Development of Trophy Index along South-East Coast of Oman Sea and its Relationship with Harmful Algae Bloom

A.R. Karbassi[1], E. Mahin Abdollahzadeh[2*], G. Attaran- Fariman[3], M. Nazariha[1], M. Mazaheri-Assadi[4]

[1] Faculty of Environment, University of Tehran, Tehran, Iran
[2,*]Faculty of Environment, University of Tehran, Tehran, Iran,
[3]Department of Marine Biology, Faculty of Marine Sciences, Chabahar Maritime University, Chabahar, Iran
[4]Biotechnology Center, Iranian Research Organization for Science and Technology, Tehran, Iran

ABSTRACT

In the recent years more population are gathered along southern coasts of Oman Sea as a result of industrial development. Thus, more untreated wastewaters are being discharged into the Oman Sea. Study of the indices that determine the state of eutrophication in coastal waters is of special importance. Such studies will be used to control pollution and subsequently to prevent the phenomenon of algal blooms. In the present investigation, chemical and biological parameters in the southeast coasts of the Oman Sea were determined to develop trophy index (TRIX). The average six-month value of TRIX varies from 5.24 to 6.45 and decreases (on average) as we approach the eastern part of the Oman Sea. Unfortunately, all of the stations showed eutrophic and hypertrophic conditions due to discharge of wastewaters from urban and industrial sectors into the coastal waters. The highest and lowest values of TRIX index is observed in mid-September and early May, respectively. It should be pointed out that TRIX value increases during the summer, especially after the monsoon phenomenon. The four identified species of phytoplankton that are responsible for algal blooms include Cochlodinium, Prorocentrum, Rhizosolenia and Leptocylindus. Statistical analysis revealed a good correlation amongst these species with nitrate, phosphate, and chlorophyll a content of coastal waters. It can be inferred that nutrients and chlorophyll a can be very influential in the occurrences of algal blooms in coastal waters of the Oman Sea.

KEY WORDS: TRIX, algal bloom, nutrient, chlorophyll a, Cochlodinium

1. INTRODUCTION

Coastal waters are among the most important valuable water resources from the economic, social, and recreational points of view. Coastal waters are being deteriorated by the negative effects associated with the development of societies and industrial activities. Untreated discharge of urban and industrial wastewaters are among the main sources of pollution in coastal waters. Moreover, the phenomenon of red tide or phytoplankton bloom has been observed in the waters of the Persian Gulf and the Oman Sea in recent years [1], and has reduced the quality of these waters. Use of qualitative indices is one of the common and simple methods employed worldwide for evaluating the quality of coastal waters [2]

Seas have their own unique characteristics and differ from each other in nutrients, and population and species of local phytoplankton. For this very reason, it seems unlikely that a qualitative index suitable for all coastal regions can be found because each of the available indices developed so far has its own limitations. Among the various types of qualitative indices, the TRIX index is dependent on the parameters of the studied region and can be developed. Moreover, it considers physical parameters in addition to biological ones. Furthermore, a simple function is introduced in the TRIX index for determining the qualitative status of the coastal regions that can be used as the basis for comparing various regions through applying a 0-10 scale for water status. The TRIX index is more accurate than other qualitative indices because it uses a larger number of qualitative parameters [3, 4]. In this method, chemical and biological parameters are changed into a single number and scaling and classification of these numbers makes it possible to determine to what class the quality of a specific body of water belongs [5]. Marine eutrophication is a coastal phenomenon resulting from a massive nutrient inflow into the sea. Human activities including disposal of urban wastewater, agriculture, and industry substantially accelerate this process. Bodies of water are classified into the classes containing low (Oligotrophic), average (Mesotrophic), high (Eutrophic), and very high (Hypertrophic) quantities of the various groups of nutrients, and one of the uses of the indices is to determine the probability of occurrence of eutrophication [3].

Corresponding Author: E. Mahin Abdollahzadeh, Faculty of Environment, University of Tehran, Tehran, Iran,
e.abdollahzadeh@ut.ac.ir

In the coastal waters of Iran, as in most sensitive coastal regions of the world, phytoplankton blooms have occurred during the past two decades. When the population of phytoplankton exceeds one million cells per liter of water, algal bloom occurs and the high density of phytoplankton (diatoms, dinoflagellates, and blue-green algae) in the water changes its color to green, milky, red, brown, or orange. Among the main contributing factors are rising temperatures and the entrance of chemicals such as nitrate and phosphate caused by human activities [6-8]. A harmful algal bloom caused by *Cochlodinium polykrikoides* happened in September 2008 extending from the south of the Oman Sea to the Strait of Hormuz and the Persian Gulf and lasted for more than nine months [1, 9]. One of the natural factors in the occurrence of red tide is the rising of warm currents that are rich in nutrients. Based on Herring's theory, winds that blow in the various seasons are one of the main causes of harmful algal blooms. These winds cool surface waters and raise the level of the deeper and warmer waters, which is followed by the transfer of nutrients together with large volumes of dinoflagellates to the surface of the water [10].

