Distribution of Nutrient Salts and Chlorophyll-a in Surface Water along the Gulf of Aden and Arabian Sea Coast, Yemen

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ABSTRACT: The distribution of inorganic nutrient salts (ammonium, nitrite, nitrate, phosphate and silicate) and phytoplankton chlorophyll-a (Chl-a) were investigated in the Gulf of Aden and along the Arabian Sea coast, Yemen. Seventy two surface water samples were collected during cruises in August 2014 and January 2015. The sampled area extends from As Suqayyah in the west of the Gulf of Aden to Hawf in the east. The study showed that the average values of nutrient salts (μg/l) in waters collected in August 2014 and January 2015 were 0.83 and 0.60, 10.98 and 10.03, 16.41 and 14.73, 10.36 and 8.76, and 29.72 and 22.67 for ammonium, nitrite, nitrate, phosphate and silicate, respectively. The average values of Chl-a (mg/m^3) in August 2014 and January 2015 were 0.26 and 0.21, respectively. The results showed that nitrate levels were very high but those of ammonium very low. This may reflect the oxidation of ammonia to nitrite and then nitrate, leading to a very favorable ratio of ammonia and nitrate values. The low levels of dissolved inorganic nitrogen (DIN)compounds, (ammonium, nitrite, and nitrate), phosphate, silicate and Chl-a indicated that the southern coast of Yemen is not in a eutrophic condition. The highest nutrient salt values were in the eastern part of the study area, and may have resulted from water originating from the Indian Ocean and upwelling. Statistical analysis to seek correlations between nutrient salts and Chl-a show very good to excellent correlation, which may be due toconstant coastal environment.

Keywords: Arabian Sea; Gulf of Aden; Nutrient salts; Chlorophyll-a; Yemen.

توزيع الأملاح المغذية والكلوروفيل-أ في المياه السطحية لساحل خليج عدن وبحر العرب، اليمن

إبراهيم الأكحلي، نبيل الشوافي و شهاب الكبش

الملخص: تم دراسة توزيع الأملاح المغذية غير العضوية (الأمونيا، النتريت، الفوسفات، السليكات) وكلوروفيل-أ للعوالق النباتية في ساحل خليج عدن وبحر العرب في اليمن، تم جمع 72 عينة من المياه السطحية خلال رحلات بحرية في أغسطس 2014 ويناير 2015، وتمتد منطقة جمع العينات من ساحل السقية غرب خليج عدن إلى ساحل حوف بمحافظة المهرة في الشرق. وأظهرت هذه الدراسة أن متوسط قيم الأملاح المغذية (ميكروجرام/لتر) في عينات المياه التي جمعها في أغسطس 2014 ويناير 2015 كانت 0.83 و0.60، 10.98 و10.03، 16.41 و14.73، 10.36 و8.76، 29.72 و22.67 لـ الأمونيا، النتريت والنترات، الفوسفات والسليكات على التوالي، ومتوسط قيم الكلوروفيل-أ (ملغ/م^3) في أغسطس 2014 ويناير 2015 كانت 26 و 0.21 على التوالي. كما أظهرت النتائج أن قيم النترات مرتفعة، لكن قيم الأمونيا منخفضة مقارنة بالظروف البيئية الطبيعية. وهذا ربما يعكس أكسدة الأمونيا إلى النتريت ثم النترات، مما أظهر علاقة جيدة جداً بين قيم الأمونيا والنترات. وتشير المستويات المنخفضة لمركبات النيتروجين غير العضوية الذائبة (الأمونيا، النتريت والنترات) والفوسفات والسليكات والكلوروفيل-أ إلى أن الساحل الجنوبي لليمن ليس في ظروف إغناء بالمغذيات، وبالتالي فالمياه السطحية في ساحل خليج عدن وبحر العرب في ظروف بيئية طبيعية. وكانت أعلى قيم للأملاح المغذية في الجزء الشرقي من منطقة الدراسة، وقد يكون هذا ناتج عن المياه التي مصدرها المحيط الهندي وعملية الرفع، وأظهر التحليل الإحصائي بين الأملاح المغذية والكلوروفيل-أ ارتباطاً جيداً إلى ممتازاً بينهما، وقد يكون بسبب البيئة الساحلية المستقرة.

