25 taxa, and to genus level for 18 taxa. The phylum Ochrophyta with one class (Bacillariophyceae), 14 families, 23 genera and 32 species was most diverse phylum followed by Chlorophyta with 3 classes, 4 families, 5 genera and 5 species, Cyanobacteria with one class (Cyanophyceae), 2 families, 3 genera and 3 species, Myzozoa phylum with one class (Dinophyceae), 2 families, 3 genera and 3 species and the phylum Charophyta with one class (Conjugatophyceae), one family, one genus and one species. The identified species are listed in Table 2.

Table 2: TDI index range and ecological conditions along with water quality category (Żelazowski *et al.*, 2004).

Ecological status	TDI	Trophic condition	Category of Water quality
Excellent quality	35>	Oligotrophic	1
Good quality	30-50	Oligo-Mesotrophic	2
Medium quality	50-60	Mesotrophic	3
Poor quality	60-70	Eutrophic	4
Very poor quality	75<	Hypertrophic	5

The results of one-way analysis of variance showed that there was significant difference among different stations in different seasons (p<0.05); however, no significant difference was observed among different seasons p>0.05. The highest Shannon diversity index in autumn was calculated to be 1.18±0.05. The highest value of this index (2.29±0.08) was obtained in winter in station 2 (Two-way customs office). The lowest value (0.24±0.11) was obtained in spring in station 4 (Minoo Island). The highest Simpson dominance index in spring was

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calculated to be 0.37±0.08 (Fig. 2 and Table 3).

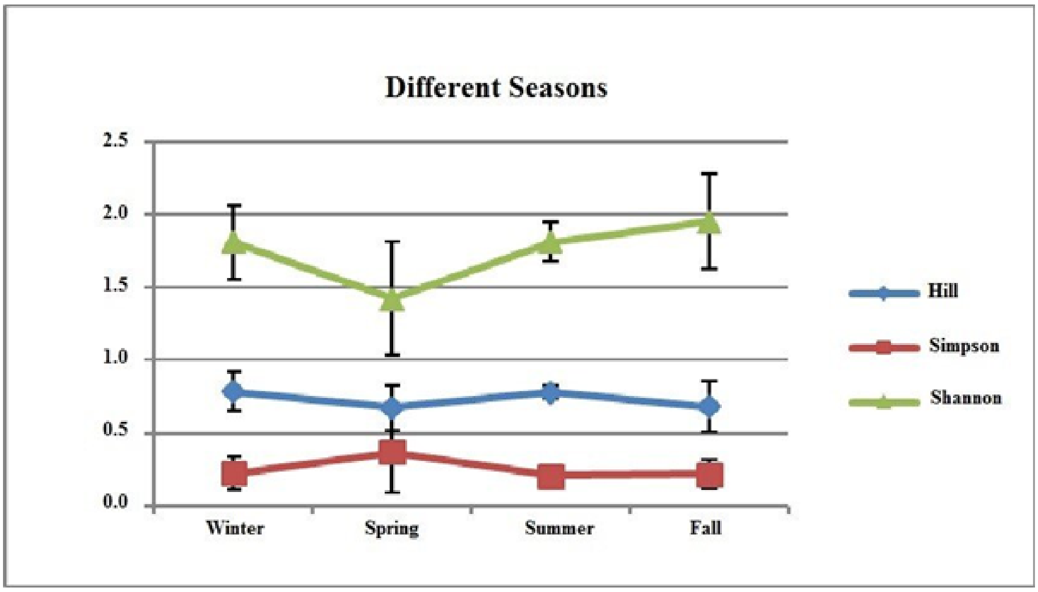

Figure 2: Changes in Shannon Diversity Index, Simpson Dominance Index and Hill Biodiversity Index in different seasons in Arvand River (2015-2016), error bars represent standard deviation.

Table 3: Identified phytoplankton during the study period (2015-2016), Arvand River.

