Distribution of nutrients in surface seawater from the Aden coasts/Gulf of Aden, Yemen

Shaif Mohammed Kasem Saleh1* and Fursan Thabet Ahmed Al-Halmi2

1 Department of Chemistry, Faculty of Science, University of Aden, Yemen
2 Department of Chemistry - Faculty of education - Radfan, University of Aden, Yemen

*Corresponding author: shamq2002@yahoo.com

Abstract. The concentrations of nutrients as well as some physico-chemical parameters were evaluated at the surface seawater of eight stations in Aden city coasts during winter 2019 and summer 2020. The results indicated that the concentration of nutrients were high in the study stations, exception the reference station which was far from the sources of pollution, where the domestic sewage effluents that discharge to sea. Seasonal variations showed that nitrite and nitrate concentrations in all stations were higher during winter (0.053 and 5.460 mg/L) compared to their corresponding values in summer which were 0.029 and 3.130 mg/L respectively. On contrast, seasonal distributions of phosphate and silicate exhibited significantly higher values in summer 0.746 and 1.004 mg/L compared to their corresponding values in winter, which were 0.451 and 0.881 mg/L, respectively. The results of the study confirm the importance of protecting Aden coastal waters from various pollutants, especially wastewater pollutants.

Recommendations: Maintaining and repairing the sewage network and reconnecting cities with Al-Arish station. The waste is not directly discharged to the sea until after it has been treated, provided it is safe. The application of legislation and regulations related to the protection of the marine environment.

Keywords: Nutrients, physicochemical properties, seawater, Gulf of Aden, Yemen.

1. Introduction

Pollution of sea water is one of the serious environmental impacts that threaten human health and marine organisms, and pumping sewage into the sea is one of the main causes of pollution of the marine environment. These waters can carry high levels of toxins and pathogenic bacteria, which may be transmitted to humans or marine organisms [1]. The most commonly accepted definition of marine pollution is given by [2]: “The introduction by man, directly or indirectly of substances or energy into the marine environment resulting in such deleterious effects as harm to living resources; hazards to human health; hindrance of marine activities including fishing impairment quality for use seawater; and reduction of amenities.

Coastal waters are subjected to a significantly increasing stress. The anthropogenic ally driven changes in the coastal area are intense essentially due to elevated population density and rapid rate of population growth. These water bodies receive different hazardous wastes which reach the environment with industrial, agricultural and municipal wastewater [3]. The Pollutants from wastewater significantly affect the physico-chemical properties of the waters and potentially
intimidates marine organism, ecosystems, and biodiversity of the marine waters inhabitants beside it affects the quality and productivity of marine ecosystems [4,5].

Wastewater and the lack of sewage treatment station or liquid waste are among the main causes of seawater pollution in Yemen [6]. In the city of Aden, wastewater treatment is neglected, especially after the suspension of the Al-Arish station due to the last war in 2015, where it discharge directly into the sea, this contributes to increasing the nutrients and changing in the chemical and physical properties of sea water.

The discharge of excessive nutrients from urban and industrial wastewaters, contributes to the enrichment of inorganic and organic material in marine waters. Eutrophication can lead to the detrimental changes of the structure and function of both living organisms and non-living components in an ecosystem [7,8]. Several literature reports have described the occurrence of eutrophication as a result of high concentrations of nutrient chemicals in coastal waters [9-18]. 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, water quality degradation and changes in the balance of organisms. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services [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 [9,19].

Figure 1. Study Area and Sampling Sites

2. Materials and Methods
Surface water samples were collected in December, 2019 and June 2020 from eight sampling stations along the coastal area of Aden (Figure 1 and Table 1). Water temperature, pH and Salinity were
measured directly in situ using graduated thermometer, pH-meter (HQ40d multi/HACH) and hand-held Salinity refract meter respectively. A turbidity meter (2100Q HACH) was used to measure turbidity of the water samples. Dissolved oxygen was fixed immediately after collection and then determined by Winkler’s method. Two samples were considered for this analysis. DO was determined for the first sample immediately. The second sample was incubated for five days and then the DO was determined. The BOD was determined using the relation, BOD = DO before incubation - DO after incubation.

The water samples for NO₂, NO₃, PO₄ and SiO₄ determination were analyzed according to the recommended methods by Parsons et al., [21] using UV-Spectrophotometer DR 3900 HACH.

