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Research Article

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Impact of Human Activity on Marine and Coastal Environment in the Gulf of Tadjourah

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Abstract

Extensive research with the aim of establishing seawater quality monitoring is considered essential of any integrated coastal management program. The present study reports for the first time the republic of Djibouti costal water quality. The state of the sixteen stations' seawater quality was assessed on the basis of determination of temporal and spatial variability of inorganic nutrients with physicochemical variables. The samples were collected seasonally from different areas such as harbor and important touristic area in the Gulf of Tadjourah for three years (2008, 2009 and 2012). The seawater temperatures, pH or Chlorophyll a of sampling sites were evaluated and compared to those of the Gulf of Tadjourah or Red Sea waters. Relatively high concentrations of nutrients (for some sites) and very low chlorophyll a concentrations (0.006 to 0.06 µg.l^{-1}) were observed at sampling sites. The seawater concentrations of trace metals in ten stations across the Doraleh coast, where is located the main port of Djibouti, were also investigated in 2012 and the values were compared to the normal range of concentrations for seawater. The levels of microbial concentrations were also determined for the main beaches of Djibouti-city and showed relatively higher concentrations for stations beaches close to sewage outfall.

Keywords: Djibouti; Gulf of Tadjourah; Seawater; Inorganic nutriments; Heavy metals; Coliform

Introduction

Seawater and beach quality monitoring assessment is considered essential parts of any integrated coastal management program [1]. Extensive research with the aim of establishing guidelines and standards for recreational water quality has been conducted all over the world. In this context, social, cultural, environmental, and economic factors should be taken into consideration because of the great variation from one area to another [2]. The republic of Djibouti (Horn of Africa), with a coastal length of about 372 Km lies between 10-13°N and 41-44°E. About 58% of the population of the Republic of Djibouti, which has been estimated at about 800000 inhabitants, lives in the capital city of Djibouti [3]. In Djibouti-city, untreated waste waters were directly discharged into the coastline. This situation is of great concern for the coastal environment as well as for the health of the people. Djibouti coastline is experiencing a rapid increase of coastal utilization for several purposes such as recreation and refreshment, fishing or industrial development. This makes coastal water quality and proper environmental management highly pressing. At present very little information is available on the state of the water quality of Djibouti coastline. Realizing the importance of this information for tourism development and consequently on the national economy, the Government of Djibouti in collaboration with the Regional Organization for Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA) promoted the initiation of a sustainable monitoring program of the coastal and marine environment, aiming at establishing a national database that serves the Republic of Djibouti and feeds in a regional database of the Red Sea and Gulf of Aden. A database will help significantly in the scientifically based management of the coastal region. The aims of this work are to investigate the spatial and temporal pattern of the water quality along the Djibouti coasts and thus provide a basic profile of seawater characteristics on the coasts of Djibouti. The area under investigation includes industrial effluent sites, recreational resorts, urban agglomeration, fishing ports, shipping and industrial activities area as well as coastal site away from development and a reference point five Kilometers offshore.

Material and Methods

Reagents and standards

Seawater certified reference materials (MOOS-2, NASS-5, and CASS-4), were provided by National Research Council (NRC), Canada. Standard stock solutions of each metal (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were purchased from Sigma-Aldrich (Germany). Hydrochloric and nitric acid were purchase from Sigma-Aldrich (Germany). Reagents and standard solutions used during the analyses were of supra pure grade.

Sampling site selection and identification

The sampling campaigns were conducted at 26 selected sampling sites for the investigations of seawater in Djibouti shoreline area (Table 1 and Figure 1). Sixteen sites were positioned along the Djibouti coasts and were selected on the basis of human activity, such as recreation, on the coast. Seawater for inorganic nutriments (nitrate, nitrite, phosphate, and silicate in µM) analyses was collected from these locations during summer (August) and winter (December) in three years (2008, 2009 and 2012). Ten sampling sites were located in Doraleh Port (Figure 1) and were selected due to specific activities take place.

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Sites #	Sampling site	GPS Coordinates	
1	Off shore	011°40'11,0"	043°10'43,75"
2	Abattoir	011°34'57,34"	043° 09' 32,78"
3	Siesta Beach	011°35'56,02"	043°09'13,62"
4	Peltier Hospital	011°37'03,61"	043°09'24,13"
5	Kempesky Hotel	011°37'23,76"	043°08'49,01"
6	Escale – Venus	011°36'04,33"	043°08'34,85"
7	Fishing Port	011°35'59,77"	043°07'49,53"
8	Doraleh Port	011°34'51,75"	043°29'31,85"
9	Petit Ambado Beach	011°35'33,90"	043°03'27,11"
10	Khor Ambado	011°35'37,11"	043°01'20,21"
11	Arta Beach	011°35'04,19"	042°49'13,59"
12	Goubet	011°32'08,48"	042°31'53,93"
13	Tadjourah	011°46'42,07"	042°54' 08,63"
14	Sable Blanc Beach	011°46'41,08"	042°55'30,47"
15	Maskali Island	011°42'39,04"	043°08'57,38"
16	Moucha Island	011°43'04,00"	043°11'19,90"
17	Doraleh coastline	011°35'43,4"	043°04'19,9"
18	Doraleh coastline	011°35'43,5"	043°04'08,0"
19	Doraleh coastline	011°35'43,7"	043°04'06,8"
20	Doraleh coastline	011°35'45,7"	043°04'00,1"
21	Doraleh coastline	011°35'43,4"	043°03'56,6"
22	Doraleh coastline	011°35'43,3"	043°03'52,6"
23	Doraleh coastline	011°35'42,0"	043°03'50,2"
24	Doraleh coastline	011°35'41,6"	043°03'49,1"
25	Doraleh coastline	011°35'42,06"	043°03'43,03"
26	Doraleh coastline	011°35'43,37"	043°03'43,04"

Table 1: Sampling sites identification information.

Sample collection

All containers used to collect and store seawater were soaked in 10% HCl for 24 hours and washed with deionized distilled water prior to using to prevent contamination. All containers used to collect and process the samples were rinsed at least three times with water samples prior to their collection. Water samples for the determination of nutrients and chlorophyll a were taken in polyethylene containers and kept on an ice box during the transportation. Upon return to the laboratory, the samples were filtered through Nylon Millipore membrane filters (0.45 μm). The Nylon filters were used for the determination of chlorophyll a and the filtrate for nutrients analysis. For heavy metal analysis, water samples were acidified to pH2 using concentrated HNO_3 immediately after collection, and stored at 4°C until analysis.