الكلمات المفتاحية: بحر العرب، خليج عدن، الأملاح المغذية، كلورفيل-أ، اليمن.

1. Introduction

The most overwhelming feature of the Gulf of Aden and Arabian Sea coastal regions affecting every aspect of the present day physical, biological and socio-economic environment is the fact that the area is a desert. The Yemen coast is characterized by a narrow coastal plain between the Gulf of Aden and the mountain range that parallels the shoreline [1]. The Yemen coastal region is influenced by two distinct monsoon seasons. The months of April and May, and September and October are transitional months as global pressure patterns re-adjust to the changing incoming solar energy [2]. The climate of the Yemen coast and nearby waters is dominated by hot and extremely arid conditions characteristic of the Arabian Peninsula [3]. Consequently, the present work was undertaken to study the nutrient salts and Chl-a in the Gulf of Aden and Arabian Sea coastal areas by different cities within Yemen. Therefore the results of these investigations could be considered to be a pilot for further similar studies in the coastal waters of the Gulf of Aden and Arabian Sea.

The high primary productivity, due in part to upwelled nutrients, supports a feed web which ultimately sustains the fish community. The seasonality of the monsoon wind and the upwelling can see seasonal periodicity throughout the food web [4].

Among the components of waste water most likely to have an impact on the marine ecosystem are nutrients, organic matter and microorganisms. Several literature reports have described the occurrence of eutrophication as a result of high concentrations of nutrient chemicals in coastal waters [5-7]. Eutrophication is a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to increased growth, primary production and biomass of algae, changes in the balance of organisms, and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services [8]. The phenomenon of eutrophication due to nutrient inputs from land-based pollution sources is a major environmental problem and the geographical distribution of eutrophication in the different seas occurs in densely populated areas characterized by intensive economic activities [9]. There are good reasons to believe that eutrophication can, in the near future, become a common hazard in marine coastal areas in many parts of the world. Such a process would have damaging effects on both inshore fisheries and recreational facilities. Monitoring major nutrient levels, therefore, is important to assess the degree of pollution and/ or the quality state of water resources [6,10-12]. Riley *et al*., [13] reported that, the range of nutrient concentrations in marine water under normal environmental conditions are as follows (μg/l): nitrate, 1.0-120; phosphate, 1.0-160; ammonia, 0.0-50 and nitrite, 0.2-30. Coastal waters have higher concentrations of nutrient salts and Chl-a than the open sea waters [14,15].

The present study aimed to determine inorganic micronutrient salts (DIN, phosphate and silicate) and Chl-a variation along the coastal area of the Gulf of Aden and Arabian Sea, Yemen.

2. Materials and Methods

Seventy two surface sea water samples were collected using a clean plastic bucket from the surface (0.90 m) at 12 stations (Figure 1) for nutrient salt and Chl-a analysis and transferred to cleaned 100 ml polyethylene bottles which had been prewashed with 10% hydrochloric acid. At the time of sampling, the sample bottles were rinsed twice with the sampled water, and then filled with it. For nutrient salt analysis, samples were filtered through Whatman GF/C Millipore filter papers (0.47μm) and frozen (−20 °C). Once in the laboratory, the samples were allowed to thaw for 24 hours prior to determination of dissolved nutrients [16]. The phytoplankton standing crop as Chl-a was extracted with 90% acetone. The measurements of dissolved nutrient salts and Chl-a were performed using a Shimadzu double beam spectrophotometer UV-150-02, following the methodology of Strickland and Parsons [17]. Double distilled water and/or deionized water was used for dilution of samples. Blank determinations were carried out for each group of samples on a monthly basis. The concentrations of the nutrient salts and Chl-a were measured three times and the mean values were taken. Correlation matrices were estimated to show the relationship between nutrient salt concentrations and Chl-a. These analyses were applied to interpret the data and to obtain better information about the surface water of the studied stations.

2.1 Study area

The Gulf of Aden and Arabian Sea is dominated by the Indian Ocean monsoon system (Figure 2). From January to March the northeast monsoon blows in a south western direction. Between May and September, the south west monsoon generates winds which blow onshore and replace surface waters by cooler nutrient-rich water from deeper layers. This upwelling has limited the growth of coral reefs but triggers high primary production which supports the region's rich pelagic fish stocks [18,19].