**Table 1. Sampling Stations**

| Name of Station | Station No. | Latitude | Longitude |
|-----------------|-------------|----------|-----------|
| Sira Island     | Station 1   | 12°46'35"N | 45°02'48"E |
| AL-Omal Island  | Station 2   | 12°48'36"N | 45°01'06"E |
| Abyan Coast     | Station 3   | 12°50'02"N | 45°2'04"E  |
| Gold moor       | Station 4   | 12°46'28.4"N | 44°59'04"E |
| AL-Hiswah       | Station 5   | 12°49'27"N  | 44°55'59"E |
| AL-Farsi        | Station 6   | 12°46'19.2"N | 44°53'16.8"E |
| AL-Khissa       | Station 7   | 12°44'45"N  | 44°54'26"E |
| Ras Imran       | Station 8   | 12°45'52"N  | 44°44'52"E |

3. Results and Discussion

3.1 Physico-chemical properties

3.1.1 Water Temperature (°C)

Surface water temperature in the study stations ranged from 26.30 °C at station 8 in winter to 33.00 °C at station 7 in summer, with general mean 29.40 °C. Seasonal variation of surface water temperature showed higher values in summer compared to winter in all stations; this was associated with the air temperature, which was higher in summer. Also, the results showed a spatial variation in surface water temperature values, where the highest in temperature values observed in some stations such as station 5, station 2 and station 7 as shown in Table 2, these stations recorded high pollution rates by untreated sewage. Where the rates of chemical and biological reactions increase with increasing temperature, this indicates the effect of sea water pollution with untreated sewage on the water temperature, while the reference station recorded the lowest value [5].

3.1.2 Hydrogen Ion Concentration (pH)

As shown in Table 2 the pH values ranged from 7.85 at station 5 in winter to 8.29 at station 8 (reference station) in summer, with general mean 8.07. The values obtained for pH at all the locations reflected little influence of season with slightly higher values in summer, this may be due to the abundance of phytoplankton bloom which are in better environmental conditions during this season where the activity of photosynthesis processes increases causing more consumption of carbon dioxide and pH increased. Generally, in this study the pH values in all stations were slightly alkaline and consistent with the results reported by AL-Shwafi [17] found the range for pH was 7.87-8.01 in seawater of Aden coastal, AL-Shwafi [12] found pH values ranged between 7.80 and 8.03 with a mean value of 7.97 in the Gulf of Aden and Nabil and Mohsen [15] in Hadramout coast found the range pH was 7.83-8.01.
3.1.3 Salinity (S‰= ppt)
The observed values of salinity in the study area waters ranged between 36.50 ppt at station 7 in winter and 38.40 ppt at station 2 in summer with general mean 37.5 ppt (Table 2). The highest salinity values were in summer compared to winter; this could be associated with higher temperature that leads to increasing evaporation rate of seawater in summer. Station 2 (AL-Omal Island) and station1 (Sira) exhibited the higher values of salinity, this may be due to that these sites, are more semi-closed shores, intensive evaporation, and the movement of water is limited, whereas stations 7 (Al-Khissa) and station 5 (Al-Hiswah) recorder slightly low in salinity values which were 36.80 and 37.00 ppt respectively, this may be due to increase sewage discharge at these sites.

Compared with the reference station (station 8), the salinity values of all stations were lower than the value of the reference station except for station 2 and 1, which were higher for the reason mentioned previously. The results of this study did not differ significantly from the results reported by Al-Shwafi [17] who found salinity values ranging from 37.3-38.3 ppt in sea water coasts of Aden city- Yemen, but it was higher than that reported by Nabil and Mohsen [15] 36.09 - 36.40 ppt in Hadramout coasts-Yemen. The statistical analysis showed significant differences between summer and winter seasons in terms of salinity at (P≤0.05), and significant differences between stations.

3.1.4 Turbidity
As shown Table 2, the turbidity values ranged from (2.15 NTU) at station 8 in winter to (20.10 NTU) at station 5 in summer, with general mean 8.87 NTU, where it was higher than that in Hadhramout coast, Yemen (0.1- 4.02 NTU) [11]. Seasonal values showed that the turbidity values were higher during summer compared to winter, where the statistical analysis revealed significant differences (P≤0.05) in pH between seasons (25.64%) (Table 2), may be due to the abundance of phytoplankton, massive contribution of suspended solids from sewage and the influx of rainwater carrying suspended soil particles and other substances to sea in summer. The maximum values of turbidity were at stations 5 and 7 which were 17.30 and 14.18 NTU respectively, the increase in station 5, may be due to increase sewage discharge to Al-Hiswah nature reserve and its runoff with plant debris, animal waste and soil particles into sea water, also the increase in station 7, may be due to the drainage of sewage from the village of Al-Khissa directly to the coast, as well as it is an area where fishing boats are anchored. Whereas the reference station (station 8) recorded the lowest value 2.29 NTU.