Physicochemical analysis

For the sixteen sampling sites # 1-16 (Figure 1) inorganic nutriments analysis were carried out. While for samples from Doraleh area (sites # 17-27), dissolved oxygen (DO), suspended solid (SS), Nitrite, Ammonium, Phosphate, Silicate, Chlorophyll a and Heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) were analysed. All analyses were made in triplicate. The method detection limit for Cd, Co, Cr, Cu, Fe, Mn, Pb, Zn, and Ni, were 0.1, 0.2, 0.2, 0.2, 0.2, 0.05, 1.5, 0.2 and 0.3 μg/L respectively. Two certified reference materials, CASS-4 (near shore seawater) and NASS-5 (seawater), were used as a control for the analytical methods of heavy metals in seawater (e.g. Cd, Co, Cr, Cu, Fe, Mn, Pb, Zn and Ni). On the other hand, seawater certified reference material for nutrients (MOOS-2) was used as a control for the analytical methods of nutrients. Temperature, electrical conductivity, salinity, dissolved oxygen and pH were measured in situ with a C862

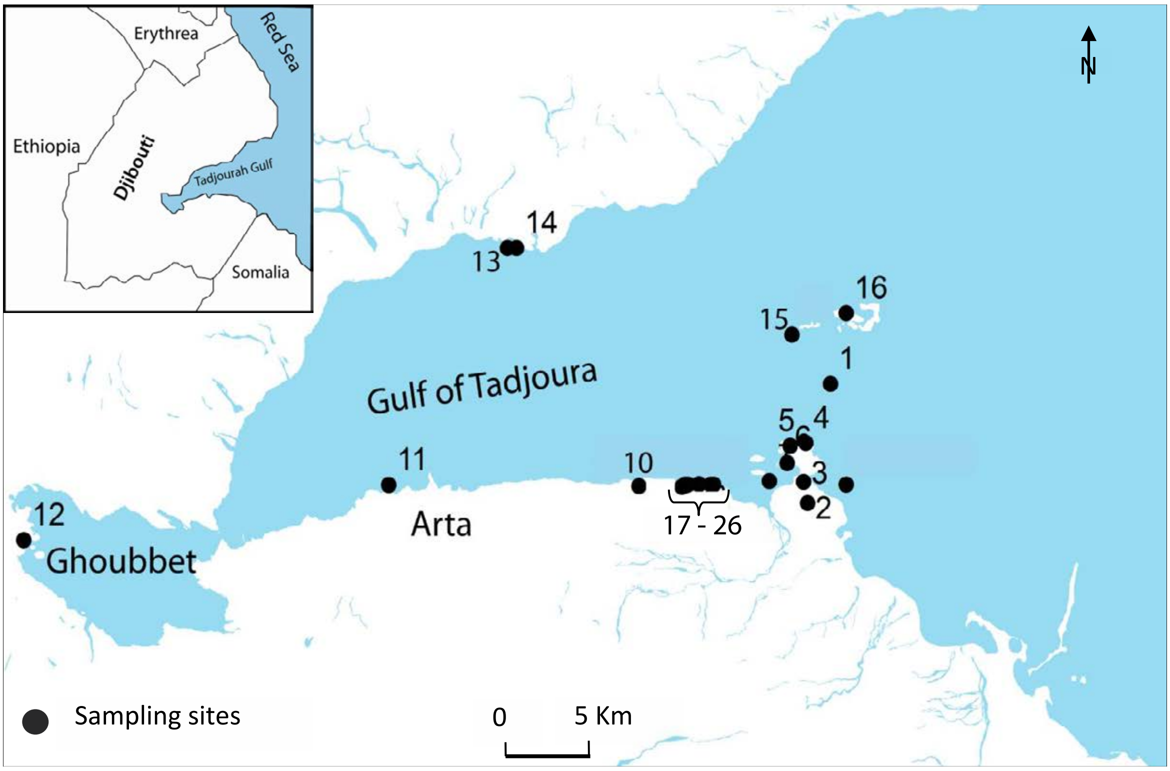

Figure 1: Djibouti National Monitoring program sampling sites (windows : location of the Republic of Djibouti).

multi-parameter meter and associated electrodes. Calibration of each electrode was checked every day prior to the start of sampling. Nitrite, Ammonium, Phosphate, Silicate, Chlorophyll a analyses were done according to protocol described by Strickland and Parsons [4]. Analyses of heavy metals were conducted using an Ultima 2 (Horiba Jobin Yvon) Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). Calibration was performed using NASS-5, to minimize matrix and other associated interference effects, while CASS-4 was used to check the precision and accuracy of the analysis.

Statistical analysis of data

The computer program R2.15.1 [5] was used to conduct statistical analysis. Data obtained from seawater samples from Djibouti recreational area (sites # 1-16) were also analyzed using the Pearson correlation coefficient (a measure of linear association) and paired sample t test.

Determination of bacteria concentration

Seawater samples for Fecal coliform (FC) and fecal streptococci (FS) analyses were collected with sterile 500 mL bottles, which was then kept in the dark and on ice during its transfer to the laboratory, and analyzed within 4 h of sample collection. An appropriate volume of a seawater sample (100 mL) was filtered through a 0.45-mm membrane filter. The membrane filters were aseptically removed and placed in the center of a pre labeled Deoxycholate Agar culture plate for the analysis of Total Fecal coliform and Fecal coliform, which were then sealed and incubated for 24 hours at 44.5 ± 2°C and at 37.1 ± 1°C, respectively. Three to five colonies from each plate were picked and biochemical tests were performed to confirm the identity [6]. Fecal streptococci (FS) were analyzed similarly to fecal coliforms, however, the membrane filters were transferred to Baird Parker medium which was then sealed and incubated at 37.1 ± 1C for 24 hours. API 20E was used to confirm FC identity, gram stain, catalase, and bile esculin tests were used to confirm FS. From each sample lot representative colonies of *S. aureus* were chosen and subjected to the coagulase test. For Salmonella and Shigella analyses, 1 L of seawater sample was filtered through a 0.45-mm membrane filter. The membrane filter was placed at 37°C in Hecktoen enrichment medium for 24 hours. Subcultures were made to xylose lysine dextrose agar (XLD) and Salmonella Shigella agar (SSA) plates (Oxoid).

Results and Discussions

Recreation area

The recreational areas in Djibouti-city such as Siesta Beach (site#3), Petit Ambado Beach (site #9), Khor Ambado Beach (site #10) as well as Escale-Venus (site #6), were selected for Djibouti National Monitoring Program initiated by PERSGA (Table 1). Two island beaches, Moucha (site #16) and Maskali (site #15), having hotels for the tourist visiting the area as well as Sable Blanc beach (site #14) and Arta beach (site #11) were also selected for this monitoring program because of touristic activity. Wastewater from the Djibouti slaughterhouse are discharged without any treatment to the seawater, at Abattoir site (site #2), which has been selected for monitoring. Furthermore, the Djibouti fishing port (site #7), which hosts some seafood industrial activities, was also selected as monitoring point. Tadjourah (site #13) has been chosen for the monitoring program as a coastal city and capital of Tadjourah District. The Goubet site (site #12), located at the embouchure of the Gulf of Tadjourah, was selected because it hosts a motel for tourist activity. The Djibouti general hospital discharges its wastewaters to the seawater. Therefore, this point of discharge, Peltier hospital (site #4), was chosen as one of the monitoring site. The coast of the largest hotel in Djibouti-city, kempeski (site #5), has also been sampled in this monitoring program. Finally, a point five kilometres offshore was selected as reference site (site #1). Seawater temperature, pH and concentration of the inorganic nutriments recorded at Djibouti monitoring sampling points for four sampling periods (April 2008, December 2008, April 2009 and December 2009) are shown in Figures 2-7. The seawater temperatures in April ranged between 30°C and 33°C and in December between 27°C and 28°C. The results indicated that upper layer temperatures of sea water are usually more important in April (summer) than in December (winter). This is in accordance with the temperatures that were found to fluctuate between 26°C and 27°C for March and 27°C to 30°C for July to September in the upper layer of the sea [7]. In the Gulf of Tadjourah, the thermocline was found around 60 m in March (end of winter). At this period, the upper layer temperature was 26.5°C and the temperature decreased to about 22.5°C between 60 and 110 m [7]. The water temperature variations of the Gulf of Tadjourah are influenced by the mixing deep water circulation from the Gulf of Aden. The vertical distribution of temperature from surface

