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Organic Carbon and Organic Matter Levels in Sediments of the Strait of Hormoz, the Persian Gulf

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Abstract

Total organic carbon has a major influence on both the chemical and biological processes that take place in sediments. Algal bloom is one of the organic carbon levels in aquatic ecosystems. In 2009 algal bloom occurred in the Hormozgan province and prolonged for months, which finally setteled down in 2010. In this study the variations of total organic carbon (TOC), organic matter (TOM) and total nitrogen (TN) contents, and the carbon-nitrogen ratio in superficial sediments collected from 33 stations at the Strait of Hormuz were investigated. Sampling was performed at the depths of 14 to 59 meters in spring of 2010 after sinking algal bloom in the area. The TOC content in the surface sediments revealed values in the range of 0.5 up to 3.5 % (mean 2 %, median 2.2 %, standard deviation 1.3%). The values generally highlighted a gradient increasing with distance from the Strait of Hormoz. According to the standards of Environmental Protection Agency of United State, the organic carbon concentrations in the analyzed sediments were in the range of sediments with low to medium organic carbon level. Organic matter levels were in the range of 4.4 to 10 % (mean 7.3 %). Statistical analysis demonstrated that there were no significant differences between the stations. According to Pearson correlation, total organic matter and organic carbon had significant correlation with each other (R2=0.81, P=0.01). Results showed that deeper parts had relatively higher organic carbon level (R2=0.66, P=0.05). Our investigation showed that the accumulation pattern of organic carbon depended on the grain size of the sements. The stations with higher percent of silt and clay had higher organic carbon. The results revealed that organic carbon level has increased in resent years, which can influence on the potential of methylation and accumulation of metals in sediment.

In this study the TOC/TN ratio for 33 sediments were between 3 and 8, which demonstrated that the source of organic carbon could be related to the recent algal bloom.

Keywords: *Organic carbon, Organic matter, Total nitrogen, Strait of Hormuz, Algal bloom.*

1. Introduction

Organic Matter (OM) as one of the chemicals in sediment (Weston and Joye, 2005) is a primary source of food for benthic organisms. Its high level can lead to the depletion of oxygen in the sediment and overlying water, which can have a deleterious effect on the benthic and fish communities (Wells, 2010).

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Total organic carbon (TOC) is the amount of carbon bound in an organic compound, which has a major influence on both the chemical and biological processes that take place in sediments. From global point of view, the stored organic matter as organic carbon and nutrients offers a model of phytoplanktons growth in an area (Seiter et al., 2004). In addition to increasing organic carbon level in sediment, planktonic bloom can have serious economic impacts due to fish mortality, breduced tourism revenues and increased health costs.

Presence of TOC in aquatic ecosystems demonstrates living organisms and decomposable materials; for this reason, it is used as an indicator of water pollution and rate of eutrophication in aquatic ecosystems (Folger 1972; USEPA 2002) and often as a non-specific indicator of cleanliness of pharmaceutical manufacturing equipment (FDA, Guidance of Pharmaceutical Products, 2006).

The Strait of Hormuz is a passage between the Gulf of Oman and the Persian Gulf. It is the only sea passage from the Persian Gulf to the open ocean and is one of the world's most strategically important pathways. On its northern coast is Iran, and on the southern coast, the United Arab Emirates and Musandam, an exclave of Oman are located. At its narrowest, the strait is 21 nautical miles (39 km) wide.

In this study, following hypotheses were tested: i) The amount of OC in the sediment of Strait of Hormuz had increased in recent years, ii) There was a relationship between the 2009-2010 algal bloom in the Strait of Hormuz and increasing TOC level in local sediments and iii) the environmental impacts of elevated TOC level in the area could be assessed.