In this research, TRIX index was developed as a qualitative index for the waters in the Oman Sea. The intra relationships amongst various parameters such as chlorophyll, dissolved oxygen, nitrogen ($N-NO_3$) and phosphorous ($P-PO_4$) with the identified species forming the algal blooms were simultaneously evaluated by cluster analysis.

1. MATERIALS and METHODS

1.1.   Study Area

The Oman Sea is a triangular strait situated between Iran, Oman, and Pakistan. It is surrounded by land on three sides and connected to the high seas on the other hand. The southern coasts of Iran stretches from the Strait of Hormuz to the Gwatar Port on the Oman Sea. The length of the Oman Sea from the Strait of Hormuz to Deccan is about 610 kilometers. It covers an area of 9.03×10^5 km^2. This sea is relatively deep (as deep as of 3500 meters). Its depth decreases on its western part and declines to 72 meters near the Strait of Hormuz. Since the Tropic of Cancer passes through this sea, it is considered one of the warm seas of Southwestern Asia. The waves generated in the Oman Sea are mostly influenced by monsoon winds. Small ports like Jask, Chabahar, and Gwatar are located in the coastal region of this sea and are used for trade and sea transportation. The important cities bordering this sea are Chabahar and Jask in Iran and Muscat in Oman.

The data used in this research included qualitative parameters along the coasts of the Oman Sea. As shown in figure 1 the sampling Stations were selected in the regions of Passabander (station 1), Bris (station 2), Ramin (station 3), Chabahar (station 4), Pozm (station 5), Kalat (station 6), and Galak (station 7).

The reasons for choosing these ports are: Pasabandar is open coast a place that HABs events happen regularly [11, 12]. In Bris and Ramin ports discharge of Tuna fishing industry has been observed. Station 4 located in the Chabahar bay along the Chabahar port almost in the middle of the southeast coast of Iran near the town of the Chabahar and is the main fishing ground for lobster in the region and in the past 5 year has been berth construction in port. Station 5 located in the Pozm port near the fishing harbor. Station 6 is also near the fishing harbor and station 7 there are no any berth in this area but is under construction [11, 12]. Samples were taken in the spring and summer of the year 2009.

**Figure 1: Sampling locations along the South-East coastal area of Oman Sea
(adapted from Attaran-Fariman, 2010)**

1.2.   Field measurements

Water samples were collected once every two weeks from late April to late September 2009. It is usually not possible to collect samples during the period of monsoon winds due to wind intensity and occurrences of severe storms, therefore, samples could not be taken in July/August [1].

Samples were collected from depths up to 50 cm using Rotner bottles or employing one-liter simple bottles employing the method introduced by Sournia (1978) [13]. In each region, one sample was used for studying the phytoplankton, one for examining the chemical factors, and one for measuring chlorophyll a. Salinity, temperature, transparency, nitrate, phosphate, silicon, dissolved oxygen, and chlorophyll a were measured. The phytoplankton samples were fixed at the sampling Stations using Lugol's solution and employing the method introduced by Parsons *et al,* 1992) [14]. If phytoplankton masses were observed at any   Station, another sample was taken but this one was not fixed.

Winkler bottles were used for determining dissolved oxygen. Three mL of manganese chloride and the KI NaOH indicator were added to each sample at the sampling Stations to fix the samples [15]. Salinity was measured using an MT110 model salinity meter with the accuracy of 0.1. Temperature was measured by a thermometer with the accuracy of 1˚C. Finally, the transparency of waters were determined by Secchi disk.

The samples were then sent to the laboratory for measuring the parameters and for studying the phytoplankton. Live phytoplankton samples were examined at the laboratory using a light microscope equipped with a camera. The phytoplankton species in the samples were identified using Internet sources, available identification guides, and various published articles. Chlorophyll a was measured using the method introduced by by Regional Organization for the Protection of the Marine Environment [16, 17] in mg/m^3 or µg/l, and pH was determined using a WTW-320 model pH meter. The method introduced by Manual of oceanographic observations and pollutant analyses methods (colorimetric spectrophotometric method) was used to measure nitrate (N-NO_3) employing a DR2000 model spectrometer and reading light absorption at 500 nm wavelength. A Hitachi U-2000 model spectrophotometer was employed for measuring phosphate and silicate at 882 and 810 nm wavelengths, respectively [15].