Phylum	Class	Family	Species
Charophyta	Conjugatophyceae	Closteriaceae	*Closterium* sp.
Chlorophyta	Chlorophyceae	Hydrodictyaceae	*Pseudopediastrum boryanum* (Turpin) E. Hegewald, 2005
		Scenedesmaceae	*Scenedesmus quadricauda* (Turpin) Brébisson, 1835
			Tetradesmus obliquus (Turpin) M.J.Wynne, 2016
	Trebouxiophyceae	Chlorellaceae	*Actinastrum* sp.
	Ulvophyceae	Ulotrichaceae	*Ulothrix aequalis* Kützing, 1845
Cyanobacteria	Cyanophyceae	Merismopediaceae	*Merismopedia* sp.
		Oscillatoriaceae	*Lyngbya* sp.
			Oscillatoria sp.
Myzozoa	Dinophyceae	Ceratiaceae	*Tripos furca* (Ehrenberg) F. Gómez, 2013
		Protoperidiniaceae	*Protoperidinium* sp.
Ochrophyta	Bacillariophyceae	Bacillariaceae	*Bacillaria paxillifer* (O.F. Muller) T. Marsson, 1901
			Nitzschia acicularis (Kützing) W. Smith, 1853
			Nitzschia radicula Hustedt, 1942

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Table 3 (continued):

Phylum	Class	Family	Species
Ochrophyta	Bacillariophyceae	Chaetocerotaceae	*Bacteriastrum hyalinum* Lauder, 1864
			Chaetoceros atlanticus Cleve, 1873
			Chaetoceros curvisetus Cleve, 1889
			Chaetoceros decipiens Cleve, 1873
		Coscinodiscaceae	*Coscinodiscus marginatus* Ehrenberg, 1840
			Coscinodiscus oculus-iridis (Ehrenberg) Ehrenberg, 1840
			Coscinodiscus radiatus Ehrenberg, 1840
		Entomoneidaceae	*Entomoneis* sp.
		Fragilariaceae	*Diatoma* sp.
			Fragilaria sp.
			Synedra sp.
		Hemiaulacae	*Eucampia* sp.
		Mastogloiaceae	*Mastogloia* sp.
		Melosiraceae	*Melosira* sp.
		Naviculaceae	*Navicula lanceolata* (Kützing, 1844)
		Pleurosigmataceae	*Gyrosigma acuminatum* (Kützing) Rabenhorst, 1853
			Pleurosigma sp.
		Rhizosoleniaceae	*Sundstroemia setigera* (Brightwell) Medlin in Medlin et al. 2021
		Skeletonemaceae	*Skeletonema* sp.
		Stephanodiscaceae	*Cyclotella striata* (Kützing) Grunow, 1880
			Cyclotella stylorum Brightwell, 1860
		Surirellaceae	*Cymatopleura* sp.
			Surirella capronii Brébisson & Kitton in Kitton, 1869
			Surirella fastuosa Ehrenberg, 1843
			Surirella robusta Ehrenberg, 1840
			Surirella tenera W.Gregory, 1856
		Thalassionemataceae	*Thalassionema nitzschioides* (Grunow) Mereschkowsky, 1902
		Thalassiosiraceae	*Planktoniella* sp.
			Thalassiosira sp.

The results of dominant species in Table 4 show that *Cyclotella striata* was dominant in winter and did not have high density in other seasons. But *Cyclotella stylorum* had high density in spring and winter. *Coscinodiscus marginatus* had high density in autumn and spring, which increased the overall density of phytoplankton in these two seasons compared to summer and winter. *Bacillaria paxillifer* showed high density in winter and summer. *Oscillatoria sp.* of Cyanophyceae was also a dominant species in three seasons of summer, autumn and spring. Comparison of changes in values of Shannon diversity, Simpson dominance, and Hill indices in different seasons is shown in Figure 2.

Table 4: Total abundance of dominant phytoplankton species in different seasons, Arvand River (2015–2016).

Season	Species	Total abundance (cells/m^3)
Autumn 2015	*Coscinodiscus marginatus*	22330.53
	Scenedesmus quadricauda	40905.36
	Ulothrix aequalis	46302.86
	Oscillatoria sp.	45383.35
Winter 2015	*Cyclotella striata*	117820.61
	Bacillaria paxillifer	91275.89
	Cyclotella stylorum	53167.86
	Spirulina sp.	48870.33
Spring 2016	*Coscinodiscus marginatus*	703013.25
	Nitzschia radicula	60496.55
	Oscillatoria sp.	46017.61
	Cyclotella stylorum	40905.36
Summer 2016	*Ulothrix aequalis*	33896.35
	Oscillatoria sp.	32199.36
	Pleurosigma sp.	25573.36
	Bacillaria paxillifer	22679.76

The total value of this index during the research period was 62.31±3.09, which is in class 4 and according to Table 2 showed poor quality of the ecosystem and eutrophic status. Its highest rate (90±3.02) was in station 6 (Faw Estuary) in autumn and the lowest in summer and autumn. According to one-way analysis, there was a significant difference between seasons ($p<0.05$). Mean values of the diatom trophic index identified in the study stations are presented in Figure 3.

