

# The Effect of Climate on the Chemical Composition of the Coral Reefs around Kubbar Island—Kuwait

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## ABSTRACT

Thick recent carbonate sediments cover all the intertidal and subtidal zones consist of mainly different shell and coral reef debris. The chemical investigations of the coral fragments were done on controlled bases, which depend on the coral size and seasons, in order to elucidate the effect of weather parameters on the coral reefs. Geochemical investigation indicated that corals gathered from high-tide mark are mainly contaminated by copper, cobalt, and chromium and the corals gathered from low-tide mark are contaminated by lead and zinc. All the analyzed coral samples are contaminated by copper. The major contamination sights by heavy metals are related to the weather pattern around the islands. Calcium concentration in all the corals indicates a low-Magnesium calcite or aragonite composition, except for some coral samples which were gathered during October from the high-tide mark. Trace element concentration levels show high concentrations at sights of low-wave action around the island during the various seasons. Chemical analysis on the coral derbies indicates compositional variations regarding calcium and magnesium mole% between the seasons and at different locations and it is dependant on wind direction and water salinity. Some localities are iron rich others are aluminum and potassium rich. Generally, aluminum, iron, and potassium occur in lower quantities than the other elements. Therefore, all the chemical data regarding trace elements indicate relationship to weather and environmental parameters.

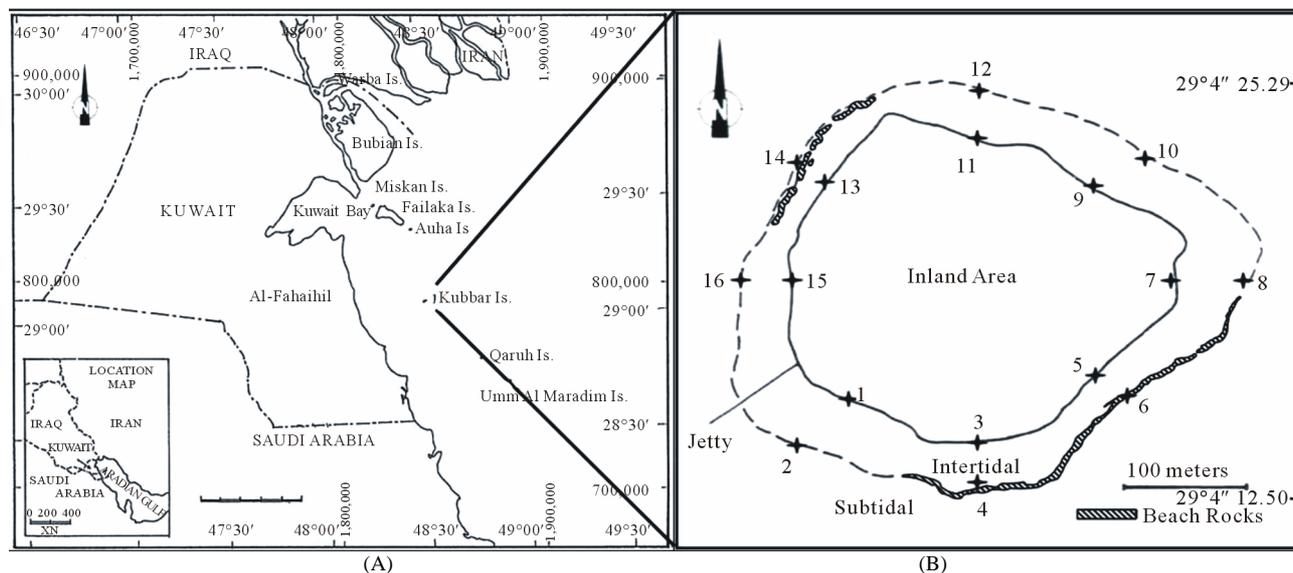
**Keywords:** Kubbar Island; Back Reef; Coral Debris; Seasonal Chemical Variations