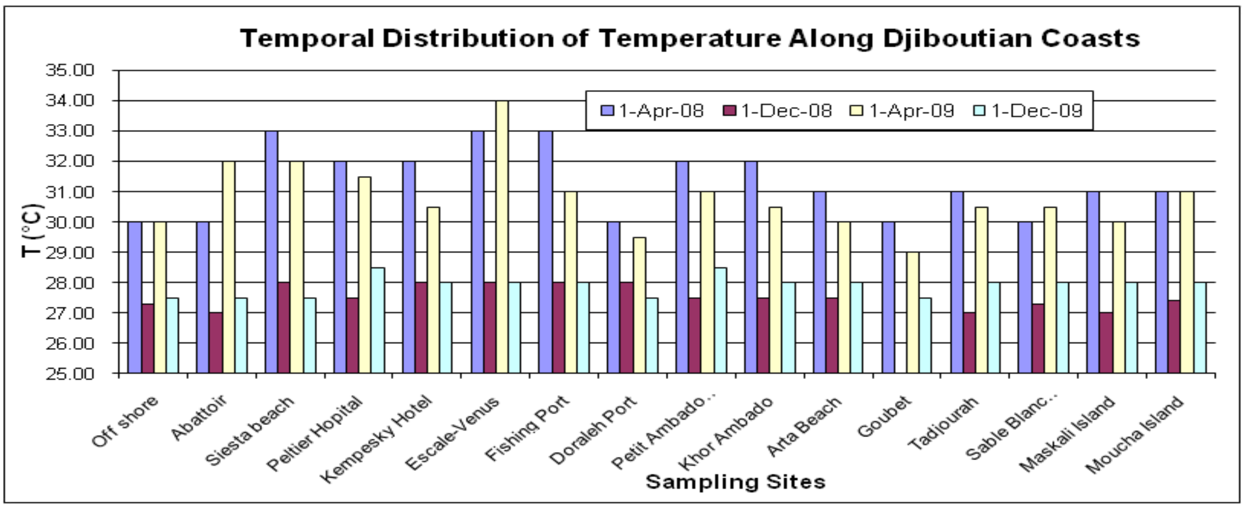

Figure 2: Seawater surface temperature at Djibouti monitoring sites during April and December 2008, 2009.

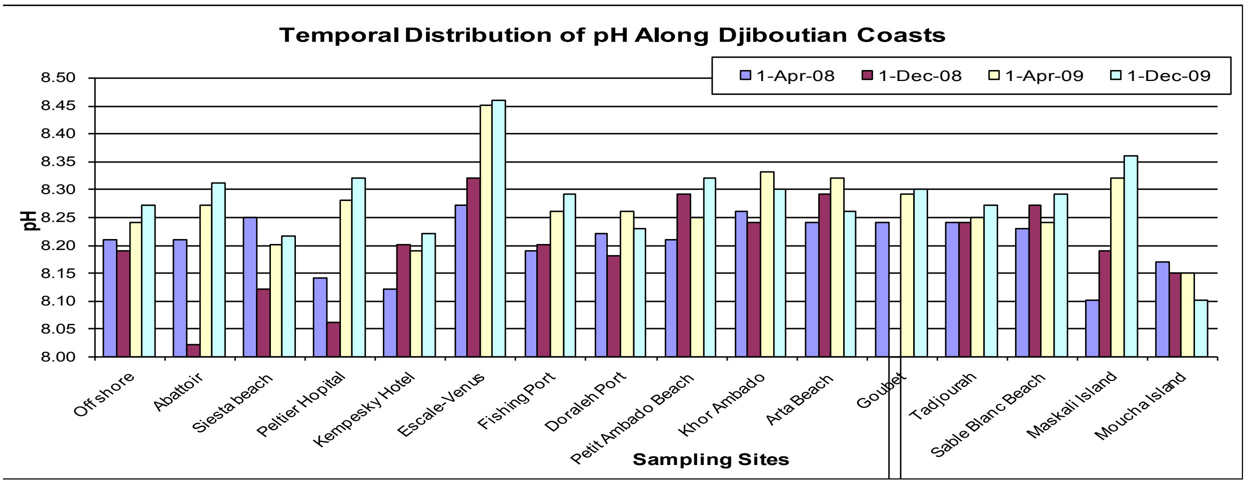

Figure 3: Surface seawater pH at Djibouti monitoring sites during April and December 2008, 2009.

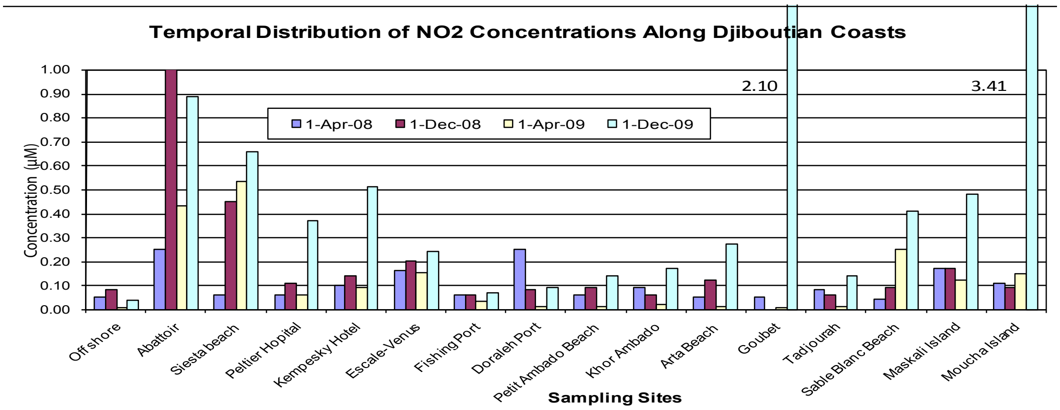

Figure 4: Surface seawater nitrite concentration at Djibouti monitoring sites during April and December 2008, 2009.