Physico-chemical parameters determined in the six-stations of the study area are summarized in Table 5. The lowest mean temperature was recorded at station 3 (Dairy Farm) in winter 2015, while the highest mean value was recorded at station 4 (Minoo Island) at the end of summer 2016. Minimum salinity was recorded 1.01 mg L^{-1} at station 1 (The confluence of Karun) in winter and maximum salinity was recorded at 8.81 mg L^{-1} at station 6 (mouth of the estuary) in Summer 2016.

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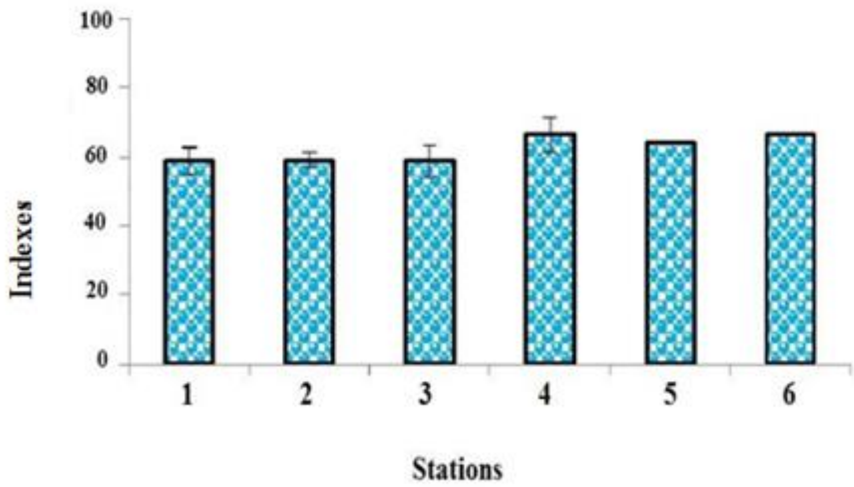

Figure 3: Changes in Trophic Diatoms Index, in different seasons in Arvand River (2015-2016), error bars represent standard deviation.

Table 5: Average values of physicochemical parameters of Arvand River in 2015–2016.

Season	Station	Temperature (°C)	Salinity (mg L^{-1})	pH	DO (mg L^{-1})
Autumn 2015	The confluence of Karun River	18.53	1.21	6.93	6.15
	Two-way customs office	17.13	1.39	6.96	6.09
	Dairy Farm	17.10	1.93	6.93	6.01
	Minoo Island (tourist area)	19.20	1.73	6.92	6.80
	Abadan Refinery	18.20	2.12	6.95	6.70
	Mouth of the estuary	17.13	8.21	6.90	6.22
Mean ± Standard Deviation		17.88 ± 0.64	2.75 ± 2.69	6.94 ± 0.89	6.3 ± 0.89
Winter 2015	The confluence of Karun River	14.43	1.01	7.95	6.80
	Two-way customs office	14.13	1.73	7.96	7.70
	Dairy Farm	13.10	1.83	7.99	7.10
	Minoo Island (tourist area)	14.10	1.86	7.99	6.55
	Abadan Refinery	15.20	2.14	7.85	6.66
	Mouth of the estuary	15.13	7.19	7.91	6.59
Mean ± Standard Deviation		14.35 ± 0.6	2.62 ± 2.27	7.94 ± 0.41	6.9 ± 0.28
Spring 2016	The confluence of Karun River	18.96	1.12	8.04	6.21
	Two-way customs office	18.52	1.22	8.33	6.98
	Dairy Farm	18.50	1.33	8.35	7.71
	Minoo Island	19.40	1.43	8.23	6.55
	Abadan Refinery	17.40	1.31	8.17	6.51
	Mouth of the estuary	17.70	6.76	8.08	6.50
Mean ± Standard Deviation		18.41 ± 0.34	4.14 ± 486	8.18 ± 0.49	6.7 ± 0.49

Table 3 (continued):

Season	Station	Temperature (°C)	Salinity (mg L^{-1})	pH	DO (mg L^{-1})
Summer 2016	The confluence of Karun River	26.00	2.15	8.16	6.21
	Two-way customs office	27.10	2.12	8.13	6.15
	Dairy Farm	27.30	1.89	8.20	6.19
	Minoo Island	28.00	1.90	8.29	6.10
	Abadan Refinery	27.02	2.04	8.19	6.16
	Mouth of the estuary	27.20	8.71	8.11	6.20
Mean ± Standard Deviation		27.1 ± 0.23	3.13 ± 2.73	8.18 ± 0.23	6.1 ± 1.23

The amount of nitrate and phosphate is measured and shown in Figures 3 and 4. One-way analysis of variance results showed significant difference among different stations in the sampling seasons ($p<0.05$). The highest level of nitrate (5.56 mg/L) was observed in spring in station 1 (near Khorramshahr city) and the lowest (1.10 mg/L) in station 6 (Fully offshore station) (Fig. 4). Phosphate levels were measured at different stations and seasons (2015-2016, Fig. 5).