## 1. Introduction

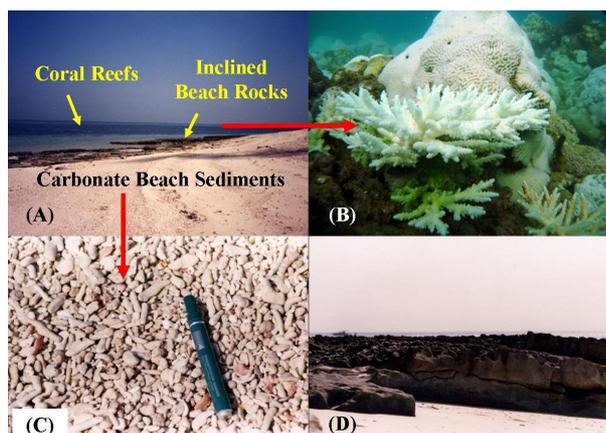
The southern section of Kuwaiti waters includes three islands; Kubbar, Qaruh and Umm Al-Maradim. Large number of coral reef colonies is flourishing in the subtidal zones of the three islands but most pronounce around Qaruh Island. Kubbar Island is relatively small with an area of 0.9 km<sup>2</sup> and a maximum elevation above sea level that equals to 4.5 m. The distance between Kubbar and Failaka Island is 36 km; it is located at approximately 34 km perpendicularly east from Al-Fahaihil area (**Figure 1**). It is considered a natural heaven for many species of different plants, great number of seagulls, birds, and the best nesting grounds for different types of sea turtles. Natural vegetation and coral reef colonies are considered the principal features of Kubbar Island (**Figure 2**). It is undeveloped except for the presence of landing field for helicopter, guarding tower and a jetty.

The intertidal zone has a width ranging between 5 to 11 m. The island beaches are relatively tranquil and covered by coarse to medium-grained calcareous sands (**Figure 2(C)**). The carbonate constituents are mainly

represented by shell fragments and coral reef debris, and to a lesser extent, some oolitic grains and quartz sand grains. The supratidal and inland zones form a raised platform of about 4.8 m above sea level, and is characterized by moderately to steep banks with a dipping angle ranging from 40° to 75°. Fieldwork observation indicated the occurrence of large number of bullet shells, as well as, empty cans is seen at the supratidal and inland zones, which resulted from the shooting of sea birds by many island visitors and the dumping of their garbage. Many pebbles of various sizes are found scattered among the surface sediment, which consists mainly of quartz and igneous rock fragments and sedimentary rock fragments. The majority of the sedimentary pebbles were mainly produced by the reworking action of waves on the beach rocks, whereas the quartz and igneous pebbles were extracted from the constructing materials used along the beaches. The island is characterized by a strategic and touristic importance, and considered significant fisheries. The diverse types of fish and the abundance of marine life made the island site for diving and fishing, as well as harmful human activities on the mainland of the island. Therefore, safeguarding the coral reefs of the island



**Figure 1. Showing, (A) Map of Kuwait and the location of Kubbar Island; (B) Sample location and the different zones around Kubbar Island.**



**Figure 2. Field photomicrographs from Kubbar Island showing, (A) Carbonate beaches, inclined beach rocks at the southern tip of the island, and the coral reef around the island; (B) Underwater photographs for corals from the coral reef around the island; (C) Carbonate beach sediments; (D) Inclined beach rocks.**

should be the main priority, because these corals are the main reason for the existence of many types of fauna and flora species in the waters around it. Moreover, the aquatic biota as well as land dwelling animals and bird species are greatly influenced by toxic materials in their host sediments, which are the result of human activities. All of these activities are greatly noticed and they are affecting the well-being and the existence of the coral reefs around the island, as well as the existence of many types of bird communities and other land and marine fauna and flora.

