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RESEARCH ARTICLE

ANALYTICAL STUDY OF SOME PHYSICO-CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF SEA WATER IN ADEN COASTS/ GULF OF ADEN

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Abstract

The present research aimed to study some of the physiochemical and biological properties of seawater samples collected in December 2019 from eight beaches around the city of Aden, southern Yemen. The physicochemical properties ranged as follows: Temperature (26.30-27.10 C°), pH (7.85-8.23), Salinity (36.5- 37.9 ppt), Turbidity (2.15-14.40 NTU), Electrical conductivity (58800-61400 us/ cm), Total dissolved solids (39396-41138 mg/L), Dissolved oxygen (3.88-5.40 mg/L), and biochemical oxygen demand (0.45-3.08 mg/L). The results showed that the levels of nutrients in the study stations were high, as the values of the nutrients (nitrates, nitrites, phosphates and silicates) ranged between (0.78-11.50 mg/L), (0.006-0.122 mg/L), (0.04-0.91 mg/L) and (0.170-1.777 mg/L) respectively. The results of the microbiological analysis of total coliform and fecal coliform also indicated to presence of high levels of contamination, where ranged from 52 to 1022 MPN/100 ml and from 0 to 151 MPN/100 ml, respectively. The results of the study confirm the importance of protecting Aden coastal waters from various pollutants, especially wastewater pollutants.

Keywords: Physico-chemical properties; Total coliform and fecal coliform; Nutrient salts; Pollution of sea water

1 Introduction

Marine waters which is a part of the marine ecosystem cover more than 70% of the surface of the Earth and account for more than 97% of Earth's water supply **[1]**. Marine systems control the global climate, contribute to the water cycle, preserve biodiversity, offer food and energy resources, and generate opportunities for recreation and tourism **[2]**.

Marine environment is subjected to contamination that arises in many different forms, such as: toxic chemicals (e.g., organic compounds, pharmaceuticals, pesticides, and metals), solid waste pollutants (e.g., plastic bags or bottles), increased nutrient (e.g., nitrates silicates and phosphates) and sediment inputs due to human activities such as industry, agriculture, deforestation, sewage discharge, aquaculture, radioactivity, oil spillages, and superfluous fishing nets **[3]**. Pollution in marine waters changes the physical and chemical characteristics 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]**. Nevertheless, pollution is eventually caused by population growth and industrialization, but it can be prevented if appropriate controls are in place to reduce the release of waste materials **[5]**.

It is worth noting that, in addition to the invasion of different kinds of substances into the seawater bodies, the definition of marine pollution includes the contribution of energy, such as thermal (e.g., discharge of cooling water from nuclear plants) and acoustic (noise) where the introduction of noise into the marine environment may have noteworthy influences on marine species and ecosystems **[6]**.

Wastewater and the lack of sewage treatment station or liquid waste are among the main causes of seawater pollution in Yemen **[7]**. In the city of Aden, wastewater treatment was 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. There are many studies that dealt with pollution in sea water in the Gulf of Aden and the Red Sea, such as **[8-16]**. These studies have shown that pollutants especially wastewater contributes in change the physiochemical properties and increase the concentration of nutrients in the water.

Sewage contain many viruses and bacteria that cause disease in humans and also contain large amounts of nutrients. Although plankton and marine plants need these nutrients (nitrates and phosphates), but excess amounts of nutrients cause fertilization of coastal waters in a phenomenon called "eutrophication" **[17]**. The fecal indicator bacteria (total coliforms, E.coli and fecal streptococci) are used to measure the sanitary quality of water for recreational, industrial, agricultural and water supply purposes. These bacteria are natural inhabitants of the gastrointestinal tracts of humans and other

warm-blooded animals. The sewage discharge, harbor activities, boats and vessels and heavy recreational activities are the main sources of bacterial contamination **[18]**.

The problem of water pollution is a global problem that did not stop at a country or a city without other cities or countries bordering the seas, so Aden is among these cities that were not safe from the damages of marine pollution by wastewater, as many areas were built on the coasts of the sea or near it and receive its residues in it, including the Brega region, Saira, Al.Tawahi, Al-Hiswah and Khormaksar, the subject of the study, whose streams flow into the sea, where it is loaded with large quantities of chemical pollutants of various types and sources, in addition to consumer wastes, all of which contain dangerous pollutants that cause damage to marine life in the coast of these regions. Likewise, the smells emitted from pollution of the sea with wastewater reduce the sea goers for the purpose of excursion and tourism in the absence of environmental awareness and indifference on the consequences of misuse and consumption of marine resources and the absence of the law of deterrence and hard work from the relevant authorities in this regard.