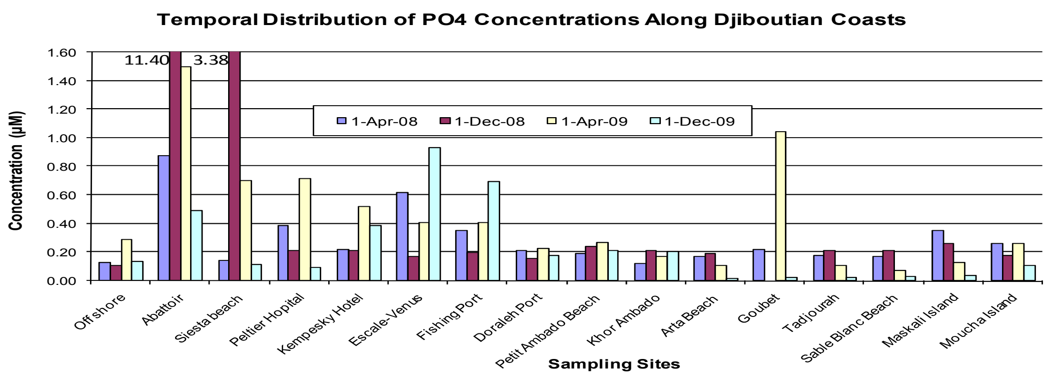

Figure 5: Surface seawater phosphate concentration at Djibouti monitoring sites during April and December 2008, 2009.

to 400 m depth in the Gulf of Aden shows that the thermocline is weaker in winter (from 16 to 25.5°C) than summer (from 16.5 to 29°C) [8]. Moreover, the deep water of the Gulf of Aden shows a steady decrease of temperature as low as 10°C from 1000 to 2000 m depth. This is a result of its direct connection with the Indian Ocean [9]. Seawater temperature is a conservative characteristic of a marine ecosystem that along with salinity are amongst the most important physical variables determining basic features of a water body. In addition of setting tolerance limits to most living organisms, these two variables combined determine the density of a water body, which in turn plays a significant role in controlling water transport both vertically and horizontally. The shore of the Gulf of Aden is considered as one of the hottest climates in

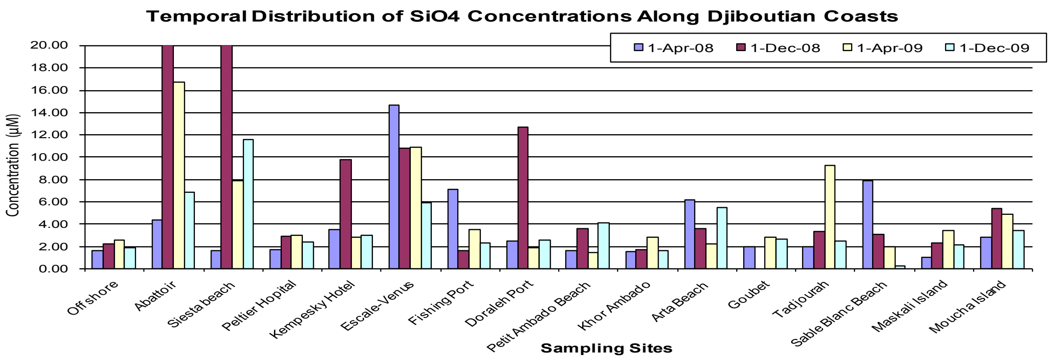

Figure 6: Surface seawater silicate concentration at Djibouti monitoring sites during April and December 2008, 2009.

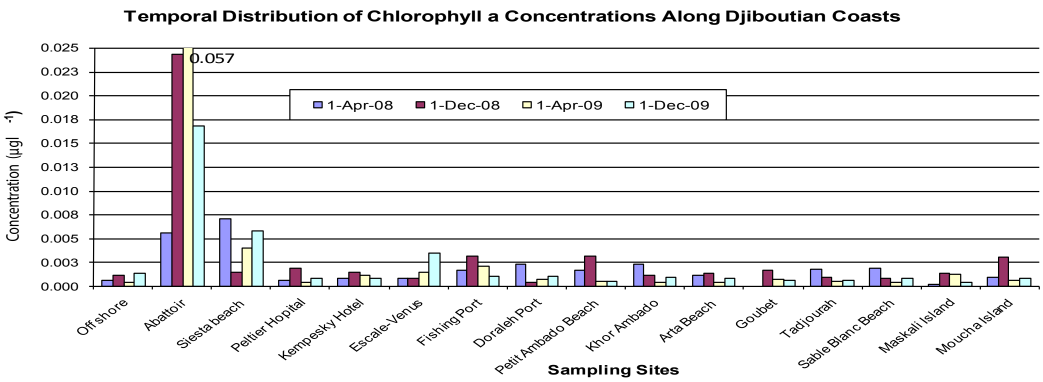

Figure 7: Surface seawater chl a concentration at Djibouti monitoring sites during April and December 2008, 2009.

the world [9]. The highest surface water temperatures recorded in April in the Djibouti costal water were positively correlated to the high air temperatures found (30°C to 40°C) at this season (April to September). The mixing process seems to have little influence on the temperature of the coastal water compared to temperature variations observed in the Gulf of Tadjourah or the Gulf of Aden. The surface seawater pH ranged between 8.0 and 8.5. All pH measurement were found to be in the normal seawater pH range, 7.5-8.5 [10] and typical of waters of the Red Sea and Gulf of Aden [11]. These pH values suggest the absence of upwelling waters in the sampled costal sites during the sampling periods. The pH values are lower in the upwelling waters body in the equatorial regions and are proportional to the temperature [12]. Chlorophyll a (Chl a) concentrations were generally low in all sampling sites, rarely exceeding 0.06 $\mu g.l^{-1}$. These concentrations are to be considered indicative as the amount of seawater filtered for the spectro-photometric analysis of Chl a was relatively small. However, the spatial distribution of Chl a concentrations indicated clearly that Abattoir site had the highest value in three sampling events (Dec. 2008, Apr. 2009, and Dec. 2009) as compared to the other sites. Low Chl *a* concentration was reported in the Red Sea from 1998 to 2009 with concentrations as low as 0.08 $\mu g.l^{-1}$ [13]. Strong co-variations between Chl a and the physical parameters (e.g. wind) showed that physical processes have effect on the changes in the phytoplankton blooms in the Red Sea [13] (Table 2). Relatively high concentrations of nutrients were recorded, such as a nitrite concentrations of 2.10 and 3.41 µM at Goubet and Moucha Island respectively in December 2009; phosphate concentration of 3.38 µM at Siesta Beach in December 2008; and silicate concentration of 52.58 µM at Siesta Beach in December 2008. The Gulf of Aden is known for upwelling that occurs in late summer and results in increased nutrient concentrations in the surface water. High nutrient concentrations have been recorded in August and September with nitrite concentrations reaching up to 20 µM during upwelling of Somalia and southern of Yemen [14]. With all sampling events in the present study not coinciding with upwelling season, the elevated nutrient concentrations need further investigation before solid judgments on the cause could be made. Wastewater discharge into the Djibouti shoreline influences the quality of the marine environment, which is extremely important to Djibouti as a renewable source of food, a source of desalinated water for drinking and a place for recreational activities. On the other hand, microbial contamination of marine waters worldwide is estimated to cause millions of gastrointestinal and acute respiratory infections [15] and numerous skin infections [16] every year. Runoff, floods, and sewage discharges release large numbers of microorganisms, including fecal indicators, into seawater. This was clearly demonstrated by the high fecal coliform (FC) and fecal streptococci (FS) contents of Djibouti-city Beaches (Table 3). The highest concentration of fecal indicators was found in Siesta beach (site #3) (Table 3). This beach is the most frequented one in Djibouti-city and was far about 1 Km from sewage outfall. It is noteworthy that during the sampling process there are no bathers. Abattoir (site #2) and Peltier (site # 4) locations, adjacent to sewage outfalls, have shown also high level of FC and FS contents (Table 3). On the other hand, Escale-Venus location (site # 6), where restaurants discharged directly their wastewaters into the sea, is much less polluted than locations 2-4 (Table 3). This could be due to the fact that the sites 2-4 were located near sewage outfalls that discharged mainly septic wastewater with long retention times compared to site 6 where restaurant discharge directly their wastewater into the sea. Generally, domestic wastewater in