Ref. [1] elucidated the effect of weather variations such as prevailing wind direction and temperature, and

water salinity on the coral colonies and the nature of the accumulated sediments along the shores of the southern islands. Moreover, [1] indicated that the petrographic study on intertidal sediments from all the southern islands specify variation in grain size, micritization and boring extent of the carbonate constituents between the seasons. The present study revealed that the presence of halite and gypsum crystals as cements and detached crystals is higher during June and October. The results also indicate differences in grain size along the shores of the islands, which is dependent on the prevailing wind direction and wave action [1-3].

The corals of Kuwait are living in a stressed environment, which is subject to high and temperatures and also oil pollution. Ref. [4] concluded that the major problems facing these corals at present are anchor damage to corals, over fishing and litter. Refs. [5,6] indicated that Anchors have destroyed large tracts of the reefs at all sites, and over-fishing has reduced populations of large predators, such that few fish greater than 20 cm are seen. They also postulated that oil pollution has not caused massive mortalities to reefs, even though most were in the path of the massive oil spill during the Gulf War. Ref. [6] postulated that, the reefs of Kuwait are exposed to a very heavy load of particles due to the shallow water environment and input from the Shatt Al-Arab. The interest of studying the affect of weather parameters on corals arises from the importance of coral reefs for the support of marine life, hence the productivity of the marine environment and the availability of marine food resources.

The purpose of this research is to investigate the variations in chemical composition of the corals according to

the changes in climate, especially temperature, wind pattern and water temperature, salinity and the pollution degree these corals are affected with.

## 2. Material and Methods

### 2.1. Sample Collection

The intertidal sediment samples were gathered from the eight geographic quadrants: North, South, East, West, Northeast, Northwest, Southeast, and Southwest. Normally two sediment samples were gathered at each location, one from the highest tidemark and one from the low-tide mark within the intertidal zone of Kubbar Island, odd numbers referred to high-tide locations and even numbers for low-tide locations (**Figure 1(B)**). The total number of gathered sediment samples is 48 and is from three different seasons. The abbreviations used in tables K, KO, KJA and KJ are referred to Kubbar, October coral samples, January coral samples and June coral samples, respectively. Sampling was carried out after drawing a square with sides equal to 30 cm (30 cm × 30 cm), and the depth of sediment samples collected from this square should not exceed 2 cm.

### 2.2. Chemical Investigations

This study is based on chemically analyzing all coral

fragments of the size portion 0.5 mm (controlling factor) from high-tide and low-tide points from all the eight geographic directions. Some sediment samples lack coral sizes of 0.5 mm, therefore the researcher separated corals from the 2 mm and 1 mm size portions (**Table 1**). A total of 48 coral samples were analyzed by two different methods to measure the total Ca and Mg, trace elements (Na, Fe, Sr, Al, K), and heavy metals (Cu, Pb, Zn, Co and Cr) concentrations. The major elements and the trace elements were analyzed by using Inductive Coupled Plasma-optical emission spectrometric method (ICP). Few bulk sediment samples were analyzed by X-Ray diffraction method to determine the mineral constituent. BDL in tables is referred to below detection limits.

## 3. Meteorology and Oceanography

The Arabian Gulf is a 1000 km long and 200 - 300 km wide open shelf in an arid subtropical area [7,8]. Refs. [7,8] also mentioned that the sea floor of the Arabian Gulf slopes gently northwards on the west, with an average overall depth of about 35 m. Maximum depth at 100 m occurs along the Iranian coast [7,8]. Normally the beaches along the Arabian Gulf coasts are exposed to the strong northwesterly winds and the 2 m spring tides, and are composed of coarse sand with aeolian quartz, ooids, shell debris, and intraclasts [9]. In very arid regions wind