2 Description of area (Aden city)

Aden is located in the southern part of the Yemeni coast in the Gulf of Aden. It is bounded by latitude 12.70°-12.90° N and longitude 44.78°-45.08° E. It is located at the south western end of Yemen and the Arabian Peninsula. Aden lies on the main world trade route through the Suez Canal. It is one of the largest natural harbors in the world with an area of about 70 km^2 of protected waters surrounded by Jebal Shamsan, Khormaxer, and the beach that extends to the small hills of Aden. Aden had a chain of communities that stretched around a well-protected bay. These include Crater, Mualla, Tawahi, Khormaksar, Sheikh Othman, Al-Mansoura, Dar Saad, and Little Aden **[19].** Aden is the largest coastal city, it is famed for its role for transit trade, bunkering, ship repairs, and boat building. Aden was the third largest bunkering port in the world, before 1967. In addition to its port related activities, Aden in known for its marine tourism, marine traffic, fishing industry, oil and gas exploitation **[15].**

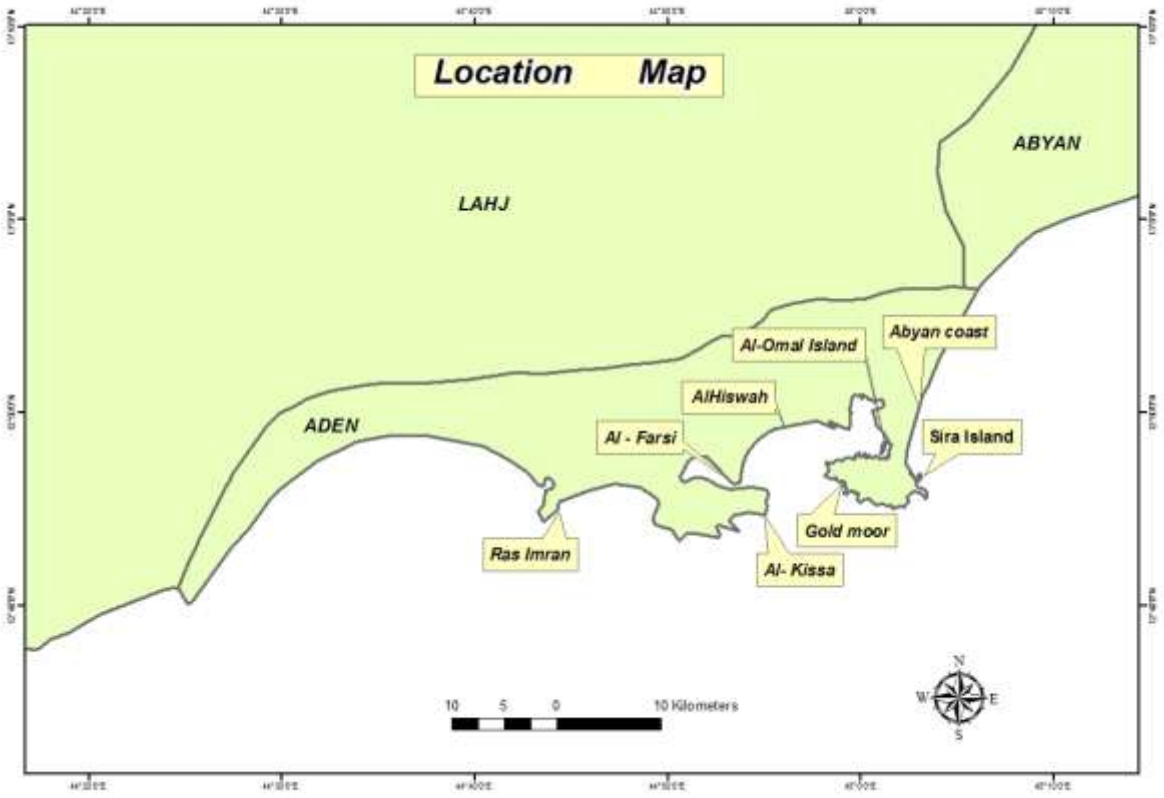

Figure 1: Study Area and Sampling Sites

3 Materials and Methods

surface water samples were collected in December, 2019 from eight sampling stations along the coastal area of Aden (Figure 1 and Table 1). The water samples were analyzed for some physical, chemical, and biological parameters. Water temperature, pH, Salinity and electrical conductivity were measured directly in situ using graduated thermometer, pH-meter (HQ40d multi/HACH), hand-held Salinity refractometer and EC-meter (HQ40d multi /HACH) respectively. Total Dissolved Solids were measured according to **[20],** by the following equation, depending on E.C. value: TDS mg/l = E.C. µS/cm X 0.67. 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 NO_2, NO_3, PO_4 and SiO_4 determinations were analyzed according to the recommended methods complied by **[21]** using UV-Spectrophotometer DR 3900 HACH.