3.1.5 Dissolved Oxygen (DO)
In this study, the dissolved oxygen (DO) concentration ranged from 3.74 mg/L at station 7 in summer to 5.40 mg/L at station 8 in winter, the mean concentration of the two seasons was 4.37 mg/L (Table 2). During the study period, the lowest values of DO observed at station 7 and 5, which were 3.81 and 3.88 mg/L respectively, this decrease may be mainly attributed to the microbial activity and consumption of DO in the oxidation of organic matter due increased untreated sewage discharge into these stations, in addition to the presence of energy production plant in the same place impact to change the nature of the marine environment based on the study, which his Saleh [22] found that the Al-Hiswah station suggesting serious anthropogenic pollution. While the highest value recorded at station 8 (Reference station) which were 5.29 mg/L. The statistical analysis revealed significant decrease for all stations compared to the reference station which significantly increased by 29.87% compared to the station 7 which gave the lowest values.

Seasonally the results showed high values in summer compared to winter. where the high temperature, increasing turbidity by rainfall and winds, increasing addition of sewage and other waste in summer might be responsible for low values of DO in summer. This was consistent with reported by Al-Edreesy [13] in the coasts of Al-Hodeidah and Manasrah et al., [10] in the Gulf of Aqaba and Red Sea, who found that the DO values were higher in summer compared to winter. The statistical analysis revealed significant differences (P≤0.05) in DO between seasons (4.25%), and significant differences between stations.
3.1.6 Biochemical Oxygen Demand (BOD5)

The BOD5 values ranged from 0.45 mg/L at station 8 during winter to 3.14 mg/L at station 7 during summer with a general mean of 2.39 mg/L as shown in (Table 2). Seasonally, BOD5 recorded the highest levels during summer and the lowest during winter, where the statistical analysis revealed significant differences at (P≤0.05) in BOD5 between seasons (5.69%). The rise in summer may be due to the high temperature, sunshine and their effect on the activity of living organisms in seawater. The obtained BOD5 data showed that the maximum values during the study period were observed at stations 7, 5, 3.11 and 3.05 mg/L respectively, while the minimum value was found at the reference station 0.48 mg/L. The results of statistical analysis refer that significant differences at (P≤0.05) between all stations (Table 2). The increase in BOD5 value at station 7 and 5 this may be due to the abundance of nutrients that accompany wastewater, which leads to an increase in the number of microorganisms, thus the demand for dissolved oxygen increases in this waters, where these stations have a higher pollution rate compared to other stations, this corresponds to the results of the study conducted by Al-Ammari et al., [5] in Libyan coast, they noticed a decrease in values of dissolved oxygen in some marine sites that have a high pollution rate.

3.2. Nutrient Salts

The Gulf of Aden is characterized by a low-salinity, nutrient-rich layer, ranging in depth between 120 and 420 m [23]. In this study, the nutrient concentrations were generally high in the seawater of the study area, especially at stations close to the sewage outlets, this indicates that the main source of nutrients in this study is untreated wastewater that is discharged directly to the sea, especially after the sewage treatment stations stopped due to the last war in 2015, such as Al-Arish/KhorMaksar station, Kabuta/Al-Shaab station and Salah El-Din station. The stations close to sewage outlets such as stations 5 and 7, as well as stations 1 and 2 had the highest nutrient values because they are more influenced by the incoming proteinic matter and poly phosphoric products from household's detergents. While stations that were slightly affected by sewage, such as stations 3, 4 and 6 had lower nutrient values, while the lowest nutrient values were at station 8 (reference station), which was further from wastewater impacts.

Seasonal variations showed that nitrite and nitrate concentrations in all stations were significantly higher during winter compared to their corresponding values in summer. On contrast, seasonal distributions of phosphate and silicate exhibited significantly higher values in summer compared to their corresponding values in winter.