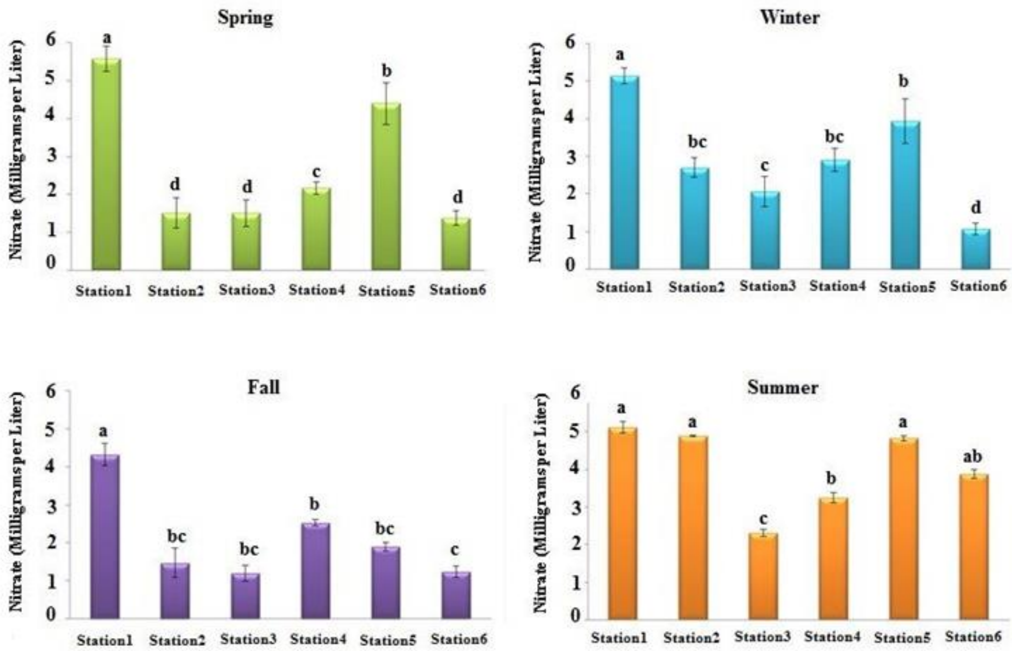

Figure 4: Changes in nitrate, in different seasons in Arvand River (2015-2016), error bars represent standard deviation (ANOVA, $p<0.05$).

Mean values of trophic diatom index identified in the study stations are presented in Table 6. Total value of this index during the research period was 62.31±3.09. Principal component analysis (PCA) was performed for environmental factors, including temperature, salinity, dissolved oxygen, acidity, nitrate, phosphate, and four groups of phytoplankton divisions during the study (Table. 7).

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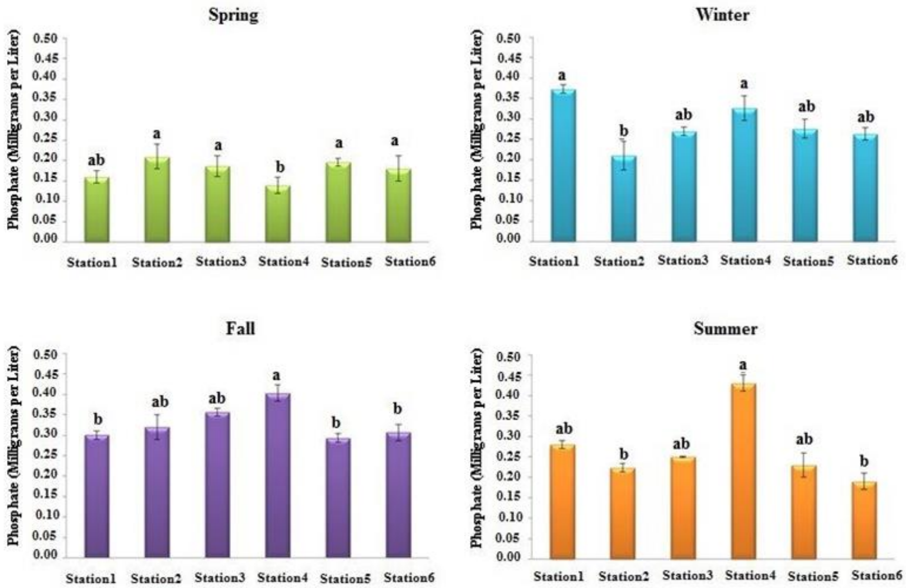