Mean surface water temperature in the Gulf of Aden and Arabian Sea coastal area is about 24.44 °C in summer (August) and about 26.60 °C in winter (January).
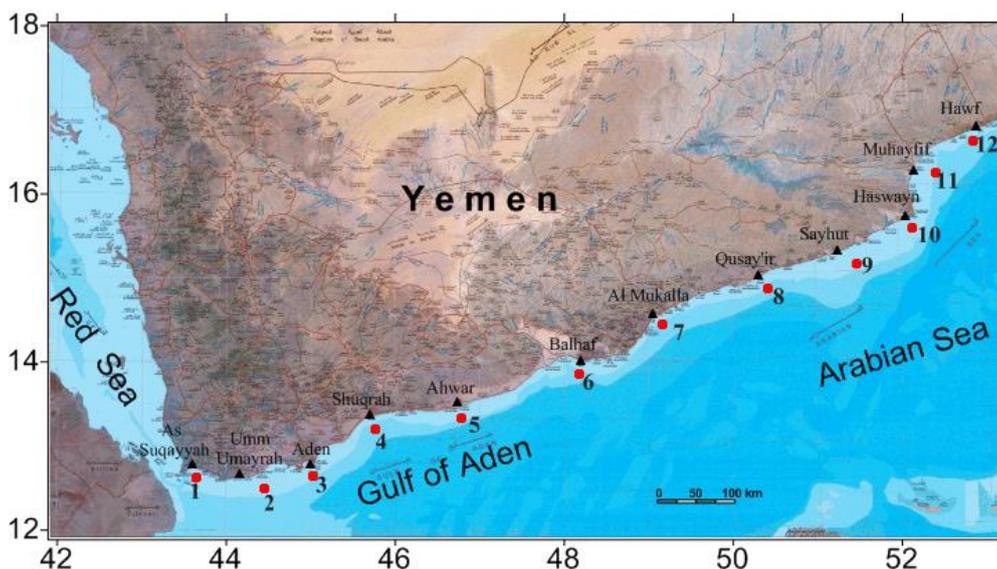
Figure 1. Map of Gulf of Aden and Arabian Sea showing the sampling stations.
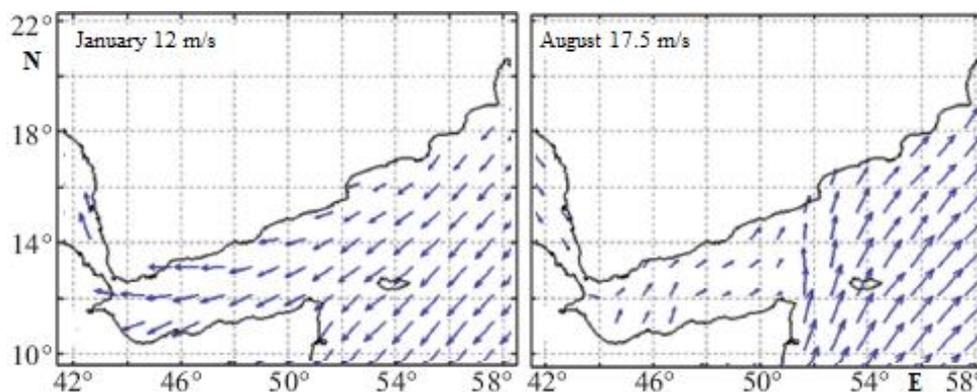

Figure 2. Gulf of Aden and Arabian Sea climatological QuikSCAT wind speed (m/s) for January and August, NE and SW monsoon [20,21].

3. Results and discussion

3.1. Nutrient salts

3.1.1. DIN (ammonium, nitrite and nitrate)

Ammonium is the major nitrogenous product of the bacterial decomposition of organic matter containing nitrogen, and is an important excretory product of invertebrates and vertebrates. As for the utilization of nitrogenous materials, NH_4 is the preferred inorganic source because of its ease of uptake and incorporation into amino acids (N-assimilation). The present study shows that August 2014 had the higher values of ammonium ranging between 0.65 and 0.95 µg/l with an average of 0.83±0.10 µg/l, whereas January 2015 had lower values of ammonium ranging between 0.33 to 0.85 µg/l with an average of 0.60±0.17 µg/l (Table 1 and Figure 3).