2. Materials and Methods

In this investigation, 33 surface sediments from depths of 12 to 59 meters were sampled at the Strait of Hormuz using Vanveen grab after algal bloom had sunk in the coastal waters of the Hormuzgan province in 2010. Samples were immediately transferred to aluminium vessels, prewashed by laboratory detergent, MQ water and Ethanol, then labeled, refrigerated (> 4 C), and transported to laboratory for further treatment. The sediments were lyophilized during 3 days. A fraction of sediment (< 63µm) was separated and kept frozen (at -20 oC) prior to chemical analyses (Wolf-Welling et al 2001).

The locations of sampling sites are illustrated in Figure 1 and their geographical specifications in addition to their physical parameters are presented in Table 1.

Table 1: Locations of the the sampling sites and their geographical and physical parameters.

Stations	Code	Sample replicate	Geographical location	Depth m	Water clarity m
	1	3	26° 51'. 83N 56° 18'.66 E	37	10.5
	2	3	26° 54'.46 N 56° 20'.08 E	45	9.0
	3	3	27° 02'.79 N 56° 10'.81 E	23	2.8
	4	3	27° 01'.36 N 56° 06'.45 E	21	1.9
	5	3	26° 54'.27 N 56° 18'.24 E	59	9.5
Starit of Hormuz	6	3	27° 05'.95 N 56° 20'.97 E	12	2.0
	7	3	27° 03'.49 N 56° 17'.98 E	16	1.5
	8	3	27° 03' 77 N 56° 07'.37 E	14	0.9
	9	3	27° 04'.12 N 56° 11'.79 E	20	1.5
	10	3	27° 00'.99 N 56° 16'.62 E	25	2.3
	11	3	27° 07'.09 N 56° 13'.69 E	16	1.5
Sediment samples analyzed in 2004					
Starit of Hormuz	1	3	26 ° 08'.60 N 57 ° 08'.90 E	13.4	-
	2	3	26 ° 01'.80 N 57 ° 01'.40 E	93.7	-
	3	3	26 ° 47'.30 N 56 ° 56'.20 E	18.8	-
Larak	4	3	26 ° 37'.30 N 56 ° 54'.10 E	59.4	-
	5	3	26 ° 27'.40 N 56 ° 52'.30 E	68.6	-
Sediment samples analyzed in 2002					
Larak		۳	26° 44' 40 N 56° 10' 55 E	58	-

Three mg sediments with grain size less than 63 µm were digested with 3 ml perchloric acid 30%, a drop of glacial nitric acid under reflax at 120 ºC during 20 to 30 minutes, subsequently pH was fixed at 3 using sodium hydroxide 5 M and magnetic agitator. 100 µL of aliquot was injected to TOC Analyzer (based on optimization the manual instruction of the instrument).

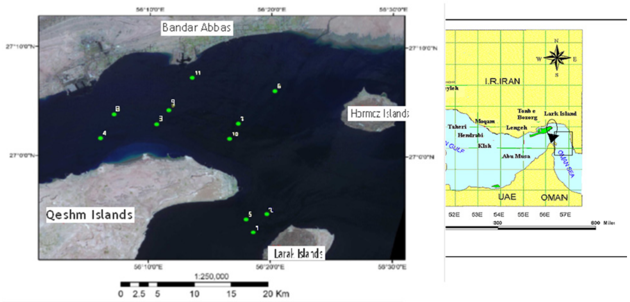

Fig. 1: The location of sampling sites. Circle shows the locatin of sampling sites in this study, triangle demonstrates the sampling sites in a study in 2002 and square indicates in 2004.

Total organic carbon was analyzed using TOC Analyzer (SGE, ANATOC Seri II Australia). Detection limit of TOC analyzer was 50 ppb (5*10-6%). The concentrations of TOC in all samples were higher than the detection limit. The recovery of methodology was 97±2%.

In this study, the optimized digestion and analysis methodology for TOC analysis was evaluated by comparing the results of this study with the results of the same samples obtained from University of Miami, Rosenstiel of Marine atmospheric science (Table 2). The precision and accuracy of the results in this study were comparable with those obtained from University of Miami.