Figure 5: Changes in phosphate, in different seasons in Arvand River (2015-2016) error bars represent standard deviation, (ANOVA, $p<0.05$).

Table 6: Mean values (±standard deviation) of trophic diatom index (TDI) identified in the studied stations and different seasons 2015-2016, Arvand River.

Station	Winter	Spring	Summer	Autumn	Average	Water quality category
1	53.89±4.31	65±1.21	51.67±4.53	65±4.21	58.89±3.16	3
2	55.18±2.83	70.83±2.36	47.61±2.39	65.56±1.08	59.05±5.62	3
3	67.88±2.21	60.59±6.51	47±3.31	59.57±2.46	58.75±4.51	3
4	77.07±5.71	64.83±3.31	60.16±6.13	64.07±4.04	66.53±2.33	4
5	64.51±3.91	57.01±6.93	67.86±3.21	67.65±1.32	64.26±1.39	4
6	65±1.31	65.69±2.21	44.91±1.13	90±3.02	66.4±9.93	4
Average	63.92±3.79	63.99±2.14	53.2±4.64	68.14±5.18	62.31±3.09	4
Category	4	4	3	3	4	

The results of PCA showed that factors of Axis 1- Axis 2 contained more than 78 percent of the information. By reviewing Table 7, it can be concluded that DO, total abundance of phytoplankton and temperature parameters were more important for the first main component and pH, phosphate and Chlorophytes were important for the second main component, and Salinity was important for the third main component.

Table 7: Inter-set correlation of significant environmental factors and phytoplankton ($p<0.05$) with first three ordination axes of PCA.

Parameters	Axis 1	Axis 2	Axis 3
Temperature	-0.314	-0.174	-0.096
Salinity	-0.296	-0.009	0.428
DO	0.332	-0.082	0.044
pH	0. 005	-0.496	0.127
Phosphate	0.198	0.401	0.119
Nitrate	0.289	-0.033	0.1473
Bacillariophyceae	0.280	-0.147	-0.433
Cyanophyceae	0.249	-0.060	0.603
Dinophyceae	-0.298	-0.197	0.226
Chlorophyta	0.026	0.478	0.246
Total abundance of phytoplankton	0.322	0.118	0.161
Shannon Index	-0.251	0.328	-0.115
Simpson Index	0.299	0. 228	0.049
Hill Index	-0.308	-0.179	0.177
Trophic Diatom Index (TDI)	0.257	0.276	0.193

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Discussion

Along Arvand River several factors, such as urban and rural sewage discharge into the river, agricultural lands and overflow of its agricultural effluents into the river, tidal condition of the river and infiltration of saline sea water, and industrial wastewater of Abadan refinery and customs affect water quality of Arvand River.

Results of phytoplankton abundance study showed that Bacillariophyceae (Diatoms) division had the highest percentage in winter, among them *Cyclotella striata* and *Bacillaria paxillifer* were the highest in this season (Table 4). Diatoms were usually predominant in autumn and winter, as observed in Alchichica, and this increase was attributed to an increase in nutrients in the cold season (Oliva *et al*., 2008). In the results of the present study, phosphate in cold seasons had large amounts that have increased diatoms (Fig. 5). According to Table 5, increase in the frequency of different species of the genus *Cyclotella* in different seasons in Arvand River indicated existence of eutrophication in this river. Al-Hejuje *et al*. (2014) noted that the status of this river ranged from moderate quality to poor and degraded quality, eutrophication level ranged from high to elevated (very high). *Oscillatoria* species of Cyanophyceae (blue-green algae) were among dominant species of Arvand River in spring (46017.61cells/m^3), summer (32199.36cells/m^3) and autumn (45383.35cells/m^3) (Table 4). Increase of this genus also indicated eutrophication status of Arvand River. Other researchers have reported presence of *Oscillatoria* as a sign of eutrophication (Brabrand *et al*., 1983; El-Sheekh *et al*., 2003).