Site #	pH	EC (mS/cm)	T (°C)	NO_2 (µM)	PO_4 (µM)	SiO_2 (µM)	Chl *a* (µg/l)	DO (mg.l^{-1})	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Zn (µg/L)	Ni (µg/L)
17	8.41 ± 0.03	50.41 ± 0.05	28	0.343 ± 0.01	1.383 ± 0.02	8.53 ± 0.3	0.020 ± 0.01	7.1 ± 0.1	< 0.1	< 0.2	0.88 ± 0.003	< 0.2	0.56 ± 0.002	04.39 ± 0.004	< 1.5	< 0.2	< 0.3
18	8.42 ± 0.03	50.43 ± 0.04	28	0.167 ± 0.01	0.510 ± 0.01	4.4 ± 0.2	0.012 ± 0.01	7.5 ± 0.2	< 0.1	< 0.2	0.76 ± 0.001	< 0.2	0.34 ± 0.001	04.91 ± 0.004	< 1.5	< 0.2	< 0.3
19	8.48 ± 0.05	50.93 ± 0.06	28	0.114 ± 0.02	0.874 ± 0.01	5.25 ± 0.1	0.013 ± 0.01	7.8 ± 0.3	< 0.1	< 0.2	0.55 ± 0.003	< 0.2	0.55 ± 0.004	05.56 ± 0.002	< 1.5	< 0.2	< 0.3
20	8.51 ± 0.06	50.12 ± 0.03	29	0.202 ± 0.01	0.874 ± 0.01	4.4 ± 0.1	0.010 ± 0.03	7.9 ± 0.2	< 0.1	< 0.2	0.57 ± 0.004	< 0.2	0.43 ± 0.002	03.82 ± 0.004	< 1.5	< 0.2	< 0.3
21	8.48 ± 0.06	50.15 ± 0.04	28	0.158 ± 0.01	0.620 ± 0.03	4.94 ± 0.1	0.010 ± 0.01	8.2 ± 0.1	< 0.1	< 0.2	0.84 ± 0.002	< 0.2	0.36 ± 0.001	03.97 ± 0.005	< 1.5	< 0.2	< 0.3
22	8.43 ± 0.05	50.01 ± 0.04	29	0.097 ± 0.03	0.764 ± 0.02	8.13 ± 0.3	0.013 ± 0.01	7.9 ± 0.1	< 0.1	< 0.2	0.42 ± 0.001	< 0.2	0.74 ± 0.004	12.08 ± 0.001	< 1.5	14.4	< 0.3
23	8.50 ± 0.03	50.06 ± 0.07	29	0.132 ± 0.01	0.655 ± 0.01	8.67 ± 0.3	0.006 ± 0.02	8.1 ± 0.2	< 0.1	< 0.2	0.86 ± 0.003	< 0.2	0.32 ± 0.005	06.45 ± 0.004	< 1.5	12.5	< 0.3
24	8.52 ± 0.04	50.03 ± 0.06	29	0.035 ± 0.03	0.692 ± 0.01	18.1 ± 0.5	0.007 ± 0.01	8.0 ± 0.1	< 0.1	< 0.2	0.74 ± 0.001	< 0.2	0.54 ± 0.006	09.78 ± 0.002	< 1.5	6.3	< 0.3
25	8.49 ± 0.06	50.03 ± 0.04	29	0.079 ± 0.01	0.692 ± 0.03	9.57 ± 0.4	0.01 ± 0.04	7.9 ± 0.3	< 0.1	< 0.2	0.86 ± 0.003	< 0.2	0.41 ± 0.002	06.12 ± 0.005	< 1.5	< 0.2	< 0.3
26	8.48 ± 0.05	50.12 ± 0.03	29	0.062 ± 0.01	0.656 ± 0.02	13.4 ± 0.4	0.01 ± 0.03	7.6 ± 0.1	< 0.1	< 0.2	0.79 ± 0.002	< 0.2	0.64 ± 0.001	05.52 ± 0.004	< 1.5	< 0.2	< 0.3

Table 2: Physical and chemical parameters of the Doraleh coastline seawaters.

Site #	Sampling locations	TC (UFC/100 ml)	FC (UFC/100 ml)	FS (UFC/100 ml)	SAL (UFC/100 ml)	SHI (UFC/100 ml)
2	Abattoir	45000	40000	2750	0	0
3	Siesta Beach	75000	71500	2500	0	2000
4	Peltier Hospital	55000	25000	600	0	9000
5	Kempesky Beach	60000	55000	650	0	0
6	Escale – Venus	100	24	17	0	0
7	Fishing Port	140	49	32	0	0
10	Khor Ambado Beach	0	0	0	0	0
11	Arta Beach	0	0	0	0	0

Table 3: Levels of Total Coliform (TC), Fecal Coliform (FC), Fecal Streptococci (FS), Salmonella (SAL), and Shigella (SHI).

Djibouti is of high strength and is often septic because of low flows, long retention times and high temperatures [17,18]. Kempesky beach (site # 5) seawater has shown high level of FC and FS concentrations (Table 3) even though this location was far from any sewage outfall. However, this beach is located less than 1 Km from Djibouti Port. Therefore, these results could be interpreted by the fact that the current direction was mainly from the Djibouti Port toward Kempesky beach (site # 5) most of the monitoring period. This finding suggests that any future monitoring program should take into consideration a daily record of current direction and, if possible, current speed. Khor Ambado (site # 10) and Arta (site # 11) beaches were found to be clean (Table 2). These results could be explained by the fact that there are no sewage outfalls near these beaches. During the 2012 monitoring, E. coli were isolated from all sampling points except Khor Ambado (site # 10) and Arta (site # 11) beaches. Djibouti-city beaches were mainly evaluated using the European Community (EU) standards for FC (EU mandatory: 2000 cfu/100 ml and EU guidelines: 100 cfu/100 ml) and FS (EU guidelines: 100 cfu/100 ml) [19]. It can be observed from Table 3 that, in general, most of the Djibouti-city beaches located near sewage outfall failed to comply with the European Community Bathing Water Directive. Furthermore, the presence of *Staphylococcus aureus* (*S. aureus*) in marine coastal environments may be considered as a risk indicator for skin, eye and ear diseases [20]. It should be noted that *S. aureus* were identified in seawater from Abattoir (site 2), Siesta Beach (site #3), Peltier (site #4), and Venus-Escale (site #6).