The level of ammonium during August 2014 and January 2015 was relatively low; this may be attributed to the increase in its consumption rate by phytoplankton. However, generally, the concentrations of ammonia during August 2014 were mostly higher than those of January 2015 (Figure 4). The available ammonium may have been the decomposition product of organic material.

Nitrite concentrations during August 2014 ranged from 9.55 to 13.60 µg/l with an average of 10.98± 1.52 µg/l, whereas the concentrations in January 2015 ranged from 8.50 to 12.60 µg/l with an average of 10.03±1.42 µg/l (Table 1 and Figure 3). The average values for the different locations of nitrite in January 2015 were slightly lower than the average values in August 2014 (Figure 4).

Table 1. Mean concentration of nutrient salts and Chl-a at selected stations in the Gulf of Aden and Arabian Sea coast surface water during August 2014 and January 2015.

Station No.	Location name	Month	Nitrite (µg/l)	Nitrate (µg/l)	Ammonium (µg/l)	phosphate (µg/l)	Silicate (µg/l)	Chl-a (mg/m^3)
1	As Suqayyah	Aug. 2014	9.55	14.33	0.65	8.80	20.40	0.10
		Jan. 2015	8.50	12.25	0.33	7.00	18.30	0.09
2	Khor-Omair	Aug. 2014	9.60	14.50	0.70	8.85	20.60	0.12
		Jan. 2015	8.60	12.50	0.40	7.30	18.60	0.09
3	Aden	Aug. 2014	9.63	14.60	0.72	8.95	20.80	0.09
		Jan. 2015	8.65	12.55	0.45	7.65	19.00	0.11
4	Shuqrah	Aug. 2014	9.80	14.65	0.80	9.50	21.00	0.14
		Jan. 2015	8.90	12.70	0.50	8.00	20.30	0.10
5	Ahwar	Aug. 2014	9.83	14.80	0.83	10.30	25.30	0.13
		Jan. 2015	9.50	13.00	0.53	8.30	20.30	0.13
6	Balhaf	Aug. 2014	10.25	15.30	0.83	10.50	27.80	0.20
		Jan. 2015	9.56	13.50	0.55	8.50	20.55	0.12
7	Al-Mukalla	Aug. 2014	10.30	15.65	0.85	10.75	30.00	0.33
		Jan. 2015	9.80	14.30	0.61	9.30	21.00	0.20
8	Qusayír	Aug. 2014	11.53	17.00	0.90	11.00	33.40	0.37
		Jan. 2015	10.30	15.50	0.66	9.50	23.50	0.25
9	Ras Sharwin	Aug. 2014	11.76	17.30	0.93	11.30	35.60	0.36
		Jan. 2015	10.50	16.53	0.73	9.55	25.80	0.30
10	Haswayn	Aug. 2014	12.35	19.00	0.93	11.30	37.40	0.40
		Jan. 2015	11.00	17.40	0.81	9.70	26.20	0.33
11	Al-Muhyfif	Aug. 2014	13.50	19.50	0.92	11.50	40.00	0.43
		Jan. 2015	12.50	18.00	0.80	10.00	28.30	0.37
12	Hawf	Jan. 2014	13.60	20.30	0.95	11.55	44.30	0.45
		Aug. 2015	12.60	18.50	0.85	10.30	30.20	0.40
Minimum		Aug. 2014	9.55	14.33	0.65	8.80	20.40	0.09
		Jan. 2015	8.50	12.25	0.33	7.00	18.30	0.09
Maximum		Aug. 2014	13.60	20.30	0.95	11.55	44.30	0.45
		Jan. 2015	12.60	18.50	0.85	10.30	30.20	0.40
Average		Aug. 2014	10.98	16.41	0.83	10.36	29.72	0.26
		Jan. 2015	10.03	14.73	0.60	8.76	22.67	0.21
STD		Aug. 2014	1.52	2.16	0.10	1.07	8.39	0.14
		Jan. 2015	1.42	2.35	0.17	1.11	4.03	0.12

The present data of nitrite was similar to that recorded off the Hadramout coast; 10.34-13.50 µg/l [4]. A very strong to excellent positive correlation was recorded between nitrite and ammonium (r = 0.84 on August 2014 and = 0.94 on January 2015) (Table 2).