3.2.1 Nitrite (NO2–)

The nitrite concentration in the study stations ranged from 0.002 mg/L at station 8 in summer to 0.122 mg/L at station 2 in winter, with a general mean 0.041 mg/L (Table 3). Nitrite levels were lower during summer compared to winter, the decrease in nitrite levels during summer may be as a result of nutrients consumption by phytoplankton and aquatic plants which are more concentrated in this season. Similarly, maximum value in winter season and minimum value in summer season was also recorded by Fahmy et al., [24] in the Egyptian red sea coastal waters and Manikannan et al., [25] in southeast coast of India.

During the study period the maximum of nitrite concentration observed at station 2 which was 0.103 mg/L, whereas the minimum concentration was 0.004 mg/L (0.004 mg/L) at station 8 (Reference station), the increase at station 2 may be attributed to the decomposition of the organic materials that come from untreated wastewater, as this region is semi-isolated and the movement of water is limited and not affected by tidal currents. Compared with the reference station (station 8) which it has a lower pollution rate, the nitrite concentrations of all seven stations were higher than the reference station. The obtained results in this study were higher than that reported by Al-Akhalay [9] who found the average for nitrite in waters collected in August 2014 and January 2015 was 10.98 and 10.03 ug/L in the Gulf of Aden and Arabian sea coast, Yemen, and AbuBaker et al.,[16] found the nitrite concentrations ranged between 1.43-7.84 ug/L in the coastal water of the red sea, Yemen.
3.2.2 Nitrate \((NO_3^-)\)

The range of Nitrate values was 0.750 mg/L at station 8 in summer to 11.500 mg/L at station 5 in winter with general mean 4.290 mg/L (Table 3).

The seasonal variation of the nitrates were lower during summer and higher during winter. Where the statistical analysis revealed significant differences \((P \leq 0.05)\) in NO3 between seasons \((42.67\%)\), the decrease during summer compared to winter may be due to the high temperature, which increases the photosynthesis process and thus the increased consumption of nitrate by phytoplankton growth. Similarly maximum values in winter season and minimum values in summer season were also recorded by Mukhaysin et al., [11] in Hadhramout coast, Gulf of Aden and Elmorsi et al., [26] in Manzala Lake, Egypt.

The results showed that the nitrate concentrations of all stations were higher than the reference station, which recorded the lowest value during the study period. The statistical analysis revealed significant differences in NO3 between all stations, where station 5 gave the highest value by significant increasing was 91.85\% compared to the reference station. This is consistent with the study of Saleh [22] that the Al-Hiswah station of the most coastal areas polluted by human activities.

During the study, stations 5 and 7 recorded the highest values of nitrate ions, which were 9.450, and 7.050 mg/L respectively, this increase may be due to the increasing amount of domestic discharges into these stations, which enhanced oxygen consumption that resulted in low oxygen concentrations but high concentrations of NO3. Also slightly higher concentrations of NO3 were observed at stations 1, 2 and 3 which were 5.100, 4.380 and 4.060 mg/L. while at stations 6 and 4, observed decrease in nitrate concentrations compared to the previous stations where recorded 2.210 mg/L for station 6 and 1.350 mg/L for station 4, this indicates that the effects of untreated sewage on these stations were low. The results of this study were higher than those observed by Nabil and Mohsen [15] who found NO3 values ranging from 17.30- 20.90 ug/l in Hadramout coast-Yemen, AbuBaker et al., [16] that found the NO3 values ranged between 1.79- 17.45 ug/l in the coastal water of the red sea, Yemen, whereas it was lower than that reported by Mohorjy and Hussein [18] found the range for NO3 was 28.3-130.0 mg/L in the Red Sea Coast near Jeddah, Saudi Arabia.

3.2.3 Phosphate \((PO_4^{3-})\)

As shown in Table 3 the phosphate concentration ranged from 0.030 mg/L at station 8 to 1.250 mg/L at station 7, with general mean 0.599 mg/L. Seasonally, the present study indicated that the high levels of phosphate were in summer compared to winter, where the statistical analysis revealed significant differences \((P \leq 0.05)\) in PO4 between seasons \((39.54\%)\), this increase in summer may be due to the increase in household water discharges containing high concentrations of soap and detergents due to the high temperature in this season. Similarly maximum values in summer and minimum values in winter were also recorded by Fahmy et al., [24] in the Egyptian red sea coastal waters. The results of the present study showed that phosphate concentration in all stations were higher than the reference station, where the statistical analysis revealed significant differences in PO4 between all stations, where station 5 gave the highest value by significant increase was 96.71\% compared to reference station.