Doraleh port area

Doraleh port is one of the two main ports of Djibouti where almost all commodities as well as oil is delivered. Thus, the Doraleh port was selected as one of the monitoring point for the Djibouti Sustainable National Monitoring Program. Furthermore, in 2012, an elaborated campaign was conducted to collect water samples from ten (10) stations at the Doraleh littoral area for nutriment and heavy metals analyses (Figure 1). The locations of these stations are summarized in Table 1. In the Red Sea the horizontal and vertical circulation, water temperature and salinity mainly determine the concentration of dissolved oxygen [21]. Indeed, the dissolved oxygen in water is usually depending on its temperature and salinity. It is also depending on a considerable degree on the quantity of organic matter present in the aquatic environment. The dissolved oxygen levels in Doraleh coastal waters ranged 7.1-8.2 mg/L**,** with an average mean level of dissolved oxygen 7.8 mg/L (Table 2). These values were in the range of the concentration of dissolved oxygen in the surface water of the Red Sea during winter [21]. Nitrite concentrations ranged from 0.04 to 0.34 µM (Table 2). These values are within the reported nitrite concentrations in Red Sea, Aqabe Gulf (Jordanian) and Jeddah Red Sea [22]. Phosphate concentrations at Doraleh coastal area ranged from about 0.50 to 1.38 µM (Table 2). These values are slightly higher than the phosphate concentration reported for Jeddah Red Sea [22]. However, phosphate concentrations at Doraleh coastal are in the same range than to other sites in Djibouti Monitoring Program (Figure 5). Silicate Concentrations in the present campaign, ranged from 4.40 to 18.15 µM. These values were in the range of Djibouti coastline silicate concentration [23]. It has been reported that diatoms always numerically dominated the phytoplankton community when concentrations of silica were in excess of 2.2 µM [24]. On the other hand, the diatoms depend also on N/PO_4 [25] and SiO/N ratios [26]. Dominance by diatoms ceased or became more variable when concentrations of Si were less than this value. Previous study in Doraleh area reported that the silicate ranged from 2.55 to 4.11 µM in summer and 1.38-1.87 µM in winter [23]. On the basis of this study, one can speculate that diatoms dominate the summer phytoplankton community in Doraleh coastline. Chlorophyll a concentrations ranged from 0.006 to 0.02 $\mu g.l^{-1}$ for the Doraleh coastal area. These values are well below the reported value for chl a in Aqaba Gulf and Suez Gulf, 0.1-1.0 µg/L and 0.5-4.0 µg/L respectively [26]. However, Chl a concentrations in Doraleh shoreline are in the same order of magnitude that the Gulf of Tadjourah seawaters (Figure 7). In addition, similar Chl a concentrations were obtained when 5 or 10 liters of seawater were filtered for the spectrophotometric analysis of Chl a. In other terms, Tadjourah Gulf seawaters featured low Chl a concentrations in summer as well in winter. In order to further investigate the natural cycle that is responsible for this low Chl a concentration, three stations were set up in 2014 into the Gulf of Tadjourah to monitor at different depths the temperature, salinity, dissolved oxygen, and Chl a on a daily basis. Heavy metal concentrations at the 10 sampling stations within Doraleh coastline are shown in Table 2. The copper, lead, cadmium, nickel and cobalt were below the detection limits for all station. Zinc was revealed in three stations (sites # 22-24) while iron, chromium and manganese could be detected at all stations (Table 2). The chromium concentrations of the Doraleh coastal waters ranged from 0.42 to 0.88 $\mu g.l^{-1}$ (Table 2). These values are within the normal range for seawater [26]. On the other hand, Tring Xuan Gi [26] reported that in general the zinc concentration in seawater (over the world) range from 0.65 µg/L (Pacific Ocean) to 42 $\mu g.l^{-1}$ (South China sea) passing through 7.92 $\mu g.l^{-1}$ (Atlantic Ocean) and 27 $\mu g.l^{-1}$ (South African Coast). For Doraleh coastal water, the zinc concentrations for stations 17-22 and 25-26 are below the detection limits (0.2 $\mu g.l^{-1}$), while the zinc concentrations of stations 6-8 range 6.32-14.4 $\mu g.l^{-1}$. These values were within the normal range for seawater [26,27]. Iron is present in very low concentrations in the oceans (0.003-0.11 $\mu g.l^{-1}$) [28-30], despite its enhanced abundance in the earth's crust (5.6%) [31], and is a vital constituent of plant life. The element plays an important role in plant metabolism where it is essential for photosynthetic and respiratory electron transport, nitrate reduction, chlorophyll synthesis and detoxification of reactive oxygen species [32]. The iron concentrations in Doraleh coastal waters range 0.32-0.74 $\mu g.l^{-1}$ (Table 2). These values were greater than typical iron concentration in ocean. However, samples taken from a point 1 kilometer offshore in Doraleh coastline area showed iron concentrations below 0.1 $\mu g.l^{-}$

[1], which was within the normal range for seawater [28-30]. In other terms, the iron concentration in seawater sampled in the vicinity of the Doraleh Port were slightly high (0.32-0.74 μg.l[-1]), while those from a point 1 kilometer offshore were in the normal range for seawater (0.1 μg.l[-1]). Therefore, the slightly high iron concentrations of Doraleh coastline would probably originated from the Doraleh Port activity.

Statistical analysis

Hierarchical cluster analysis (HCA) is a commonly used method to classify observations or variables, in order to define more or less homogeneous groups and emphasize their genetic relations [33]. A classification scheme using Euclidean distance for similarity measurement, together with Ward's method for linkage [34] produces the most distinctive groups where each member within the group is more similar to its fellow members than to any member outside the group [35]. In this study, HCA was applied to the Djibouti recreation area data. Twenty four variables (T-Summer-2008, pH-Summer-2008, NO_2^--Summer-2008, PO_4^{3}-Summer-2008, SiO_2-Summer-2008, Chl a-Summer-2008, T-Winter-2008, pH-Winter-2008, NO_2^--Winter-2008, PO_4^{3}-Winter-2008, SiO_2-Winter-2008, Chl a-Winter-2008, T-Summer-2009, pH-Summer-2009, NO_2^--Summer-2009, PO_4^{3}-Summer-2009, SiO_2-Summer-2009, Chl a-Summer-2009, T-Winter-2009, pH-Winter-2009, NO_2^--Winter-2009, PO_4^{3}-Winter-2009, SiO_2-Winter-2009, Chl a-Winter-2009) were considered to classify all the water samples from this study. In HCA the variables are log transformed and normalized so that each variable has equal weight. The HCA results were presented in a dendrogram (Figure 8). The hierarchical analysis allowed us to distinguish four groups of water: Cluster 1 (samples # 1, 4, 5, 7-16), Cluster 2 (sample # 3), Cluster 3 (sample 6), and Cluster 4 (sample # 2). Principal components analysis (PCA) allows one to define eigenvectors of a variance –covariance or a correlation matrix from a data set corresponding to a raw matrix of n rows of observations by p columns of variables [33]. PCA was performed on a data set of twenty four variables (T-Summer-2008, pH-Summer-2008, NO_2^--Summer-2008, PO_4^{3-}-Summer-2008, SiO_2-Summer-2008, Chl a-Summer-2008, T-Winter-2008, pH-Winter-2008, NO_2^--Winter-2008, PO_4^{3-}-Winter-2008, SiO_2-Winter-2008, Chl a-Winter-2008, T-Summer-2009, pH-Summer-2009, NO_2^--Summer-2009, PO_4^{3}-Summer-2009, SiO_2-Summer-2009, Chl a-Summer-2009, T-Winter-2009, pH-Winter-2009, NO_2^--Winter-2009, PO_4^{3-}-Winter-2009, SiO_2-Winter-2009, Chl a-Winter-2009) and sixteen sea water samples. Principal components analysis of water chemical variables produced three components (Table 4), accounting for 72.31% of the total variance of the dataset. Table 4 presents the principal component loadings, as well as their respective explained variance. Loadings, that represent the importance of the variables for the components are in bold for values greater than 0.7 (Table 4). Most of the variance is contained in the PC1 (43.25%) which is associated with the variables PO_4-Summer 2008, Chl a-Summer 2008, pH-Winter 2008, NO_2-Winter 2008, PO_4-Winter 2008, SiO_2-Winter 2008, NO_2-Summer 2009, Chl a-Summer 2009, PO4-Winter 2009, SiO_2-Winter2009, and Chl a-Winter with squared regression coefficients of 0.783, 0.893, -0.845, 0.866, 0.970, 0.924, 0.766, 0.928, 0.789, 0.869, and 0.986 respectively. PC2 (19.03%) is mainly related to SiO_2-Summer 2008, T-Summer 2009, pH-Summer 2009, pH-Winter 2009 with squared regression coefficients of 0.829, 0.746, 0.889, and 0.873 respectively. The water sample observations of the two principal component axes are plotted in Figure 9. In score plot PC1 vs. PC2 (Figure 9) the water samples are divided into four distinct clusters mainly according to their geotectonic units: Cluster 1 (samples # 1, 4, 5, 7-16), Cluster 2 (sample # 3), Cluster 3 (sample 6), and Cluster 4 (sample # 2). The principal component analyses of the water samples show the same groupings that were apparent in the hierarchical clusters analyses (Figures 8 and 9). It is of interest to note that the Cluster 1 (sample # 2) corresponds to the seawater sample from the shoreline that receives wastewater from the Djibouti slaughterhouse (Figure 1). The Cluster 2 (sample # 3) and Cluster 3 (sample # 6) were related to the seawater samples from Djibouti-city shoreline that receives untreated domestic wastewaters (Figure 1). On the other hand, the Cluster 4 (samples # 1, 4-5, 7-16) include seawater samples that were not subject to any wastewater discharge. Therefore, the spatial difference in the water quality parameters in the Gulf of Tadjourah is mainly related to