Nitrate is the final oxidation product (nitrification) of other nitrogen compounds in toxic seawater having a high redox potential. The nitrate form is generally considered the most stable and predominant DIN in oxygenated sea water [22]. Its concentration during August 2014 ranged from 14.33 to 20.30 µg/l with an average of 16.41±2.16 µg/l, whereas the concentration during January 2015 ranged from 12.25 to 18.50 µg/l with an average of 14.73±2.35 µg/l (Table 1 and Figure 3). The distribution of nitrate showed that the concentration during August 2014 was higher than that in January 2015 (Figure 4). In addition, it was observed that the concentration of ammonium was less than that of nitrate. This relates to the fact that the rate of nitrification is mostly similar to that of denitrification, or due to the oxidation of ammonium to nitrite and nitrate either chemically or biologically.

Table 2. Correlation coefficients of nutrient salts and Chl-a.

	Nitrite	Nitrate	Ammonium	Phosphate	Silicate	Chl-a
Nitrite	1.00					
Nitrate	0.99 0.97*	1.00				
Ammonium	0.84 0.94*	0.84 0.97*	1.00			
Phosphate	0.86 0.92*	0.85 0.94*	0.98 0.98*	1.00		
Silicate	0.97 0.97*	0.97 0.99*	0.91 0.96*	0.94 0.92*	1.00	
Chl-a	0.93 0.96*	0.93 0.99*	0.90 0.96*	0.93 0.94*	0.97 0.98*	1.00

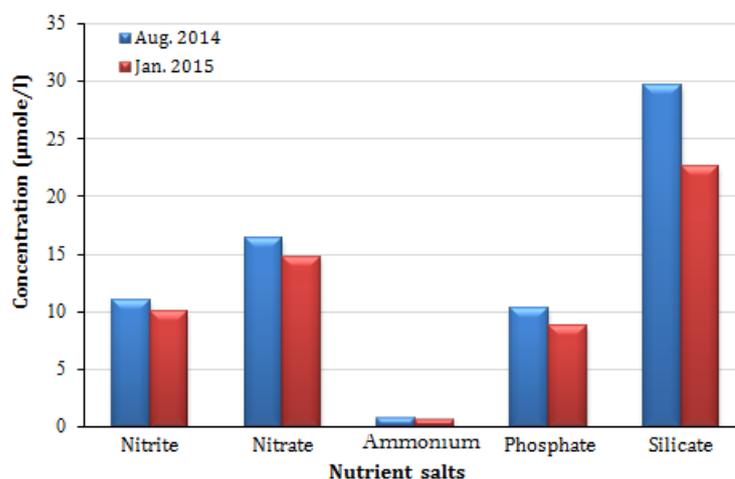r = 0.86 for August 2014   r = 0.92* for January 2015

Figure 3. Average concentrations of nutrient salts in the Gulf of Aden and Arabian Sea coast surface water during August 2014 and January 2015.

The present data for nitrate was similar to that previously recorded on the Hadramout coast; 17.30-20.90 µg/l [4]. An excellent positive correlation was recorded between nitrate and nitrite (r = 0.99 in August 2014 and = 0.97 in January 2015) and a very strong to excellent positive correlation was recorded between nitrate and ammonium (r = 0.84 in August 2014 and = 0.97 in January 2015) (Table 2). Lower DIN concentrations were detected in As Suqayyah and high concentrations were detected in Hawf.

The average values of nitrate concentrations of 16.41 and 14.73 µg/l for August 2014 and January 2015, respectively, were much higher than the average contents of nitrate of 10.98 and 10.03 µg/l for the same period, respectively, while the concentration of ammonium was fifteen and tenfold less than those recorded for nitrate and nitrite, respectively. Based on these results, the abundance of nitrogen species in the study area is principally in the order nitrate > nitrite > ammonium. This reflects the preferred uptake of the DIN species by phytoplankton organisms in their N-assimilation.