Detection of Total and Fecal Coliform was done using Membrane Filtration technique **[22, 23]**. Water samples (100ml each) were filtered using a Whatman filter paper 125mm pore size to eliminate large particles, and then they were re-filtered using a Sartorius

membrane filter 0.45 m pore size. One of the filters was carefully transported and placed in sterile Petri dishes containing the food medium, (M-Endo Broth), then incubate at 37 C° for 24 hours to detect the presence of total coliform. The other filter was carefully transported and placed in a sterile petri dish containing the food medium, (M-Fc broth), then incubated at 44C° for 24 hours to detect the presence of fecal coliform. After that the dishes were removed and filters were thoroughly examined using a colony counter to identify and count the colonies. Calculation of Total and fecal Coliform were done according to the following formula: Total or fecal Coliform per gram dry weight = colonics counted x 100 / volume of sample chosen(ml).

Table 1: Sampling Stations with their Latitude and Longitude

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

4 Results and discussion

4.1 Water temperature

As shown (Table 2) the water temperature values ranged between 26.30 and 27.10 C^o with a mean of 26.60 C^o. Compared with the reference station, slightly increase in seawater temperature observed in some stations, such as stations 5, 7, 2 and 1 which were 27.1, 26.8, 26.8 and 26.7C^0 respectively, these stations recorded high pollution rates, where the rates of chemical and biological reactions increase with increasing temperature, and this can indicate the effect of sea water pollution with untreated wastewater on The temperature of this water. In the other stations, seawater temperature was similar and ranged between 26.3 and 26.5 C^0. The results of statistical analysis showed that temperature values for every stations were significantly different at $p<0.05$.

4.2 Hydrogen Ion concentration (pH)

The pH test measures the acidity of the water body. In the study stations, pH values ranged between 7.85 and 8.03 as shown (Table2). Compared with the reference station, which recorded the highest values (8.23), the results in the seven stations showed a decrease in the pH

values, especially at station 5 and 7 which recorded the lowest values 7.85 and 7.92 respectively, this decrease may be due to the increased discharge of untreated wastewater into these stations, as the amount of oxygen used in the oxidation process decreases and the production of carbon dioxide increases, which reduces the pH value. Data of the present investigation coincide with that obtained with by **[10]** on the Gulf of Aden coastal region concerning pH values ranging from 7.80-8.03 and **[13]** who found the range of pH was 7.83-8.01 in Hadramout coast. The results of statistical analysis showed pH values for every stations were significantly different at $p<0.05$.

4.3 Salinity

Salinity of water values ranged from 36.5 ppt to 37.9 ppt (Table 2). Stations 2 and 1 showed the highest salinity values 37.9 and 37.8 ppt this increase may be due to the fact that these coasts are semi-isolated, the rate of evaporation of water is large and the movement of water is limited, thus salinity values are high, while stations 7 and 5 recorded the lowest values 36.5 and 36.8 ppt respectively, this decrease may due to increase sewage disposals into these areas and its near from the discharge points. The results of statistical analysis showed that salinity values of for every stations were significantly different at $p<0.05$.

4.4 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The electrical conductivity values ranged between 58500 uS/cm to 61400 uS/cm with a mean of 60100 uS/cm (Table 2). The EC values of the seven stations were higher Compared to the reference station, which recorded the lowest values (58800 uS/cm). The maximum value of EC observed at station 2 and 5 which were 61400 and 61300 uS/cm. this increase may be due to increase sewage discharge that contains ions such as chloride, nitrates and phosphates that contribute to increased conductivity as well as an increase temperature in these two stations.

TDS values ranged from 41160 mg/L to 42980 mg/L with a mean value 42026 mg/L (Table 2). TDS values related to conductivity values, as they increase and decrease with increasing and decreasing conductivity.