2.3. Trophic Index (TRIX)

The data used to develop this index have been collected from 1982 to 1993 in Adriatic Sea along the Emillia-Romagna coasts [3]. The component of TRIX are chlorophyll a (milligrams per cubic meter), total nutritional factors (NT, PT; milligrams per cubic meter), or mineral nutritional factors *(*N_{min} = N − *(*NO_3 +NO_2 + NH_4*)*, P − PO_4; milligrams per cubic meter) and oxygen as absolute deviation from saturation [aD%O = ABS(100 − %O)]. Distribution of these parameters is assumed to be lognormal and the basic structure of the TRIX is:

$$TRIX = \frac{K}{n}\sum_{I=1}^{N}\left[\frac{LogM_i - LogL_i}{LogU_i - LogL_i}\right] \qquad (1)$$

where M_i is the measured value, U_i is the upper limit, L_i is the lower limit, *n* is number of parameters, and TRIX value is between zero and *K*. To simplify the calculation, the range of ($LogU_i$− $LogL_i$*)* in Emillia-Romagna coast was standardized to three, *K* was fixed to 10 and the number of parameters was four. Putting these values in equation (1), we obtained:

$$TRIX = \frac{10}{4} * \left[\frac{Log(Chla*aD\%O*N*P) - Log(Chla_{min}*aD\%O_{min}*N_{min}*P_{min})}{3}\right] \qquad (2)$$

Finally, the TRIX was calculated as [3]:

$$TRIX = \frac{Log(Chla*aD\%O*N*P) - (-1.5)}{1.2} \qquad (3)$$

This method expresses a simple number for water quality that can be used for water quality classification. TRIX index includes both chemical and biological parameters, where nutrient parameters show the potential of the system for eutrophication and Chlorophyll a shows the existence of trophic state. It is worth mentioning that constant values in equation 3 are site specific and should be calculated in a new case study. Table 1 describes the values for describing the systems:

Table 1: List of values and the designations of the TRIX scale [3]

Scale TRIX	State water quality	Level of eutrophication
0-4	High	Low
4-5	Good	Medium
5-6	Bad	High
6-10	Poor	Elevated

2. RESULTS AND DISCUSSON

Average 6-month values of the qualitative parameters that can be used in the TRIX index (such as chlorophyll a, Nitrate (N-NO$_3$), phosphate (P-PO$_4$), and oxygen saturation deficits) are presented in Figure 2. As shown in Figure 2, the average values of nutrients, especially phosphate, increased from the Chabahar towards those in Jask that is indicative of more wastewater discharge at the latter station. Percentages of oxygen saturation deficits are highest at stations 4 and 5. Furthermore, Stations 5 and 7 had the maximum chlorophyll a values.
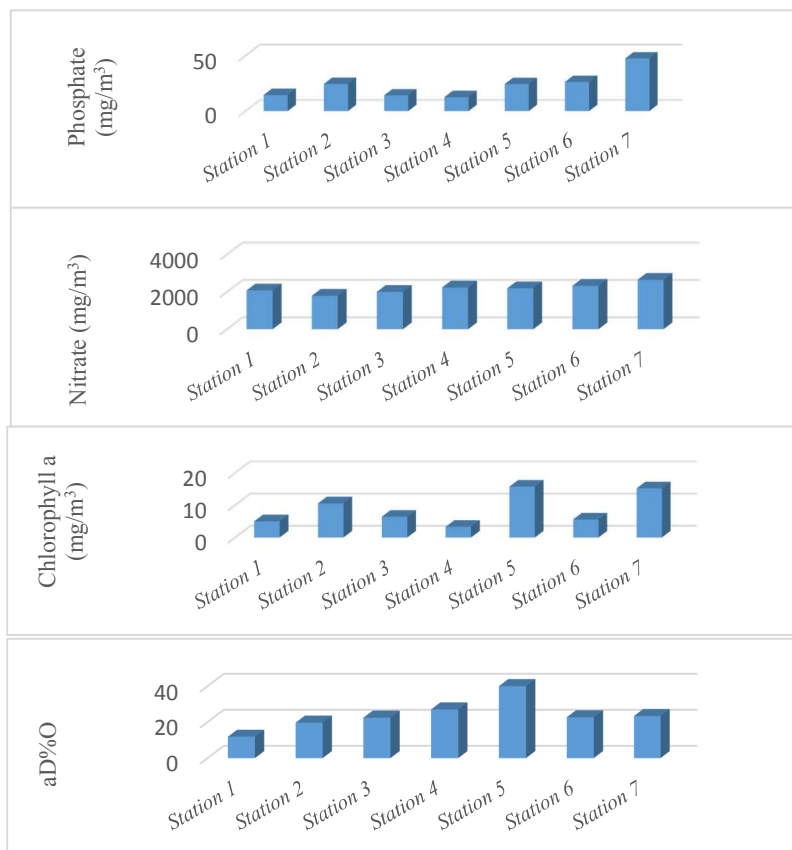