3.1.2. Reactive phosphate

Phosphorus plays a major role in biological metabolism; it is an essential nutrient element in photosynthesis and other processes in plants. Phosphate concentrations in August 2014 ranged from 8.80 to 11.55 µg/l with an average of 10.36±1.07 µg/l, whereas concentrations in January 2015 ranged from 7.00 to 10.30 µg/l with an average of 8.76±1.11 µg/l (Table 1 and Figure 3). The average value of phosphate in August 2014 was higher than the average value in January 2015 (Figure 4). Lower phosphate concentrations were detected in As Suqayyah and higher concentrations were detected in Hawf (Figure 4).

A very strong to excellent positive correlation was recorded between phosphate and other nutrient salts (r ≥ 0.85) and Chl-a (r ≥ 0.93) (Table 2).

The present data for Phosphate was similar to that previously recorded for the Hadramout coast; 10.30-11.20 μg/l [4].
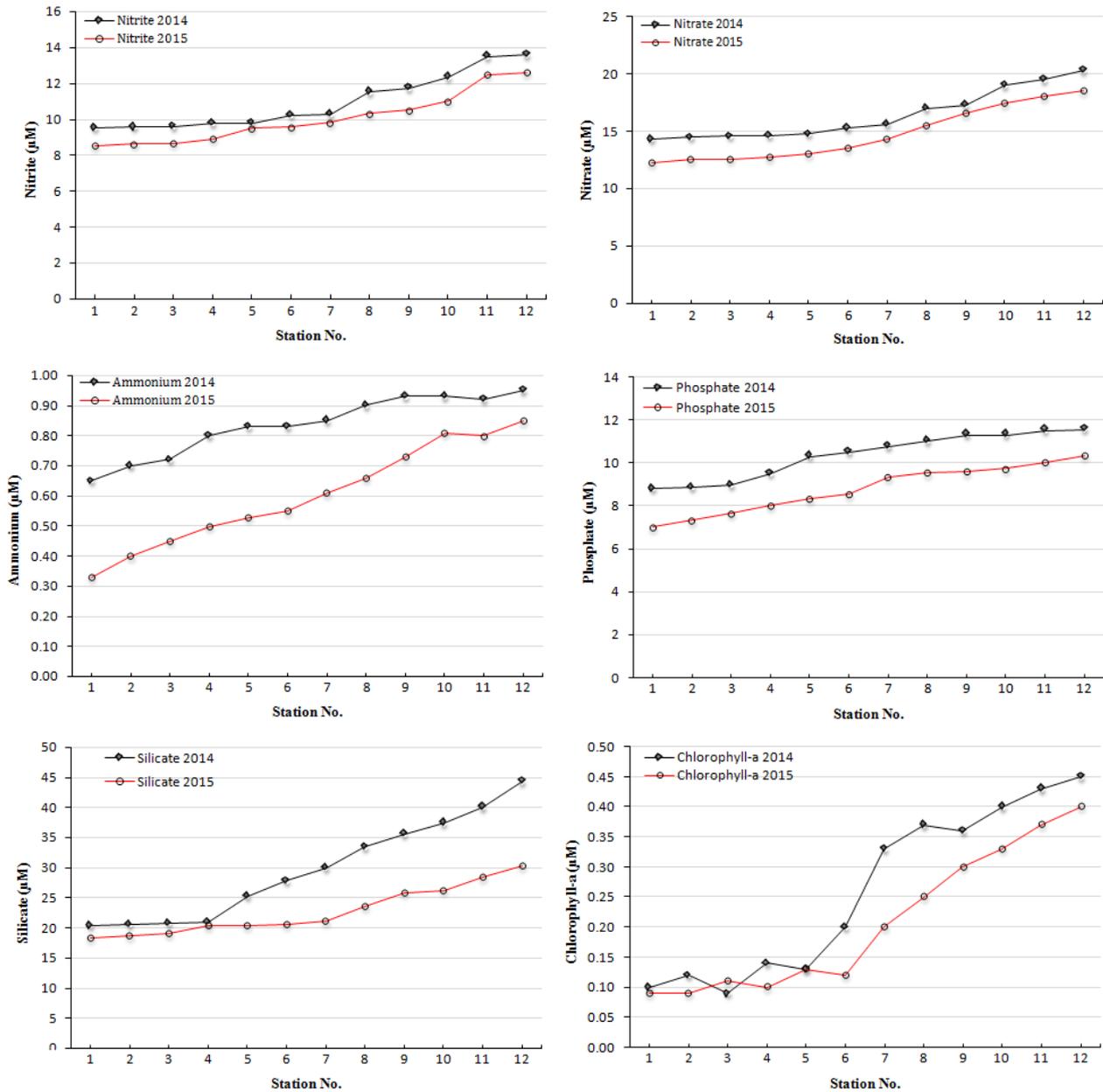