The maximum value of PO4 during the study period observed at station 5, which was 1.065 mg/L, may be due to the mixing of land run off from the Al-Hiswah nature reserve contaminated with super phosphates and alkyl phosphates from soap and detergents used by the public for bathing and washing clothes and end up in the sea, also at station 7 the phosphate concentration was \((0.975 mg/L)\), this may be due to increasing amount of domestic discharges from Al-Khissa city with grow the population. At stations 1 and 2 the phosphate concentrations were 0.900 mg/L and 0.720 mg/L respectively. While in the other stations 3, 6 and 4 the phosphate concentrations were lower than previous stations, \((0.615 mg/L), (0.385 mg/L)\) and \((0.095 mg/L)\) respectively, this indicate that effect of local sewage discharge was low in these stations. The results of this study were higher than that reported by Al-Shwafi [14] in Mangrove environment of red sea coast of Yemen who registered PO4 values ranged 0.30-6.10 ug/L, Nabil and Mohsen [15] who found PO4 values ranging from 10.30-11.20 ug/L in Hadramout coast-Yemen, whereas it was lower than that reported by Mohorjy and Hussein [18] who found the range for PO4 was 0.74-3.81 mg/L in the red sea coast near Jeddah.
3.2.4 Silicate (SiO$_4^{-4}$)
The silicate concentration in the study stations ranged from 0.170 mg/L at station 6 during winter to 2.014 mg/L at station 5 during summer, with general mean 0.943 mg/L (Table 3). The seasonal variation of the silicate was higher during summer (0.178–2.014 mg/L), and lower during winter (0.170–1.777 mg/L), where the statistical analysis revealed significant differences ($P\leq0.05$) in PO$_4$ between seasons (12.25%), this increase during summer may be due to increased untreated sewage discharge, the effect of run-off from land and sandstorms in this season.

The result of the analysis of silicate in the surface water showed that the highest levels were at stations close to untreated sewage outlets such as stations 5, 2, 7 and 1 which were 1.804, 1.792, 1.067 and 0.998 mg/L respectively, this indicating that the sewage as a source of silicate in this study. While the lowest concentration (0.174 mg/L) have been registered at station 6, this decrease may be due to the effect of local sewage discharge was low in this area.

The results referred that silicate concentrations in all stations were higher than the reference station except station 6, which was lower. The statistical analysis revealed significant differences in SiO$_4$ between all stations, where station 5 gave the highest value by significant increasing was 73.97% compared to the station 6.

The results of this study were higher than that reported by Al-Shwafi [14] registered silicates concentrations ranged 15.30 ug/L to 23.40 ug/L with mean 18.833 ug/L in Mangrove environment of red sea coast of Yemen, Mohorjy and Hussein [16] found the silicates values ranged between 29.05-92.95 ug/l in the coastal water of the red sea, Yemen.

4. Conclusion
It is evident from the results of the study that most of the sites are polluted with sewage waste as a result of being discharged into the sea directly without treatment. Therefore, the necessity of restarting the Al-Arish sewage treatment plant, through the maintenance and restoration of the old sewage network, connecting the rest of the cities to the network, and treating the household waste in the Al-Arish station.

Table 2. Physico-chemical analysis of seawater samples in Aden coasts

| Stations | Parameters | Water Temperature (C°) | Hydrogen Ion concentration (pH) |
|----------|------------|------------------------|-------------------------------|
|          |            | W         | S         | Mean | L.S.D | W    | S    | Mean | L.S.D |
| St.1     |            | 26.70     | 32.30     | 29.50 |        | 8.00 | 8.07 | 8.04 | 0.026 |
| St.2     |            | 26.80     | 32.80     | 29.80 | 0.174  | 7.90 | 7.98 | 7.94 |        |
| St.3     |            | 26.50     | 32.00     | 29.30 |        | 8.05 | 8.12 | 8.08 |        |
| St.4     |            | 26.30     | 31.40     | 28.90 |        | 8.15 | 8.24 | 8.19 |        |
| St.5     |            | 27.10     | 33.00     | 30.10 |        | 7.85 | 7.89 | 7.87 |        |
| St.6     |            | 26.30     | 31.50     | 28.90 |        | 8.12 | 8.22 | 8.17 |        |
| St.7     |            | 26.80     | 32.60     | 29.70 |        | 7.92 | 7.95 | 7.94 |        |
| St.8     |            | 26.40     | 31.20     | 28.80 |        | 8.23 | 8.29 | 8.26 |        |
| Mean     |            | 26.60     | 32.10     | 29.40 |        | 8.03 | 8.10 | 8.07 |        |
| Range L.S.D |        | 26.30-33.00 | 7.85-8.29 | 0.087 | 0.013 |
| Salinity (ppt) |        | 0.315 |        | 38.00 |         | 8.10 | 10.30 | 9.20 | 1.687 |