Table 2: Comparing the TOC levels in the sediments analyzed in this study with those analyzed at the University of Miami, Rosenstiel of Marine atmospheric science.

samples	Results from USA (average)	RSD	Results from Iran	RSD
1-2	3.31±0.40	12%	3.35±0.45	13%
3-3	2.85±0.38	13%	2.77±0.25	9%
4-1	2.29±0.32	11%	3.42±0.53	15%
5-3	3.32±0.23	8%	2.97±0.10	3%

The organic content was determined by Loss On Ignition (LOI) method (oven temperature at 430±20 (Galle and Runnels 1960, Dean 1974). Total nitrogen was calculated as sume of Kjeldahl nitrogen (organic nitrogen and ammonium (NH_4^-) levels), nitrate (NO_3^-) and Nitrite (NO_2^-). Nitrate and nitrite were analysed based on reference standard ASTM-D4327-11 and using the HACH method (2610), respectively (Hach manual; ASTM, 2006). Water Clarity depth was detected using secchi disk.

Statistical analysis of the data was carried out using SPSS V13. Prior to determining correlations between different parameters, a Kolmogorov-Smirnov test was accomplished to analyze normality of data distribution. In order to assess significant differences between parameters in different sampling sites, we considerd skewness (Sk) and kurtosis (K). Where $|Sk|<0.5$ was considered as normal distribution. Relation between various metals was established via Pearson correlation.

3. Results and Discussions

Concentrations of organic carbon, organic matter, N Kejeldal, nitri nitrate, TN levels, TOC/TN and grain size of the sediments are presented in the Table 3.TOC levels were in the range of 0.5 to 3.5 % d.w. with an average of 2 % (Standard deviation of 1.3%, n=99), organic matter were in the range of 4.4 to 10 % with an average of 7.3 % (Table 3). There was a strong positive significant correlation between TOC and TOM levels (Figure 2; R2=0.81, P=0.01). The Kjeldahl nitrogen level in the sediments varied between 0.03 to 0.18 % (Table 3).

US EPA (2002) recommended the following assessment categories for TOC in sediments:

Low impact: ≤ 1%

Intermediate impact: 1 to 3%

High impact: >3%

The threshold values were based on EMAP data that indicated TOC values between 1% and 3% were associated with impaired benthic communities.

However, these thresholds are still under evaluation. According to the standards of Environmental Protection Agency of United State (US EPA, 2002), the organic carbon levels in the analyzed sediments were in the range of sediments with low to medium organic carbon level. For unexplained reason such as local factors, station 6 had abnormally high TOC level in comparing to the other stations. Although the result of station 6 is accurate, statistical analysis showed that it was outlier (Figure 3). Hence, it was ignored in determining the correlation between data and depths.

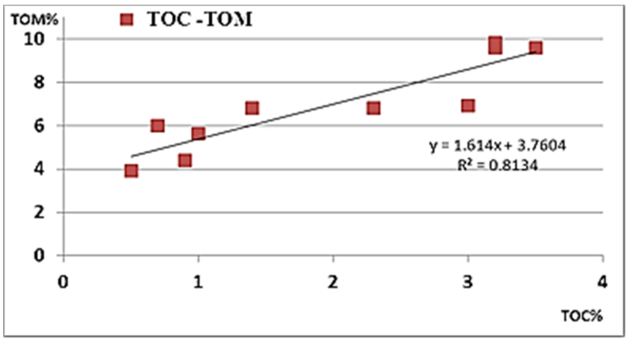

Fig. 2: Correlation between TOC and TOM levels in the sediments.

Q-Q plot revealed that the data had normal distribution, so Pearson correlation was determined between organic matter and depth (R2=0.66, P=0.05). Results showed that deeper parts had relatively higher organic carbon level (Figure 4).