Figure 4. Spatial distribution of inorganic nutrient salts and Chl-a at selected stations in the Gulf of Aden and Arabian Sea coast surface water during August 2014 and January 2015.

3.1.3. Reactive silicate

Silicate is one of the major mineral constituents in sea water. It is a good indicator of fresh water dispersion and of the potential for diatoms [23]. Silicate concentration in August 2014 ranged from 20.40 to 44.30 μg/l with an average of 29.72±8.39 μg/l, whereas the concentration in January 2015 ranged from 18.30 to 30.20 μg/l with an average of 22.67± 4.03 μg/l (Table 1). The average value of silicate in August 2014 was higher than the average value in January 2015 (Figure 3). Lower silicate concentrations were detected in As Suqayyah and actually high concentrations were detected in Hawf (Figure 4).

The concentration of silicate in the present study revealed high levels (>18 μg/l). Probably, during August, the dissolution of diatom skeletons by increasing temperature, up-welling and sandstorms are responsible for high levels of silicate. The average concentrations of silicate were higher than those of the other nutrient salts. This means that silicate is not a limiting factor for phytoplankton growth in the stations studied. An excellent positive correlation was recorded between silicate and other nutrient salts (r ≥ 0.91) (Table 2).

The present data for silicate was similar to that previously recorded on the Hadramout coast; 20.30-40.50 μg/l [4].

The coastal areas of the Gulf of Aden and Arabian Sea exhibit comparatively high values of nutrient salts, indicating the probable effects of upwelling. Upwelling of variable intensity is reported to occur along these coasts depending mainly upon influencing factors like wind stress, and acceleration of the vertical movements due to the changing current regime [24].

Spatial distribution of surface nutrient concentrations showed high concentrations of ammonium, nitrite, nitrate, phosphate and silicate in the east of the study area but lower concentrations to the west during both cruises (Figure 4).

3.2. Chlorophyll-a (Chl-a)

Marine phytoplankton play a central role in the planktonic food web and biogeochemical cycling in the global ocean. Primary production by phytoplankton is consumed or decomposed to support other trophic levels, including the fish we harvest, or is exported to deeper waters [25].

Chl-a is the main pigment that can be used for the determination of phytoplankton biomass [26], and it is used as a trophic state indicator. Chl-a concentration in August 2014 varied between 0.09 and 0.45 mg/m^3 with an average of 0.26±0.14 mg/m^3, whereas the concentration in January 2015 varied between 0.09 and 0.40 mg/m^3 with an average of 0.21±0.12 mg/m^3 (Table 1). The average value of Chl-a in August 2014 was higher than the average value in January 2015 (Figure 5).
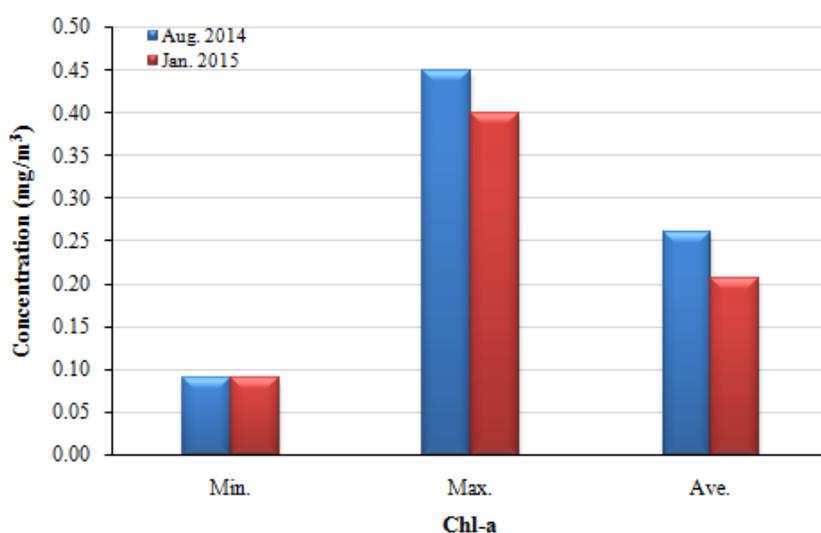