Figure 2: Semiannual mean values variation of the qualitative parameters including Phosphate, Nitrate, Chlorophyll a and deviation from saturation oxygen (aD%O) in the stations of South-East of Oman Sea

As shown in table 2, nutrient concentrations vary in different seas. Therefore, it is not surprising that different indices yield different results. TRIX variations in Oman coastal waters were different from TRIX variations in other coastal waters in the word. Table 2 compares mean values of chlorophyll a and nutrients in the four different coastal regions of the Oman Sea, the Persian Gulf [18], the Caspian Sea [4], and the Adriatic Sea [3]. The value of chlorophyll a in the coastal region of Oman Sea is six times that of the Persian Gulf coastal waters but lower than those of the other two coastal regions. Its average phosphate is four times that of the Adriatic but lower than that of the Caspian Sea coastal region. The Nitrate value in Oman Sea is the most highest as compared to those of the Persian Gulf, the Caspian Sea, and the Adriatic coastal regions. This implies that coastal water quality parameters vary in different seas and local indices cannot be used universally. The differences in the qualitative parameters of these waters are related to the environmental characteristics of the regions as well as urban industrial activities that result in chemistry of waters.

Table 2: Nutrient and chlorophyll a mean values in four different coastal areas [3, 4, 18]

Coastal area	Chl a (mg/m^3)	PO$_4$ (mg/m^3)	NO$_3$ (mg/m^3)	aD%O
Oman sea	8.85	23	2179	19.43
Persian gulf	1.42	24.61	114.26	8.57
Caspian sea	13.8	34.67	24	12.49
Adriatic	11.3	5.6	267.2	13.1

To apply the trophic index, outliers (values of parameters out of range $\mu \pm 2.5\ \sigma$) were removed after logarithmic transformation [3]. Data regarding the study region was converted into logarithmic form and analyzed using SPSS. Result of data distribution indicated normality of skewness/kurtosis. The Kolmogorov-Smirnov test was used to test normality of the data. Results obtained from the software indicate all test results had levels of significance higher than 0.05 and, therefore, the data could be considered normal with a high confidence interval).

As mentioned earlier, Eq. 2 is based on data from Adriatic Sea and it should be modified for the region in Oman Sea. For this purpose, the minimum, maximum, and range of each parameters used for TRIX in the Oman Sea were calculated (Table 3).

Table 3: Minimum, maximum and amplitude of TRIX component parameters

	NO$_3$ (mg/m^3)	PO$_4$ (mg/m^3)	a D%O	Chl a (mg/m^3)
Minimum (L)	600	2	0.031	0.362
Maximum (u)	4300	233	59.93	61.5
Log Minimum	2.778	0.301	-1.508	-0.441
Log Maximum	3.633	2.367	2.188	1.788
Amplitude (LogU-LogL)	0.855	2.066	3.697	2.230

The mean range of the amplitude (LogU-LogL) parameters was assumed to be 2.20 and the sum of log minimum of the parameters was selected as 1.13. The new trophic index was then calculated as:

$$TRIX = \frac{\log(Chla * aD\%O * NO3 * PO4) - 1.1}{0.84} \qquad (4)$$

After applying the above function on the qualitative data related to the Oman Sea, the TRIX index was obtained for the sampling stations for the period from about mid-April to mid-September (and is presented in Table 4). Figure 3 shows the average 6-month values for each station varies from 5.24 to 6.45, with the highest value at station 5 and the lowest that at station 1. The average values of the TRIX index for the stations related to each 15-day sampling are presented in Figure 4 where the maximum value of 6.6 belongs to mid-September and the minimum of 4.75 to early May.

Results of applying the TRIX index (which was developed for the Oman Sea) in the study region are shown in Table 4. The 15-day average of this index in the seven stations varied from 5.24 to 6.45. This average, which indicates the eutrophication of the study region, increased in the summer, especially after the monsoon phenomenon. According figure 5, Nitrate concentration during the sampling period has its maximum value in the September after the monsoon winds, which indicates that with the start of the monsoon, upwelling can be transfer middle and deep nitrogen-rich water layers to the surface and increasing the nitrogen concentration at the late monsoon period. This can also lead to an increase in the trophy index.