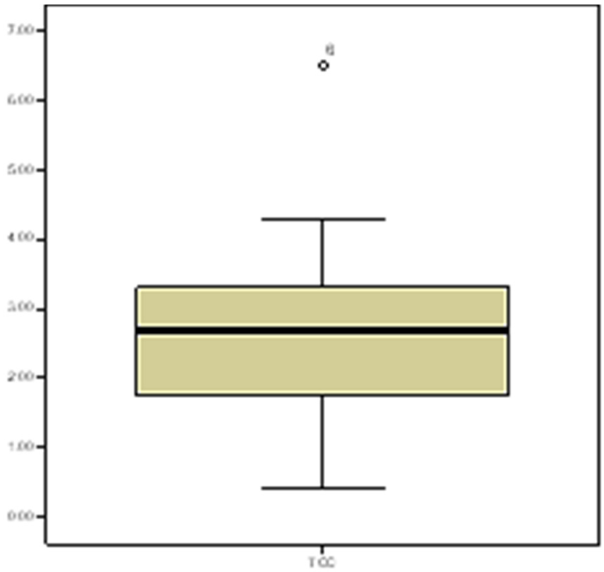

Fig. 3: Statistical analysis of outlier

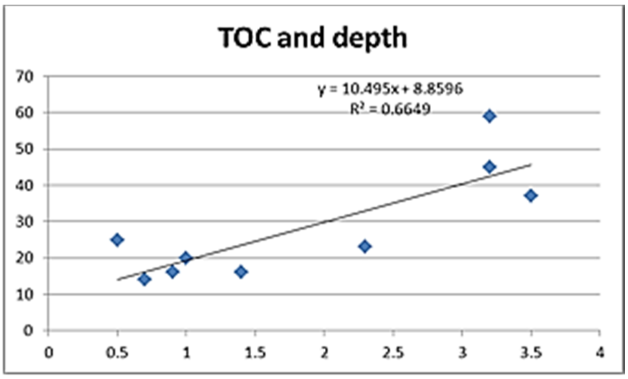

Fig. 4: Pearson correlation between organic matter and depth

Table 3: Concentrations of organic carbon, organic matter, N Kejeldal, nitri nitrate, TN levels, TOC/TN and grain size of the sediments.

stations	TOC %	TOM %	N Kejeldal %	Nitrit %	Nitrate %	TN %	TOC/TN	Silt %	Clay %	Sand %	Silt & clay %
1	3.5±0.3	9.6±1	0.18	0.15	N. d	>0.33	<10	96.1	1.05	2.86	97.15
2	3.2±0.2	9.6±1	0.16	0.04	0.1	0.3	10	88.5	1.05	10.5	89.55
3	2.3±0.2	6.8±1	0.15	0.10	0.27	0.52	4.4	75.8	2.02	22.7	77.82
4	3±0.4	6.9±1.1	0.16	0.17	N. d	>0.33	<9	41.6	0.71	57.7	42.31
5	3.2±0.9	9.8±0.8	0.16	0.09	0.1	0.35	<9	86.6	0.92	12.5	87.52
6	6.5±0.3	10±0.2	0.17	0.26	outlier	outlier	outlier	87.1	2.13	10.26	89.23
7	1.4±0.2	6.8±1.1	0.06	0.04	-	-	-	74.7	1.04	24.15	75.74
8	0.7±0.1	6.0±0.8	0.05	0.13	-	-	<4	56.75	1.52	41.63	58.27
9	1±0.4	5.6±0.9	0.04	0.23	-	-	<3.7	34.8	0.59	64.63	35.39
10	0.5±0.1	3.9±0.3	0.03	0.14	-	-	<3	34.9	0	64.78	34.9
11	0.9±0.1	4.4±0.9	0.06	0.28	-	-	<3	97.7	2.74	0	100.44

Our investigation showed that the accumulation pattern of organic carbon depended on the grain size of the sements (Table 4). Stations with higher percent of silt and caly had higher organic carbon. Stations 7, 8, 9 and 10, which were located between Hormoz and Qeshm Islands, with higher percent of sand (14 to 65%) had relatively lower organic carbon content.