The results of statistical analysis showed that Electrical conductivity values and TDS values for every stations were significantly different at $p<0.05$.

4.5 Turbidity

As shown (Table 2) the turbidity levels at the study stations ranged from 2.15 to 14.40 NTU. The maximum value of turbidity was recorded at station 5 which was 4.40 NTU, this 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 at Station 7, increase in the value of turbidity 11.55 NTU was observed, may be due to the discharge of sewage from the Al-Khissa city, it is also an area where

fishing boats are anchored, and therefore it has oil spills and pollutants from boats. The turbidity values at study stations were high compared with the reference station which recorded the lowest values (2.15 NTU). Results of the present study coincide with that obtained with by **[16]** on the Jeddah coastal area concerning turbidity values ranging from 2-13 NTU. The results of statistical analysis showed that turbidity values for every stations were significantly different at $p<0.05$.

4.6 Dissolved Oxygen (DO)

The dissolved oxygen concentrations ranged between 3.88 and 5.40 mg/L, with mean 4.46 mg/L (Table2).

DO concentrations in the seven stations showed low levels compared to station 8 (the reference station) which recorded the highest value (5.40 mg/L). The lowest levels of DO observed in sites heavily contaminated with sewage discharges such as station 7 and 5 which were 3.88 and 3.92 mg/L respectively, this the low 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. These observations are in agreement with **[24]** who stated that heavy contamination by wastewater causes an oxygen deficit due to decomposition of the organic matter. The results of statistical analysis showed that dissolved oxygen values for every stations were significantly different at $p<0.05$.

4.7 Biochemical Oxygen Demand (BOD_5)

BOD_5 concentrations ranged from 0.45 to 3.08 mg/L, with mean of 2.32 mg/L (Table 2). The obtained BOD_5 data showed that the maximum values recorded at stations 7 and 5 which were (3.08 and 3.00 mg/L) respectively, which have a higher pollution rate compared to other stations, 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, while the lowest concentration was 0.45 mg/L at station 8 (the reference station) that was farther from pollution sources. As shown in (Table 2) BOD_5 values in the seven stations were higher compared to the reference station. The results of statistical analysis showed that biochemical oxygen demand values for every stations were significantly different at $p<0.05$.

4.8 Nutrient Salts

Large quantities of nutrients released into the coastal water through the sewage waste-water may result in nutrient enrichment stimulating algal growth that in turn affects the photic zone depth, cause dissolved oxygen depletion, bioaccumulation of organic and inorganic compounds, and alteration of trophic interactions among both aquatic flora and fauna **[25].** The levels detected for nitrate, nitrite, phosphate, and silicate were high in the study area, this may be due to untreated

wastewater was discharged directly to the sea water, especially after the sewage treatment stations have been suspended since the last war in 2015, such as Al-Arish station /Khor Maksar, Kabuta station / Al-Shaab and Salah El-Din station.

The stations close to sewage outlets such as station 5 and 7 , as well as station 1 and 2 had the highest nutrient values which were because they are more influenced by the incoming proteinic matter and polyphosphoric products from the detergents households. While stations that were slightly affected by sewage, such as stations 3, 4 and 6 had slightly lower nutrient values. The lowest nutrient values were at station 8 (the reference station), which was further from wastewater impacts.

4.8.1 Nitrite (NO_2)

The result of the analysis of nitrite in the surface water ranged from 0.006 to 0.122 mg/L with mean 0.053 mg/L (Table 3). The highest level of nitrite observed at station 2, this may be due 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, while at stations 3 and 4 observed decrease in nitrite levels (0.037 and 0.019 mg/L) respectively. The other stations recorded similar nitrite values (0.068 mg/L) for station 1, (0.062 mg/L) for station 5, (0.055 mg/L) for station 7 and (0.057 mg/L) for station 6. Compared with the reference station (station 8), the nitrite values of all seven stations were higher than the value of the reference station where it has a lower pollution rate. The obtained results in this study were higher than that reported by **[13]** who registered nitrite concentrations ranged from 10.34 to 13.5 ug/L in Hadramout coast-Yemen. The results of statistical analysis showed that nitrite values for every stations were significantly different at $p<0.05$.