Table 4: The mean values of TRIX in Southeast Oman Sea in all stations

	20 Apr	5-May	20-May	5-Jun	20-Jun	6-Jul	21-Jul	6-Sep	21-Sep	Mean
Station 1	5.35	2.93	5.52	3.99	4.62	7.03	5.65	5.77	6.29	5.24
Station 2	5.81	5.09	5.45	4.68	5.76	7.09	4.84	7.04	6.84	5.84
Station 3	5.83	4.34	5.50	4.60	7.19	7.13	5.09	5.73	6.70	5.79
Station 4	5.49	4.80	5.30	5.87	5.69	5.93	5.18	6.29	6.56	5.68
Station 5	6.01	5.97	7.84	4.52	8.34	5.78	6.38	6.30	6.94	6.45
Station 6	6.14	4.97	6.87	6.57	6.06	5.07	6.48	6.69	6.70	6.17
Station 7	7.25	5.19	7.23	6.42	5.81	6.24	6.45	6.96	6.19	6.42
Mean	5.98	4.75	6.24	5.24	6.21	6.32	5.73	6.40	6.60	

However, the other stations, particularly station 5, were in the hypertrophic state, that can indicate more types and quantities of pollutants (especially urban and industrial wastewater, are discharged at these stations)
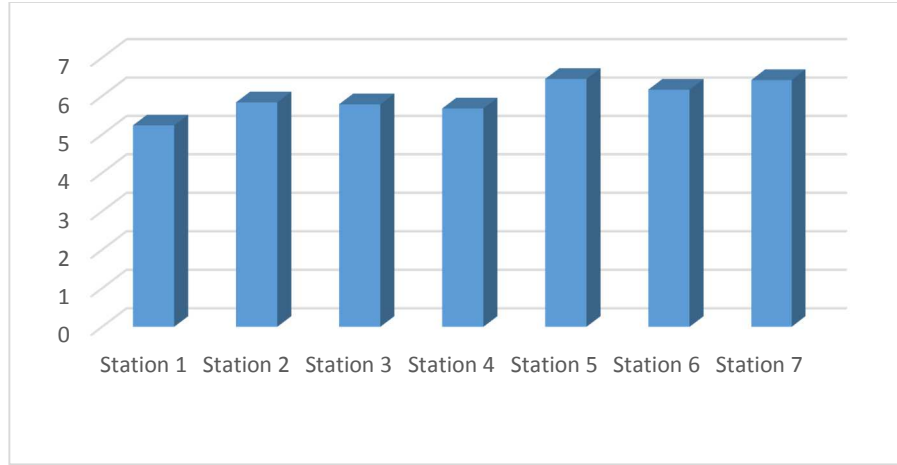
Figure 3: Semiannual mean values of Trophy Index (TRIX) in stations of South-East of Oman Sea
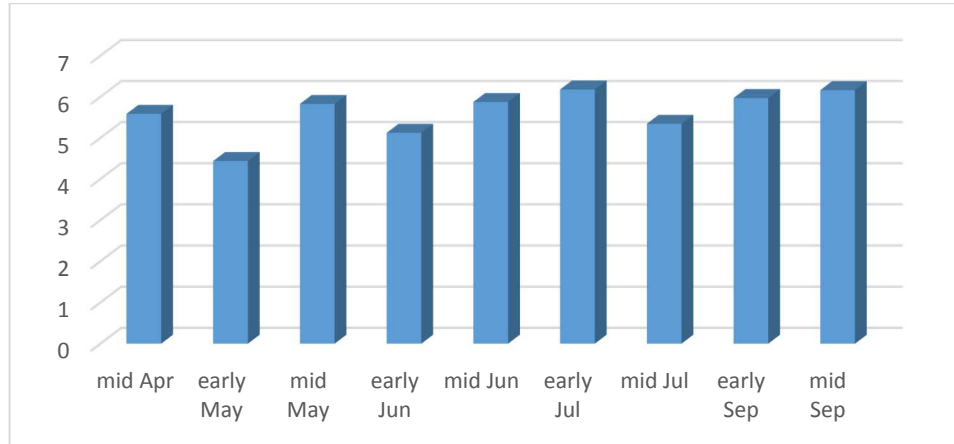

Figure 4: Fifteen day mean values of Trophy Index (TRIX) in the South-east of Oman Sea from mid-April to mid-September

Results of applying the TRIX index on the northwest coasts of the Adriatic Sea showed varying values of 4.2 to 6.3 in this region during 1982 to 1988 [3]. Average annual value of the application of this index on the coastal region of the Persian Gulf during the autumn of 1995 to 1996 was in the 5.4-6.4 range [18] while average annual value of the application of this index on the coastal region of the Caspian Sea during the summer of 1999 to 2000 was in the 4-6.3 range [4].