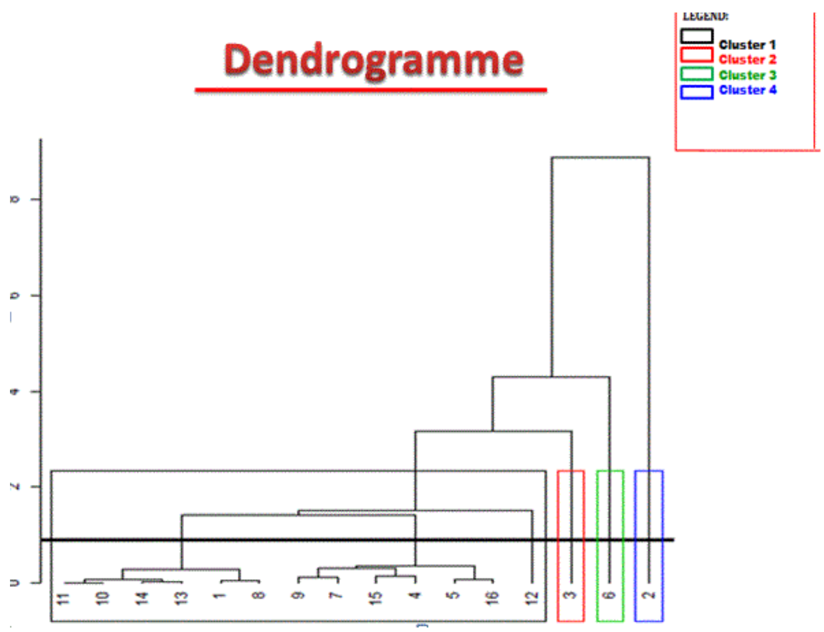

Figure 8: Four clusters in the dendrogram for the water sample in the Lake Abhe area. The black line is "phenon line".

parameters	PC1	PC2	PC2
PO_4-Summer 2008	0.783	0.396	-0.432
SiO_2-Summer 2008	0.133	0.829	0.011
Chlo*a*-Summer 2008	0.893	-0.146	-0.325
pH-Winter 2008	-0.845	0.298	0.274
NO_2-Winter 2008	0.866	-0.214	-0.001
PO_4-Winter 2008	0.97	-0.198	-0.055
SiO_2-Winter 2008	0.924	-0.1518	0.289
T-Summer 2009	0.505	0.746	0.156
pH-Summer 2009	0.111	0.889	-0.189
NO_2-Summer 2009	0.766	-0.045	0.385
Chl *a*-Summer 2009	0.928	-0.133	-0.282
pH-Winter 2009	0.065	0.873	-0.095
PO_4-Winter 2009	0.789	-0.137	0.017
SiO_2-Winter2009	0.869	0.261	-0.031
Chlo *a*-Winter 2009	0.986	-0.032	-0.049
Variance explained	10.38	4.567	2.406
% Total variance	43.25	19.03	10.03
Cumulative (%)	43.25	62.28	72.31

Table 4: Results from the principal component analysis. Vectors, eigenvalues and cumulative variance (principal vectors are in bold).

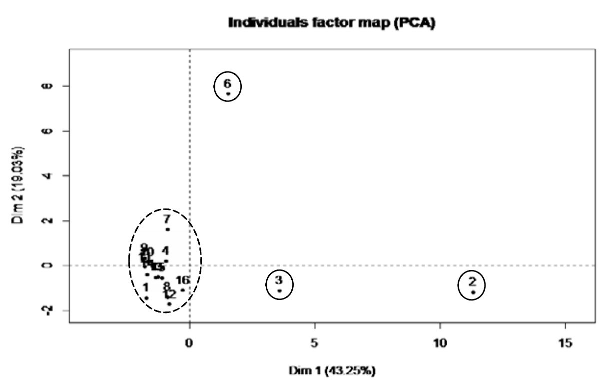

Figure 9: Principal Component's analysis results. PC1 versus PC2 plot for samples.

the impact of human activity.

Paired t tests were used to detect significant variations among parameters in the different four cluster locations (Cluster 1, Cluster 2, Cluster 3, and Cluster 4). Pearson correlation was used to detect linear correlation between the four cluster locations. Table 5 summarizes the paired t test results and the Pearson correlations of pH, NO_2, PO_4, SiO_2, and Chl a in seawater samples. The results indicated no significant difference in the parameters measured at all locations (Table 5). These results may be explained by the fact that the available data is not sufficient to be much more interpreted by means of statistical analyses. Therefore, the Djibouti seawater should be at least monitored fortnightly at each sampling site so as to have sufficient data for future statistical analyses.