**Table 1. Separated coral fragments from all locations around Kubbar Islands used in chemical analysis.**

No.	Sample Number	Location	Size mm	No.	Sample Number	Location	Size mm	No.	Sample Number	Location	Size mm
October				January				June			
1	KO1	SW	1	17	KJA1	SW	0.5	33	KJ1	SW	0.5
2	KO2	SW	1	18	KJA2	SW	0.5	34	KJ2	SW	0.5
3	KO3	S	0.5	19	KJA3	S	0.5	35	KJ3	S	0.5
4	KO4	S	0.5	20	KJA4	S	0.5	36	KJ4	S	0.5
5	KO5	SE	1	21	KJA5	SE	0.5	37	KJ5	SE	0.5
6	KO6	SE	0.5	22	KJA6	SE	1	38	KJ6	SE	0.5
7	KO7	E	0.5	23	KJA7	E	0.5	39	KJ7	E	0.5
8	KO8	E	0.5	24	KJA8	E	0.5	40	KJ8	E	0.5
9	KO9	NE	0.5	25	KJA9	NE	0.5	41	KJ9	NE	0.5
10	KO10	NE	0.5	26	KJA10	NE	0.5	42	KJ10	NE	0.5
11	KO11	N	0.5	27	KJA11	N	0.5	43	KJ11	N	0.5
12	KO12	N	0.5	28	KJA12	N	0.5	44	KJ12	N	0.5
13	KO13	NW	0.5	29	KJA13	NW	0.5	45	KJ13	NW	0.5
14	KO14	NW	0.5	30	KJA14	NW	0.5	46	KJ14	NW	0.5
15	KO15	W	0.5	31	KJA15	W	0.5	47	KJ15	W	0.5
16	KO16	W	0.5	32	KJA16	W	0.5	48	KJ16	W	0.5

plays a significant role in redistributing sediments.

Kuwait is situated on the northwestern shore of the Arabian Gulf, and Kubbar Island lies at the southern sea area of Kuwait at 29° North (**Figure 1**). Kuwait is mainly characterized by hot and dry climate, and affected by two main wind directions through out the seasons. These are the “Shamal” wind (blowing from the northwest direction) and the “Kose” wind (blowing from the southeast direction). The mean temperature reaches 45°C in July and August, and 12°C in winter [10]. Ref. [11] pointed out that the mean annual temperature of Kuwait’s surface water is 23.8°C, with maximum temperature in July and August (30.5°C - 36°C) and minimum temperature in January and February (10°C - 14°C).

The weather changes throughout the year and the corals around Kubbar Island are affected by different weather patterns. It is noted that during the months following October (November, December and January), temperature will subside and humidity increase, where the lowest mean temperature = 1.41°, mean highest temperature = 26.16°, mean humidity = 89.71% [12]. This weather pattern will results in the lack of oxygen and nutrients that corals require, hence the death of the coral polyps. The mean rain-fall precipitation from November to January equals to 112.09 mm [12]. There is another weather pattern prevailing in Kuwait after January. During February and March temperature will be moderate that boosts the growth of algae (mean low temperature = 1.09° and mean highest temperature = 25.96°) [12]. Then, during April and May there will be the monsoon season (“Sarrayat”) that is known for its high wind activity-wave action and thunder rainstorms. The mean rainfall precipitation from February to April equals to 112.09 mm [12].

In addition to extreme temperatures, seawater salinity around the island also fluctuates, but is generally high (average high = 43.43%, average low = 39.06%). Ref. [13] revealed that mean annual salinity of Kuwait’s water is 41.6 psu, however, it could reach up to 45 psu. Ref. [14] attributed abnormal salinities throughout the Arabian Gulf to the excessive evaporation and partial isolation from the Indian Ocean. Ref. [10] studied the near shore wave characteristics and tidal currents around the islands. They concluded that the high wave energy and low wave energy were found in the western and eastern areas of the islands. Generally, the prevailing winds (the “Shamal”) blow from the Northwest and provide the dominant energy input with wave-effectiveness limits at about 20 - 30 m, primarily controlling facies patterns [9].