| Turbidity (NTU) |
|----------------|
| St.1           | 37.80     |
| St.2           | 37.90     |
| St.1           | 38.10     |
| St.2           | 38.40     | 38.20 |
| St.1           | 8.10      |
| St.2           | 7.30      | 8.86  | 8.08  |
| St.1           | 10.30     |
| St.2           | 9.20      | 1.687 |
Table 3. Results of nutrient salts (Nitrite, Nitrate, Phosphate and Silicate) of seawater samples in Aden coasts

| Stations | Winter | Summer | Mean | L.S.D | Winter | Summer | Mean | L.S.D |
|----------|--------|--------|------|-------|--------|--------|------|-------|
| St.1     | 0.068  | 0.035  | 0.052 | 0.081 | 6.360  | 3.840  | 5.100 | 0.007 |
| St.2     | 0.122  | 0.084  | 0.103 |       | 5.950  | 2.800  | 4.380 |       |
| St.3     | 0.037  | 0.011  | 0.024 |       | 5.160  | 2.950  | 4.060 |       |
| St.4     | 0.019  | 0.008  | 0.014 |       | 1.760  | 0.940  | 1.350 |       |
| St.5     | 0.062  | 0.036  | 0.049 |       | 11.500 | 7.400  | 9.450 |       |
| St.6     | 0.054  | 0.027  | 0.041 |       | 3.140  | 1.270  | 2.210 |       |
| St.7     | 0.055  | 0.031  | 0.043 |       | 9.000  | 5.100  | 7.050 |       |
| St.8     | 0.006  | 0.002  | 0.004 |       | 0.780  | 0.750  | 0.770 |       |
| Mean     | 0.053  | 0.029  | 0.041 |       | 5.460  | 3.130  | 4.290 |       |
| Range    | 0.002-0.122 | 0.750-11.500 |       |       |

W: Winter, S: Summer, L.S.D: Least Significant Difference
| St.8 | 0.040 | 0.030 | 0.035 | 0.425 | 0.510 | 0.468 |
|------|-------|-------|-------|-------|-------|-------|
| Mean | 0.451 | 0.746 | 0.599 | 0.881 | 1.004 | 0.943 |
| Range | 0.030-1.250 | 0.170-2.014 |
| L.S.D | 0.015 | 0.004 |

Acknowledgements
The authors would like to express their gratitude and appreciation to Benevolent Fund for Outstanding Student (BFOS) for the support.