Conclusions and Perspectives

The present study documents the first results on inorganic nutriments (NH_4, PO_4, SiO_2, NO_2), microbiology (TC, FC, FS, Salmonella, Shigella), and heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) concentrations in Djibouti marine and coastal environment. The Gulf of Tadjourah seawater features very low chlorophyll a concentrations. In order to get deeper understanding of this particular low chlorophyll a, three stations monitoring daily the temperature, salinity, dissolved oxygen and chlorophyll a have been set up in the Gulf of Tadjourah in the end of 2014 and the results of this monitoring will be further reported. The results of the present study demonstrate that higher microbial concentrations in seawater were associated with wastewater discharge. Beaches located near wastewater outfalls failed to comply with the European Community Bathing Water Directive, while beaches far from the point source were in good compliance. This study highlights the importance of wastewater treatment before discharging in the sea for reducing the risk of anthropogenic pollution in the Djibouti-city beaches. A more effective management practice would be treating wastewater and reusing the treated water as Djibouti suffers from scarcity of fresh water resources. Preventing wastewater discharge to the sea will also reduce the risks associated with microbial contamination on seafood and on bather health directly. The heavy metals concentrations in Doraleh coastline seawater were within the normal range for seawater except for iron, which is slightly high and only for the sampling points located in the vicinity of the Doraleh port. Thus, establishing a regular monitoring of the aquatic system should

	pH		NO_2		$P0_4$		SiO_2		Chlo_*a*	
	Pearson	*t* test	Pearson	*t* test	Pearson	*t* test	Pearson	*t* test	Pearson	*t* test
2&1	1.955	-0.809	1.106	3.1032	-0.5874	1.2912	0.6522	1.5167	-0.8255	2.2476
2&3	2.5045	-0.6018	0.9647	1.5007	17.0388	1.3677	6.4749	1.2561	-0.724	1.8327
2&4	2.3366	-0.7955	0.6763	2.7425	-0.4070	1.2099	1.0627	1.4928	-0.3554	2.2467
2&5	-0.1739	-0.3882	0.5818	2.3863	-0.8610	1.2174	5.223	1.4833	0.5719	2.266
2&6	1.0874	-3.1346	1.4445	2.4699	-1.8471	1.1041	0.0427	0.8855	-0.0508	2.1917
2&7	1.09130	-0.8656	0.6765	2.9666	-1.4794	1.1711	-1.0810	1.3177	0.4279	2.1925
2&8	2.5537	-0.7712	-0.6413	2.4038	-1.2395	1.2843	5.5160	1.5880	-1.1728	2.1936
2&9	-0.2483	-0.9758	1.0967	3.0494	0.4421	1.2783	0.5539	1.4865	-0.5237	2.1688
2&10	1.6808	-1.2638	0.3110	2.8446	0.8568	1.3009	-0.0547	1.5163	-2.2547	2.1728
2&11	-0.2656	-1.0589	1.0304	3.0515	1.1141	1.3284	-0.7738	1.2964	-1.6460	2.2294
2&12	-0.3954	-1.0921	1.0118	-0.0559	0.1096	1.2023	0.2146	1.4806	-0.3283	2.2499
2&13	1.0386	-0.9188	0.4041	2.9227	1.2575	1.3275	0.0175	1.3399	-1.4730	2.2207
2&14	-0.2483	-0.9258	0.2632	2.2667	1.4723	1.3317	-0.1985	1.3841	-2.0677	2.2051
2&15	0.6687	-0.9259	0.4948	2.2252	0.4916	1.2997	0.3545	1.5081	1.5496	2.3203
2&16	1.1092	-1.1574	0.4086	-0.3072	-0.2208	1.2825	2.0712	1.4066	-0.2214	2.2075

3&1	0.7707	-1.2741	-0.4382	2.8466	-0.4593	1.1412	0.4372	1.4206	-0.1786	2.9674
3&4	0.8178	-0.0714	1.1667	2.7545	-0.3184	0.9105	0.9098	1.3924	-1.6106	2.4676
3&5	-0.9371	0.3163	1.0863	2.0506	-0.7121	0.9339	5.5192	1.3695	-5.5980	2.5978
3&6	0.2042	-2.6769	1.0846	2.0092	-2.0280	0.6462	-0.1726	0.6598	0.4453	2.4903
3&7	0.2496	-1.1675	-0.0864	2.8534	-1.4718	0.81068	-1.3249	1.1874	-2.468	1.5923
3&8	1.1222	-1.2185	-2.3254	1.8203	-1.1259	1.1173	7.3789	1.4939	2.3748	3.9834
3&9	-0.7999	-1.6026	0.4823	2.8548	0.5743	1.0976	0.9350	1.4025	-1.0418	1.8737
3&10	0.5839	-3.1726	0.2971	2.6955	0.9109	1.1625	-0.2659	1.4188	0.9305	3.2474
3&11	-0.9156	-2.0409	0.9138	2.8722	1.0644	1.2410	-0.5243	1.1788	-0.2958	2.8608
3&12	-1.3431	-2.2227	1.1897	-0.7070	0.2151	0.8683	0.1956	1.3811	-1.3598	2.6188
3&13	0.3764	-2.0233	0.1784	2.7556	1.1840	1.2375	-0.2017	1.1877	0.6271	3.2585
3&14	-0.6461	-1.7256	2.2401	3.1084	1.3354	1.2493	-0.3219	1.2545	1.1644	3.5004
3&15	-0.0835	-0.6877	0.8575	1.7060	0.4202	1.1506	0.2425	1.4085	-3.4503	2.5257
3&16	0.2401	-1.2652	1.0650	-0.6844	-0.1907	1.1108	1.5665	1.2825	-1.8938	1.9153
6&1	2.71352	2.7718	0.4855	6.9581	-0.1911	2.1157	-0.1861	4.6299	1.1069	1.5238
6&4	3.4427	5.1288	3.5183	0.6731	-0.5397	0.7393	-0.5718	4.1710	-0.3806	0.9169
6&5	1.2877	3.2062	3.0752	-0.2644	0.3294	1.2294	0.1539	2.4844	-0.8621	0.8370
6&7	5.8070	2.9505	1.6278	8.9982	3.3224	1.5303	1.6350	5.8274	-1.5164	-0.3486
6&8	1.4968	2.7113	-0.2107	1.4077	0.0942	2.0977	0.0574	1.8116	-0.2596	0.6605
6&9	0.8129	2.1885	4.1832	10.6950	-0.9293	1.7735	-1.6423	3.3251	-1.1898	0.1470
6&10	2.9300	2.2194	1.9808	5.3452	-0.1715	2.1456	-0.0376	4.7230	-0.5864	0.5206
6&11	0.7199	2.0203	8.2651	2.0161	-1.9225	2.1116	0.0799	3.1477	-0.5546	0.9484
6&12	1.0231	1.9901	7.0161	-1.1332	-1.0560	0.3011	-1.2502	4.2146	-1.1864	0.8574
6&13	2.0545	2.2796	1.9922	7.5128	-1.8382	2.0468	0.0222	2.5781	-1.0535	0.8555
6&14	0.5906	2.1761	1.1036	-0.1236	-1.4717	2.1183	3.3334	10.3198	-0.5030	0.8371
6&15	5.6191	4.7730	2.8277	-0.7135	-0.7637	1.6596	-0.6415	4.0584	-0.5474	1.0524
6&16	-1.4398	2.8771	2.3070	-0.9319	-0.6899	1.8203	-0.1392	3.2901	-0.6746	0.3106

Table 5: Paired t test and the Pearson correlation results for pH, nitrite, phosphate, silicate, and Chlorophyl *a* in seawater samples.

be helpful in setting standards for regulating discharge in the sea. Noteworthy is that Djibouti is blessed with blooming development that needs to be rationally managed to avoid adverse impacts and secure sustainability and profitability for the investors and for the country.

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