Changes in genera composition and predominance of phytoplankton can occur by different mechanisms such as temperature restriction, amount of light, and amount of nutrients, deposition and consumption by zooplankton, etc. (Ortega-Mayagoitia *et al*., 2011).

The highest Shannon diversity index was 1.9 in autumn and the lowest was 1.4 in spring (Fig. 2). Approximately changes in the Simpson dominance index are the opposite of changes in Shannon variability. In spring, *Coscinodiscus marginatus* with a density of 703013.25cells/m3 was the dominant species (Table 4). Increasing the frequency of this species increased Simpson dominance index and decreased Shannon index in spring.

Nutrients such as nitrate and phosphate are other environmental factors affecting abundance and diversity of phytoplankton (Larson and Belovsky, 2013). Amount of nitrate in spring in station 1 was higher than that in other seasons, which was due to entry of human wastewater and entry of agricultural effluents into the city of Khorramshahr (Fig. 2). The lowest amount of nitrate in summer was in station 6 (Fully offshore station), followed by station 5 (Abadan Refinery station), which could be due to entry of Abadan refinery effluents. Also, changes in phosphate content (0.45-0.17 mg/l) in Figure 2 showed that the highest phosphate level was determined in summer and station 4 (Mino Island). One-way analysis of variance showed significant difference among different stations in sampling seasons ($p<0.05$). Disposal of domestic sewage in Minoo Island mainly includes disposal of household effluents containing chemical detergents (such as washing powders) and large amounts of phosphorus. Also, polymer phosphates in detergents are widely used in construction and therefore have a significant concentration in the effluent. Finally, phosphate enters the river along with industrial wastewater. As a result, it causes rapid growth of aquatic algae (phytoplankton) and is a disturbing factor in purification processes (Rezaei and Samimi, 2013). Amount of phosphate in autumn and summer in station 5 (Abadan Refinery) was the lowest (Fig. 5). Oil pollution from the refinery has accumulated in sedimentary layers, which reduces the amount of phosphate and nitrate (Parsons *et al*., 2015). Increased nutrients due to human activity stimulate growth of phytoplankton through photosynthesis. Arvand River increases primary production and species diversity with entry of agricultural effluents (Effendi *et al*., 2016).

Mean total value of trophic diatom index (TDI) during the research period was 62.31±3.09 (Table 6). Results of TDI show that the state of Arvand River was eutrophic and was in 4th category. According to Table 2, water quality of this river was low and was in eutrophic condition. The main advantage of using diatoms as an indicator of rapid response to environmental changes is their presence in all regions and their global distribution (Feio *et al*., 2009). Diatom indices are usually area-specific and may not be appropriate for assessing ecological continuity of running water in other areas (Pipp, 2001). Al-Abbawy (2012) examined trophic state of Arvand River using TSI index and concluded that Arvand River is in mesotrophic condition. Eutrophication depends on physical, chemical, and biochemical factors. Therefore, a set of different parameters must be considered to conclude actual eutrophication of water areas. In other words, due to complexity of eutrophication of ecosystems, one parameter cannot show its condition (Howarth *et al*., 2011; Schletterer *et al*., 2011).

Changes in salinity among different stations have decreased significantly while distancing from Faw estuary and moving upstream of the river (Table 5), the highest amount of which was recorded in summer in station 6 due to increase in temperature and evaporation level in this season. According to the results of PCA (Table 7), the highest positive correlation was found between total density of phytoplankton and dissolved oxygen in the first component; however, temperature and Hill index were inversely correlated in the first component. The highest correlation between phosphates, trophic diatom index (TDI), Chlorophyceae, and Shannon index was found in the second component (Table 7).

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It seems that biodiversity of Arvand River phytoplankton has led to a eutrophic condition. Also increase in nutrients, especially phosphate and nitrate, in Arvand River indicate the eutrophic condition of this river. Factors, such as entry of Ahwaz municipal wastewater into Karun, Khorramshahr municipal wastewater to Karun in Khorramshahr and Abadan Arvand River wastewater, wastewater of Basra and Faw cities and other towns on the Iraqi border, and entry of other industrial effluents into this aquatic ecosystem increased nutrients and ultimately created a eutrophic condition. The present study investigated for the first time the Trophic Diatom Index (TDI). These results of TDI showed that the state of Arvand River was eutrophic. The data obtained from this study can serve as data on changes in pollution that can be caused by human activities, such as sewage disposal, fish ponds, oil, and gas. The information of this study can be used for the Department of the Environmental and General Administration of Ports and Shipping in this region.

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