Table 4: Pearson correlations between TOC (%), TOM (%) in the sediments and their garin size (%).

parameters	Silt	Clay	Sand	TOC	TOM
Silt	1				
Clay	.65*	1			
Sand	-1.00**	-.67*	1		
TOC	.53*	.25	-.53*	1	
TOM	.67*	.85**	-.67**	.81**	1

** Correlation is significant at the 0.01 level (1-tailed) and * at the 0.05 level (1-tailed).

Anthropogenic sources as well as plants, humans, animals and microorganisms, as natural sources can be introduce organic matter to the environment. Almost all organisms use carbohydrates as sources of energy, and likely so, bacteria quickly consume the less resistant molecules of organic matters, such as the nucleic acids and many of the proteins. In general, algal OC can be decomposed easier than terristrial OC (Opsahl and Brenner, 1995), which produce carbon dioxide. Determining the ratio between TOC and TN (C/N) can identify the source of OC (Terrestrial vs. marine). When the source of OC is terrestrial, the ratio of OC/TN is greater than 15 (C/N >15), when the source of OC is marine the ratio of OC/TN is lower than 10 (C/N < 10) (Gälman et al., 2008; Bourbonniere and Meyers 1996; Purushothaman, 2009; Tyson, 1995; Wakeham, et al., 2002). The average ratio for zooplanktons is 6 (Between 4 and 8) (Mayer, 1993). In addition to TOC/TN ratio, there are other methods to detect the source of OC for e.g. hydrogen index, microscopical approach and carbon isotope (13Corg) (Stein, 1990, 1991, 1994).

In this study, the ratios of TOC/TN for 33 sediment samples from depths of 12 to 59 m ranged between 3 and 8 (Table 5), which demonstrated the source of organic carbon could be related to the algal bloom.

Statistical analysis demonstrated that TOC (│Sk│=0.07) and TOM (│Sk│=0.19) data were normally distributed; hence there were no significant differences between the stations. Also K=-2 and K=-1.2 for TOC and TOM, respectively, showed that distribution of data were more centralized around mean values. Correlation coefficient

$$\left(r = \frac{\text{covariance (x,y)}}{\delta x^{*}\ \delta y}\right)$$

was 0.8 which showed that there was direct and incomplete correlation between the concentrations of parameters in the stations.

Comparing OC levels in this study with that in other geographical ecosystems indicated that OC in the sediments of the Strait of Hormuz which were leaned into the Persian Gulf were higher than that in sediment of shallow seas (<0.5%) (Seiter et al., 2004); continental margins (>1.5% in Seiter et al., 2004), cold seas (0.5–2%; Stein, 1990, 1991); Mexic Gulf (0.34-1.59% Goñi et al., 1997, 1998; Gordon and Goñi, 2004) and Arabian Sea (0.04-1.5 % Grandel et al., 2000). According to Esam et al.,(2008), organic carbon in the sediments of the NorthWestern parts of the Persian Gulf (0.83-1.51 %), was lower than that in this study.

The station 11 with higher percent of clay (98%) and high level of organic matter (10%) had lower organic carbon level. This station was near Bandar Abbas. Maybe local pollution affected pollution level at this station.

4. Conclusions

Comparing the average levels of TOC (3%) and TOM (10%) in the sediments of stations 1, 2 and 5 which were near to the Larak Island, with the concentrations of earlier investigations in the same area (Agah et al., 2010 and 2011) in 2002 and 2004 (1% and 8.5%, respectively), revealed that TOC level in the area was increased in the recent years. Higher TOC level could affect bacterial activities and methylation level. As organic carbon is controlling factor for accumulation of trace metals in the sediment, hence it is expected to have higher trace metals and methylmercury accumulation in the surface sediments and biota (Andersson et al., 1990; Zhang et al., 2012). Algal bloom which occurred in 2009 - 2010 in the Hormuzgan province for a prolonged season, could have partially caused an increase in the amount of organic carbon in recent years.

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