5. References
[1] Alibi S, Samiha M, Wafa H and Al Hadi M 2020 Study of the physiochemical and bacteriological properties of Berjesh seashore waters in Mahdia – Tunisia. Arabian Journal of Scientific Research 9 2020
[2] FAO, 1994. Review of pollution in the African aquatic environment CIFA Technical paper, No. 25:118.
[3] Al-Farawati R 2010 Environmental conditions of the coastal waters of southern Corinche, Jeddah, Eastern red sea: physico-chemical approach. Aust. J. Basic Appl. Sci. 4 3324-37
[4] Bald J, Borja A, Muxika I, Franco J and Valencia V 2005 Assessing reference conditions and physico-chemical status according to the European water framework directive: a case study from the Basque country (Northern Spain). Marine Pollution Bulletin 50 1508-22
[5] Al-Ammari K, Abu al-Qasim K and Ramadan A 2018. Study of bacterial pollution in the waters of the seashores east of the city of Tripoli, Libya. The International Refereed Journal of Engineering Sciences and Information Technology 5 21-5
[6] Schmidt M, Al-Nozailly F and Al-Ghorbanly A 2008 Standards for and evaluation of small-scale dam projects in Yemen. In Standards and Thresholds for Impact Assessment Springer, Berlin, Heidelberg. pp. 133-144.
[7] Parnell P 2003 The effects of sewage discharge on water quality and phytoplankton of Hawai‘ian coastal waters. Marine environmental research 55 293-311.
[8] Reoapanichkul P, Carter R, Worachananant S and Crossland C 2010 Wastewater discharge degrades coastal waters and reef ecosystems in southern Thailand. Marine environmental research 69 287-96
[9] Al-Akhaly I, Al-Shwafi N and Al-Kabsh Sh 2020 Distribution of nutrient salts and chlorophyll-a in surface water along the Gulf of Aden and Arabian sea coast, Yemen. SQU Journal for Science 25 17-24
[10] Manasrah R, Abu-Hilal A and Rasheed M 2019 Physical and chemical properties of seawater in the Gulf of Aqaba and red sea. In Oceanographic and Biological Aspects of the Red Sea Springer, Cham, pp. 41-73.
[11] Mukhaysin A, Inna I, Salem R, Tatyana F and Bogatoz M 2018 State of seasonal environmental factors of the Hadhramout coast, Gulf of Aden, Yemen. Egyptian Journal of Aquatic Biology and Fisheries 22 119-136
[12] Al-Shwafi N 2012 Hydrographical Studies on the Gulf of Aden around Aden city, Yemen. Nature Environment and Pollution Technology 11 519-522
[13] Al-Edeesey M 2012 Impact of Man-made activities on the red sea coastal waters off Al-Hudaydah (Yemen); Unpublished Ph.D. Thesis; Fac. Sci.; Alexandria Univ.; Egypt; p.325
[14] Al-Shwafi N 2011 Distribution of nutrients and chlorophyll-a in mangrove environment of red sea coast of Yemen. Nature, Environment and Pollution Technology 10 517-20
[15] Nabil A and Mohsen A 2009 A systematic Evolution of Selected Nutrient and Chlorophyll-a along of Hadramou coast-Yemen. *Scientific Notes of the Russian State Hydro meteorological University* 9 148-155

[16] AbuBaker M, DouAbul A and Al-Shwafi N 2007 Dstribution of nutrients in the coastal water of the red sea, Yemen, *L. Egypt. Acad. Soc. Environ. Develop. Egypt* 8 63-74

[17] AL-Shwafi N 2007 Concentration of petroleum hydrocarbons in seawater and coastal sediment around Aden city - Yemen. *Al-Azhar Bulletin of Science* 18 37-51

[18] Mohorjy A and Hussein M 2006 Environmental assessment of seawater pollution in Jeddah coastal area. *Proceedings of the 7th Saudi Engineering Conference (SEC7)* pp1-13.

[19] Zoffmann C, Rodriguez-Valera F, Perez-Fillol M, Ruiz-Bevia F, Torreblanca M and Colom F 1989 Microbial and nutrient pollution along the coasts of Alicante, *Spain. Marine pollution bulletin* 20 74-81

[20] Saleh Sh, Amer A and Al-Alawi A 2018 Potential ecological risk of heavy metals in surface sediments from the Aden coast, Southern Yemen. *Journal of Environmental Science, Toxicology and Food Technology* 12 42-55

[21] Parsons T, Maita Y and Lalli C 1984 A Manual of Chemical and Biological Methods for Seawater Analysis, *Pergamon Press, Oxford.*

[22] Saleh Sh M K 2007 Environmental assessment of heavy metals pollution in bottom sediments from the Gulf of Aden, Yemen", Ph.D. Thesis, *Institute of Graduate Studies and Research, Alexandria University, Egypt, 2007*

[23] Al Saafani M and Shenoi S 2007 Water masses in the Gulf of Aden. *Journal of Oceanography*, 63 1-14

[24] Fahmy M, Fattah L, Abdel-Halim A, Aly-Eldeen M, Abo-El-Khair E, Ahdy H and Shreadah M 2016 Evaluation of the quality for the Egyptian red sea coastal waters during 2011-2013. *Journal of Environmental Protection* 7 1810-34

[25] Manikannan R, Asokan S and Ali A 2011 Seasonal variations of physico-chemical properties of the great Vedaranayam swamp, point calimere wildlife Sanctuary, South-east coast of India. *African Journal of Environmental Science and Technology* 5 673-81

[26] Elmorsi R, Hamed M and Abou-El-Sherbini K 2017 Physicochemical properties of Manzala lake, Egypt. *Egyptian Journal of Chemistry* 60 519-35