Figure 5. Minimum, maximum and average concentrations of Chl-a in the Gulf of Aden and Arabian Sea coast surface water during August 2014 and January 2015.

Nutrient concentrations decline from east to west in the Gulf of Aden and along the Arabian Sea coast. The highest concentrations were recorded in station 12 and lower concentrations were encountered in station 1surface water (Figure 4). Generally, during January 2015 levels of Chl-a were lower than those recoded during August 2014 (Figure 4). The present data for Chl-a was similar to that recorded previously on the Hadramout coast, with 0.23-0.34 mg/m^3 [4], and semi-similar to that recorded in the Aegean Sea, with 10-0.80 mg/m^3 [27] and 0.03-0.70 mg/m^3 [28], but lower than that reported by Khomayis [29] in the coastal waters of Jeddah city, Red Sea (0.02-10.16 µg/l) and higher than that reported by Ignatiades *et al.*, [30] in the north and eastern Mediterranean Sea (0.01-0.15 µg/l).The study values indicate that the production potential of the Gulf of Aden and Arabian Sea coast is low.

The reason why higher concentrations were noticed at station 12 (Hawf) may be due to the intense upwelling and the advection of the upwelled water of the Somali region brought into this area due to the intensification of the Somali current, a part of which flows northwards into the area further north along the coast of Oman. The distribution of Chl-a also follows exactly the same pattern as that of the nutrient salts, indicating a higher productivity due to the blooming of phytoplankton in areas rich in nutrient salts, and showing a direct relationship between the two as illustrated in Table 2. The results show a relationship between phytoplankton and nutrients salts; this is confirmed by the excellent positive correlation between Chl-a and nutrient salt concentration (r ≥ 0.93) (Table 2).

In general, the high values of Chl-a in the coastal area investigated are undoubtedly due to the rich supply of DIN, phosphate and silicate; these nutrient salts contribute to the growth of phytoplankton, expressed by the high levels of Chl-a, which has ledto a eutrophication process in the Gulf of Aden and Arabian Sea coasts. The levels of DIN, phosphate, silicate and Chl-a indicate that, the Gulf of Aden and Arabian Sea is in a eutrophic condition.

The general trend of temporal distribution of nutrient salts and Chl-a showed slightly higher values during August 2014 than January 2015. The data in this work clearly demonstrate the oligotrophic nature of the Gulf of Aden and Arabian Sea coasts.

Conclusion

The distributions of nutrient salts and Chl-a during August 2014 and January 2015 cruises in the Gulf of Aden and Arabian Sea coasts have been investigated. The content of nitrate through the study period is higher than the content of ammonium. This observation may reflect the oxidation of ammonium to nitrite and then to nitrate which may justify the very good relation between ammonium and nitrate concentrations.

Based on the results, the abundance of nitrogen species in the study area is principally in the order: nitrate > nitrite > ammonium. This reflects the uptake preferable of the inorganic nitrogen species by phytoplankton organisms in their N-assimilation. The concentrations of nutrient salts and Chl-a during August 2014 are higher than observed concentrations during January 2015. The spatial distribution of nutrients affects the distribution of phytoplankton, as confirmed by the Chl-a data in the Gulf of Aden and Arabian Sea coasts (between 0.09-0.45 mg/m^3).

Hence, surface seawater in Gulf of Aden and Arabian Sea coast maintains normal environmental conditions. The results of these investigations could be considered as pilot for further similar studies in the coastal waters of Gulf of Aden and Arabian Sea.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

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