Changes in the 15-day averages of the parameters at the stations that were used to compare the trend of changes in the TRIX index with changes in the studied parameters are shown in Figure 5. The trend of changes in the TRIX index is closer to that of changes in chlorophyll a and to that of percentages of oxygen saturation deficits. As shown in this figure, the curve of changes in phosphate and nitrate shows these changes conform to those in chlorophyll a and the TRIX index with a 15-day delay. This trend can prove that increases and decreases in nutrients have a direct relationship with increases and decreases in the values for chlorophyll a with a delay of a few days and, hence, with the occurrence of algae bloom [19].
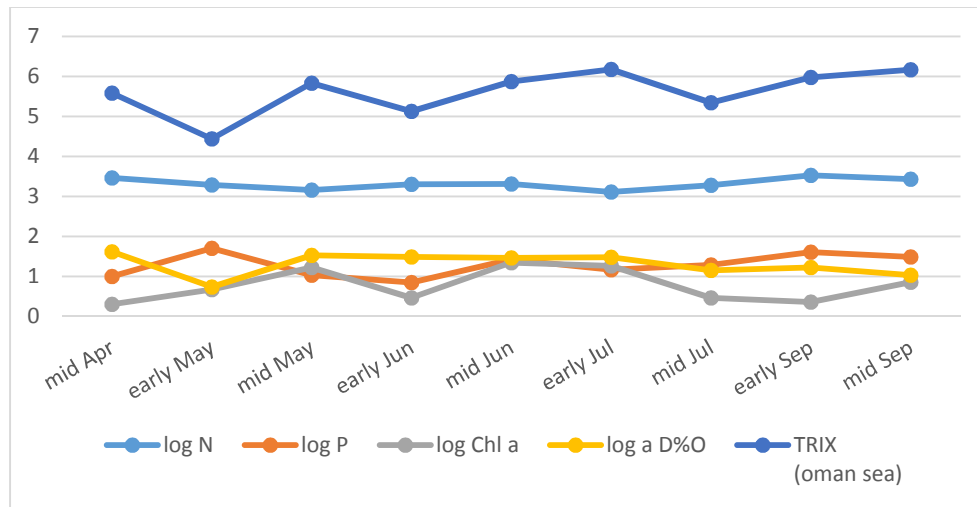
Figure 5: Fifteen day mean values of qualitative parameters (log (NO₃ , PO₄ , Chl a , aD%O) according to trend of changes in the TRIX index in the South-east of Oman Sea

Figure 6 depicts the four species of phytoplankton (*Cochlodinium, Prorocentrum, Rhizosolenia, Leptocylindrus*) identified by Fariman Attaran in 2010 that had the strongest correlations with qualitative parameters measured at the seven sampling stations on the southeast coast of the Oman Sea. The numbers of cells per liter for the four identified species of phytoplankton (out of 55 species) in the coastal region of the Oman Sea are converted into logarithmic form and presented in Figure 6. As shown in this figure, the most frequently observed phytoplankton are those of the *C. polykrikoides* species at Station 7. Some studies have shown that *C.polykrikoides* species could cause algal bloom in many coastal regions of the world [20-22].
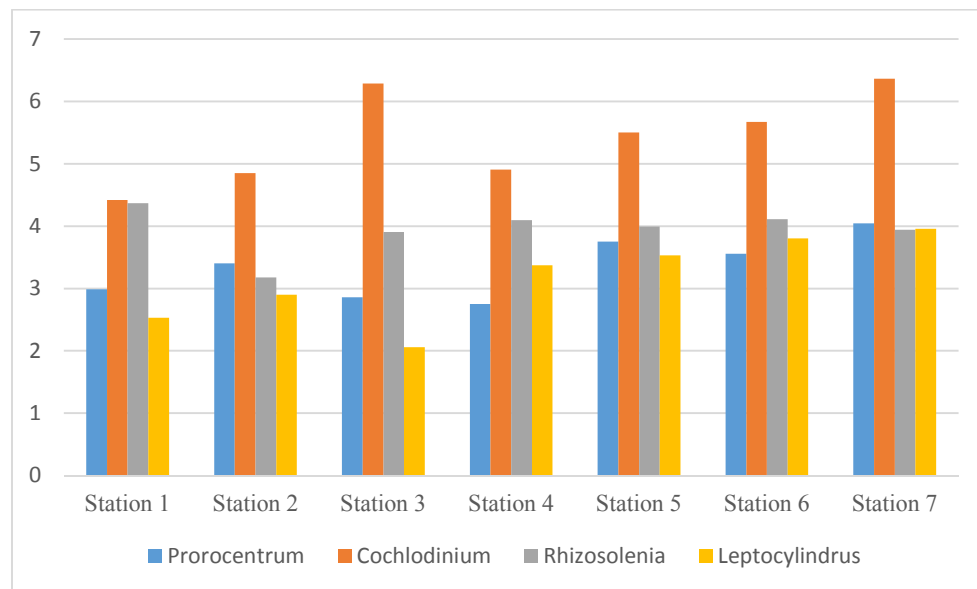