4.8.2 Nitrate (NO_3)

In the study area nitrate levels ranged from 0.78 to 11.40 mg/L, with mean of 5.456 mg/L. The maximum nitrate value recorded 11.50 mg/L at station 5 and also 9.00 mg/L at station 7, increase in nitrate levels at station 5 and 7 may be due to the increasing amount of domestic discharges which enhanced oxygen consumption that resulted in low oxygen concentrations but high concentrations of NO_3. While the lowest concentration was at station 8 (the reference station) that was farther from pollution sources. In other stations nitrate concentrations ranged from 1.95 to 6.36 mg/L as shown in Table 3. The results of this study were higher than those observed by **[13]** who found NO_3 values ranging from 17.30-20.90 ug/l in Hadramout coast-Yemen, and **[8]** who found the average values of nitrate in waters collected in August 2014 and January 2015 were 16.41 and 14.73 ug/L in the Gulf of Aden and Arabian Sea Coast, Yemen. The results of statistical analysis showed that nitrate

values for every stations were significantly different at $p<0.05$.

4.8.3 Reactive phosphate (PO_4)

Phosphate concentrations in the study area ranged from 0.04 to 0.91 mg/L with mean of 0.45 mg/L (Table 3). The highest concentrations of phosphate were at stations 5, 1 and 7 which were 0.91, 0.72 and 0.70 mg/L respectively, this increase may be due to increasing amount of domestic discharges in these sites that contains of soap and detergents used by the public for bathing and washing clothes and end up to the seawater in these sites, while at station 8 (the reference station) which was unaffected by wastewater and other human activities recorder the minimum value of phosphate which was 0.04 mg/L. the phosphate concentrations in the other stations 3, 4 and 6 were lower than previous stations, (0.38 mg/L), (0.07 mg/L) and (0.27 mg/L) respectively, this indicate that effect of local sewage discharge was low in these stations. Results of the present study were higher than that obtained with by **[14]** who found the PO_4 values ranged between 9.72- 25.17 ug/L in the coastal water of the Red Sea, Yemen, and **[9]** who found the range for PO_4 was 0.5-2.4 uM/L in Hadhramout Coast, Gulf of Aden, Yemen. The results of statistical analysis showed that phosphate values for every stations were significantly different at $p<0.05$.

4.8.4 Silicate (SiO_4)

As shown (Table 3) the Silicate levels in the study stations ranged from 0.170 to 1.777 mg/L, with mean 0.881 mg/L. 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 2, 5, 7 and 1 this indicating that the sewage as a source of silicate, where the values of the silicate were (1.777 mg/L) for station 2, (1.593 mg/L) for station 5, (1.052 mg/L) for station 7 and (0.975 mg/L) for station 1, while the lowest levels (0.170 mg/L) had been registered at station 6, this decrease may be due to the effect of local sewage discharge was low in this site. Silicate concentrations at the other stations were similar, (0.583 mg/L) for station 4, (0.472 mg/L) for station 3 and (0.425 mg/L) for station 8. The results of this study were higher than that reported by **[12]** who 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 **[14]** who found the silicates values ranged between 16.86-77.60 ug/l in the coastal water of the Red Sea, Yemen. The results of statistical analysis showed that silicate values of for every stations were significantly different at $p<0.05$.

4.9 Microbiological Analysis

The results of the microbiological analysis for study area showed signs of water pollution in the study stations with total coliform and fecal coliform, the numbers ranged between 0-151 MPN/100 ml for fecal coliform and from 52 to 1022

MPN/100ml for total coliform. As shown in Table 3 the results of the microbiological analyzes showed high levels of microbiological counts in the study area, especially in station 5 and 7, as well as stations 1 and 2 compared to other stations, this is considered a dangerous indicator of the water pollution and its dangerous impact on living organisms, this may be due to the increase in the huge amounts of untreated sewage which discharge into seawater, as well as other various human activities and the absence of environmental and regulatory controls. The analysis of sea water at other stations showed low in the microbiological counts compared to previous stations, this suggesting that the impact of the domestic wastewater discharges were low in these stations. In station 8 (the reference station), the results explained that there is no contamination of F.C (Nil) and low count in total coliform, this may be due to its unaffected by wastewater and other human activities. The results of statistical analysis showed that total coliform values and fecal coliform values for every stations were significantly different at $p<0.05$.