#### 4. Petrography

The petrographic study was an excellent tool to determine the nature of the sediments, composition, and envi-

ronment of deposition, behavior of deposition and differences and similarities between the depositional sights along the shores of the island. It indicated that the intertidal sediments from all locations share the same bioclastic components and these are divided into major and minor components, and indicative of reef to back-reef depositional environment.

The major bioclastic composition include; various types of corals, coralline algae, molluscs as bivalves and gastropods, and different types of echinoderm spines. The intragranular porosity of some bioclasts are either cemented by acicular aragonite crystals or filled by micrite, the bioclasts are affected by micritization and burrowing. The most important finding is the rosette-shaped high-Mg calcite cement and the longitudinal aragonite crystals seen by the Scanning Electron Microscope, [3].

The minor bioclastic components are foraminifera, brachiopods and ostracode tests. The SEM study indicated that the pore spaces of bioclasts are filled by finer organisms such as radiolarians, foraminifera, bryozoans, and *Coccolithis* (**Figure 3**). The non-bioclastic components consist mainly of intraclasts of various types and sizes, in addition to some minor oolitic grains and pellets. The most dominant nonclastic constituent within the sediment samples is quartz.

The study by polarizing microscope indicated that the origin of quartz grains is mainly igneous and metamorphic, and they are mainly rounded to well rounded grains, although some angular quartz grains do exist. The majority of quartz grains are of aeolian origin, especially the grains that are of fine sand to silt sizes which are wind-blown from northern Kuwait. Other nonclastic components include heavy minerals, metallic particles, rusty iron particles, and feldspars. Rusty iron particles tend to be the dominant grains among these three constituents.

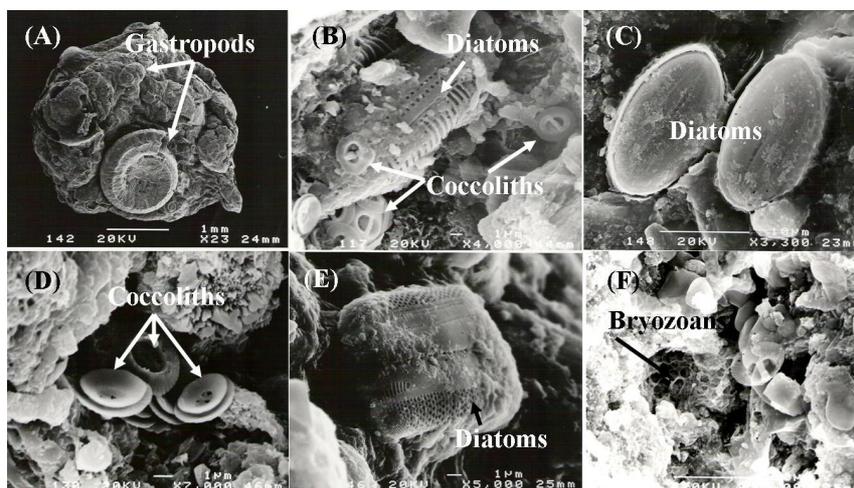
The sediments gathered in October and June show very high amount of cubic and prismatic crystals especially in the sediment portions of 0.063 and 0.032 mm namely halite, calcite and some gypsum. The existence of such crystals is an indication of high temperatures and salinity. The majority of crystals are found free, not attached to the grains composing the sediment samples.

### 5. Geochemistry

Two major elements (Ca and Mg), five trace elements (Na, Sr, Al, Fe, and K), and five heavy metals (Pb, Zn, Cu, Co, and Cr) were analysed for all the collected coral samples during all seasons. The purpose of chemical analysis of the corals is to identify any chemical variations in corals composition and effect of pollution on them.