Figure 6: Semiannual mean values variation of the species of phytoplankton (*Cochlodinium, Prorocentrum, Rhizosolenia and Leptocylindus)* in the stations of South-East of Oman Sea (cell per litre)

Pearson's correlation coefficient was used in the MVSP software to determine the correlation between the possible sources of the identified phytoplankton species that caused algal bloom and the qualitative parameters that influenced eutrophication in the coastal region of the Oman Sea [23]. In order to enhance the clarity of the results, the cluster analysis of amongst various parameters is presented in Figure 7. As shown in this figure, *Cochlodinium* is inter linked

with chlorophyll a. On the other hand *Prorocentrum* is strongly correlated with phosphate and chlorophyll a. Finally, *Rhizosolenia* and *Leptocylindus* are under influence of nitrate content of coastal waters of Oman Sea. Therefore, results indicate nutrients and chlorophyll a cause the spread of phytoplankton species and can be very influential in the occurrences of algal blooms. Especially, *Cochlodinium* that is of high frequency can enhance eutrophication in the
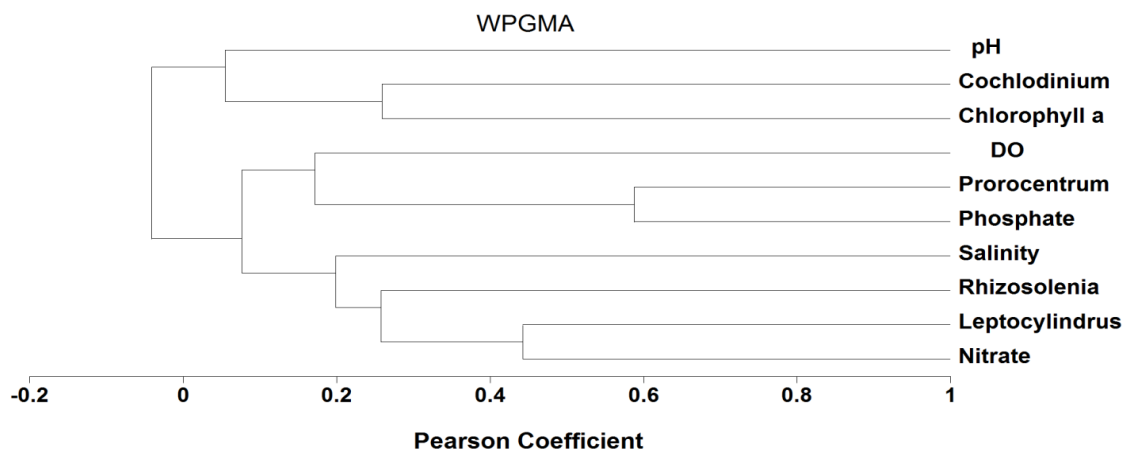
region [19, 24].

Figure 7: Cluster analysis showing intra relationship amongst phytoplankton species (*Cochlodinium, Prorocentrum, Rhizosolenia and Leptocylindus)* and the qualitative parameters (pH, Chlorophyll a, Dissolved Oxygen, Salinity and Nitrate) in the South-East Oman Sea

3.   CONCLUTIONS

The monthly average of the TRIX value at the sampling stations varied from 4.75 to 6.60. The mean value of this index indicated the region was in a eutrophic state and the value of the index increased in the summer, especially after the monsoon phenomenon. The average value of TRIX at the Passabandar station was less than other stations. However, the other stations were in eutrophic and hypertrophic state. This can be indicative of more discharge of various type of wastewaters into the coastal waters of Oman Sea at eutrophic stations. Results indicated the trend of changes in the TRIX index was closer to those of changes in chlorophyll a and percentages of oxygen saturation deficit. Moreover, increases or decreases in the quantities of nutrients had a direct relationship with increases or decreases in the quantities of chlorophyll a and the TRIX index in the region with a delay of a few days. The four identified species of phytoplankton that are responsible for algal blooms include Cochlodinium, Prorocentrum, Rhizosolenia and Leptocylindus. Statistical analysis revealed a good correlation amongst these species with nitrate, phosphate, and chlorophyll a content of coastal waters. It can be inferred that nutrients and chlorophyll a can be very influential in the occurrences of algal blooms in coastal waters of the Oman Sea and all over the world. It is very vital to equip the industries as well as urban wastewaters with adequate treatment facilities to prevent further eutrophication of coastal waters of Oman Sea.

REFERENCES

1.   Attaran-Fariman, G, 2010. Dispersion of potentially HABs former species along the south-east coast of the Oman Sea (Iranian waters). Final Report of the Project to Iran's Marine Environment Chabahar: Chabahar Maritime University, 110pp.
2.   Swamee, P. K. and A. Tyagi, 2000. Describing water quality with aggregate index. Journal of Environmental Engineering, 126(5), 451–455.