(Table 2): Physicochemical analysis of Seawater samples in Aden coasts

Parameter / Station	Tump. C^0	pH	Salinity ppt	Turbi. NTU	EC us/cm	TDS mg/L	DO mg/L	BOD mg/L
Sira Sta. I	26.70	8.00	37.8	8.10	60200	40334	4.18	2.68
AL-Omal Island Sta. 2	26.80	7.90	37.9	7.30	61400	41138	4.06	2.98
Abyan coast Sta. 3	26.50	8.05	37.2	6.82	59500	39865	4.54	2.51
Gold moor Sta. 4	26.30	8.15	37.2	3.90	59600	39932	4.92	1.88
Al-Hiswah Sta. 5	27.10	7.85	36.8	14.40	61300	41071	3.96	3.00
Al-Farsi Sta. 6	26.30	8.12	37.1	6.30	59200	39664	4.78	1.97
Al-Khissa Sta. 7	26.80	7.92	36.5	11.55	60800	40736	3.88	3.08
Ras Imran Sta. 8	26.40	8.23	37.4	2.15	58800	39396	5.40	0.45
Mean	26.60	8.03	37.2	7.56	60100	40267	4.34	2.32
Range	26.30-27.10	7.85-8.23	36.5 - 37.9	2.15 - 4.40	58800 - 61400	39396 - 41138	3.88 - 5.40	0.45 - 3.08
L.S.D	0.226	0.068	0.259	0.187	312.0	209.1	0.068	0.065

(Table 3): Results of Nutrient salts, Total coliform and fecal coliform analysis of Seawater samples in Aden coasts.

Parameter / Station	NO_3 mg/L	NO_2 mg/L	PO_4 mg/L	SiO_4 mg/L	T. Coliform MPN/100ml	F. Coliform MPN/100ml
Sira Sta.1	6.36	0.068	0.72	0.975	460	68
AL-Omal Island Sta.2	5.95	0.122	0.52	1.777	622	97
Abyan coast Sta.3	5.16	0.037	0.38	0.472	412	33
Gold moor Sta.4	1.76	0.019	0.07	0.583	137	3
Al-Hiswah Sta.5	11.50	0.062	0.91	1.593	1022	151
Al-Farsi Sta.6	3.14	0.054	0.27	0.170	244	18
Al-Khissa Sta.7	9.00	0.055	0.70	1.052	942	128
Ras Imran Sta.8	0.78	0.006	0.04	0.425	52	0
Mean	5.456	0.053	0.450	0.881	486.4	62.25
Range	0.78 - 11.50	0.006 - 0.122	0.04 - 0.91	0.170 - 1.777	52 - 1022	0 -151
L.S.D	1.080	0.029	0.064	0.454	80.79	22.43

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دراسة تحليلية لبعض الخصائص الفيزيوكيميائية والبيولوجية لمياه البحر في سواحل عدن/ خليج عدن

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المستخلص

يهدف البحث الحالي إلى دراسة بعض الخصائص الفيزيوكيميائية والبيولوجية في عينات مياه البحر التي تم جمعها في ديسمبر 2019م من ثمانية شواطئ حول مدينة عدن جنوب اليمن. تراوحت الخصائص الفيزيوكيميائية على النحو التالي: درجة الحرارة (26.30– 27.10 درجة مئوية)، درجة الحموضة (7.85–8.23)، الملوحة (36.5– 37.9 ppt)، العكارة (2.15 – 14.40 NTU)، والتوصيل الكهربائي (58800– 61400 us/cm)، مجموع المواد الصلبة الذائبة (39396–41138 ملجم/لتر) ، الأكسجين المذاب (3.88– 5.40 ملجم/لتر) والأكسجين الحيوي المستهلك (0.45–3.08 ملجم/لتر). أظهرت النتائج أن مستويات المغذيات في محطات الدراسة كانت مرتفعة إذ تراوحت قيم الأملاح المغذية (النترات والنتريت والفوسفات والسيليكات) بين (0.78– 11.50 ملجم/لتر)، (0.006–0.122 ملجم/لتر)، (0.04–0.91 ملجم/لتر) و(0.170–1.777 ملغم /لتر) على التوالي. كما أشارت نتائج التحليل الميكروبي للقولونية الكلية والقولونية البرازية إلى وجود مستويات عالية من التلوث، حيث تراوحت من 52 إلى 1022 MPN / 100مل ومن صفر إلى 151 MPN /100مل على التوالي. وتؤكد نتائج الدراسة على أهمية حماية مياه سواحل عدن من مختلف الملوثات وخاصة ملوثات مياه الصرف الصحي.

الكلمات المفتاحية: الخصائص الفيزيوكيميائية ؛ القولونية الكلية والقولونية البرازية؛ الأملاح المغذية؛ تلوث مياه