3.   Vollenweider, R.A., F. Giovanardi, G. Montanari, and R. Rinaldi, 1998. Characterization of the trophic condition of marine coastal waters with special reference to the NW Adriatic Sea: Proposal for a trophic scale. Turbidity and generalized water quality index. Environmetrics, 9, 329–357.
4.   Shahrban, M. and A. Etemad-Shahidi, 2010. Classification of the Caspian Sea coastal waters based on trophic index and numerical analysis. Environmental Monitoring and Assessment, 164(1), 349-356.
5.   Gupta, A.K., S.K. Gupta and R.S. Patil, 2003. A comparison of water quality indices for coastal water. Journal of Environmental Science and Health, Part A, 38(11), 2711–2725.
6.   Han, W.Y, 1995. Marine Chemistry of the Nansha Islands and South China Sea. China Ocean Press, 376p.
7.   Tang, D.L., H. Kawamura, T.V. Dien and M.A Lee, 2004. Offshore phytoplankton biomass increase and its oceanographic causes in the South China Sea. Marine Ecology Progress Series, 268, 31-41.
8.   Tang, D.L., H. Kawamura, H. Doan-Nhu and W. Takahashi, 2004. Remote sensing oceanography of a harmful algal bloom off the coast of southeastern Vietnam. Journal of Geophysical Research Atmospheres, 109(3), 1-7.
9.   Richlen, M.L., S.L. Morton, E.A. Jamali, A. Rajan and D.M. Anderson, 2010. The catastrophic 2008–2009 red tide in the Arabian Gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate Cochlodinium polykrikoides. Harmful Algae. 9(2), 163-172.
10.   Herring, D and M. Scott, 2002. Fish kill in the Gulf of Oman. NASA's Earth Observatory. Available on http://earthobservatory.nasa.gov/Library/phytoplankton.
11.   Attaran-Fariman, G., 2007 .Dinoflagellate cysts and Chattonella resting stages from resent sediments of thesoutheast coast of Iran. PhD thesis in University of Tasmania, Launceston, 350 pp.
12.   Attaran-Fariman, G., M.F. Desalas, A.P. Negri and C.J.S. Bolch, 2007. Morphology and phylogeny of Gymnodinium trapeziforme sp. nov, Dinophyceae): a new dinoflagellate from the southeast coast of Iran that forms microreticulate resting cysts. Phycologia, 46(6), 644-654.
13.   Sournia, A., 1978. Phytoplankton manual, monographs on oceanographic methodology, unesco, 377pp.
14.   Parsons, T.R., Y. Maita and C.M. Lalli, 1992: Amanual of chemical and biological methods for seawater analysis, pergamon press 173pp.
15.   Manual of oceanographic observation and pollutant analysis methods (MOOPAM), 1998. Kuwait: Regional Organization for the Protection of the Marine Environment.
16.   ROPME, 1987. The regional organization for the protection of marine environment. Website. www.ropme.org.
17.   ROPME, 2003. State of the Marine Environment Report. ROPME /GC-11/003. Regional Organization for the Protection of the Marine Environment, Kuwait.217pp.
18.   Taebi, S., A. Etemad-shahidi and G. Fardi, 2005. Examination of three eutrophication indices to characterize water quality in the north east of the Persian Gulf. Journal of Coastal Research, 42, 405–411.
19.   Yamaguchi, H., K. Sai, 2015. Simulating the vertical dynamics of phosphate and their effects on the growth of harmful algae Estuarine. Coastal and Shelf Science, 164, 425-432.
20.   Kim, H.G., 1997. Recent harmful algal blooms and mitigation strategies in Korea. Ocean Research, 19(2), 185-192.
21.   Anton, A., P. Teoh, S. Mohd-Shaleh and N. Mohammad-Noor, 2008. First occurrence of Cochlodinium bloom in Sabah, Malaysia. Harmful Algae, 7(3), 331-336.
22.   Fatemi, S.M.R., S.M. Nabavi, G. Vosoghi, M. Fallahi and M. Mohammadi, 2012. The relation between environmental parameters of Hormuzgan coastline in Persian Gulf and occurrence of the first harmful algal bloom of Cochlodinium polykrikoides (Gymnodiniaceae). Iranian Journal of Fisheries Sciences, 11(3), 475-489.
23.   Laplace-Treyture, C. and T. Feret, 2016. Performance of the Phytoplankton Index for Lakes (IPLAC): Amultimetric phytoplankton index to assess the ecological status of water bodies in France. Ecological Indicators, 69, 686-698.
24.   Kowalczewska-Madura K, Gołdyn R, Dera M. 2015. Spatial and seasonal changes of phosphorus internal loading in two lakes with different trophy. Ecological Engineering, 74, 187–195.