#### 5.1. Major Carbonate Elements (Ca and Mg)

CaCO<sub>3</sub> concentration in all coral samples gathered from



**Figure 3.** Backscattered images from the SEM showing different organisms: (A) Gastropods; (B) Diatoms and coccoliths; (C) Diatoms; (D) Coccoliths; (E) Diatoms; (F) Bryozoans.

high-tide mark range between 94.759 - 98.35 Mole% with an average mean equals to  $96.691 \pm 1.0$  (Table 2). Coral Samples gathered during October from high tide mark include  $\text{CaCO}_3$  concentrations that range from 94.759 - 98.10 Mole% with an average mean value equals to  $96.652 \pm 1.16$  Mole% (Table 3). Coral samples gathered during June from high-tide mark include  $\text{CaCO}_3$  concentrations that range from 94.963 - 98.35 Mole% with an average mean value equals to  $96.756 \pm 1.39$  Mole% (Table 3). Coral samples gathered during January from high-tide mark include  $\text{CaCO}_3$  concentrations that range from 95.087 - 97.90 Mole% with an average mean value equals to  $96.665 \pm 0.80$  Mole% (Table 3).

Table 2 and Figure 4, shows that although the high-tide corals are slightly Mg-rich, they show nearly the same relationship during all the seasons. Figure 4(A) show that there is  $\text{CaCO}_3$  enrichment at the following locations: NE, SE, and NW, while corals from all the other locations are enriched in Mg.

The concentration of  $\text{CaCO}_3$  corals gathered from low-tide range between 97.644 - 99.02 Mole% with an average mean equals to  $98.458 \pm 1.0$  (Table 4). Coral samples gathered during October from low-tide mark include  $\text{CaCO}_3$  concentrations that range from 98.013 - 98.729 Mole% with an average mean value equals to  $98.4 \pm 0.25$  Mole% (Table 3). Coral samples gathered during June from low-tide mark include  $\text{CaCO}_3$  concentrations that range from 97.644 - 98.422 Mole% with an average mean value equals to  $98.213 \pm 0.26$  Mole% (Table 3). Coral samples gathered during January from low-tide mark include  $\text{CaCO}_3$  concentrations that range from 98.388-99.02 Mole% with an average mean value equals to  $98.762 \pm 0.21$  Mole% (Table 3). Corals gathered from the low-tide during October and January share the same relationship, while corals gathered during June show an antipathetic relationship to corals gathered from

the high-tide (Figure 4(B)).

Figure 5 show the distribution of  $\text{CaCO}_3$  in corals according to the different seasons. Figure 5(A) indicate that all the corals gathered from the NE, SW, NW during October contain the highest  $\text{CaCO}_3$  concentrations, while all other locations are enriched in Mg. Figure 5(B) indicate that although low-tide sediments has nearly the same Ca concentration, the corals gathered from the high-tide has variable  $\text{CaCO}_3$  concentration and show an antipathetic relationship with low-tide corals. Figure 5(C) show that corals gathered during October has the same relationship with corals gathered during January.

## 5.2. Trace Elements Concentrations

**Sodium** concentration in all coral samples gathered from high-tide mark range from 2780 - 23120 ppm with an average mean equals to  $8089 \pm 4702$  ppm (Table 2). Coral samples gathered during October from high tide mark include **Na** concentrations that range from 3835 - 11730 ppm with an average mean value equals to  $8753.25 \pm 3116.47$  ppm (Table 3). Coral samples gathered during June from high-tide mark include **Na** concentrations that range from 2780-23120 ppm with an average mean value equals to  $8211.38 \pm 6782.26$  ppm (Table 3). Coral samples gathered during January from high-tide mark include **Na** concentrations that range from 3131 - 13770 ppm with an average mean value equals to  $7303.63 \pm 3961.41$  ppm (Table 3). **Sodium** concentration in corals gathered during June and January share a sympathetic relationship at all locations, where all the SE and NW coral samples show a decrease in **Na** concentrations and all other locations show an increase in **Na** concentrations (Figure 6(A)). The highest **Na** concentrations were encountered at the western direction in corals gathered during June and January. The lowest **Na** concentration is encountered in

**Table 2. Major, trace and heavy elements concentrations in the coral debris from high-tide mark around Kubbar Island.**

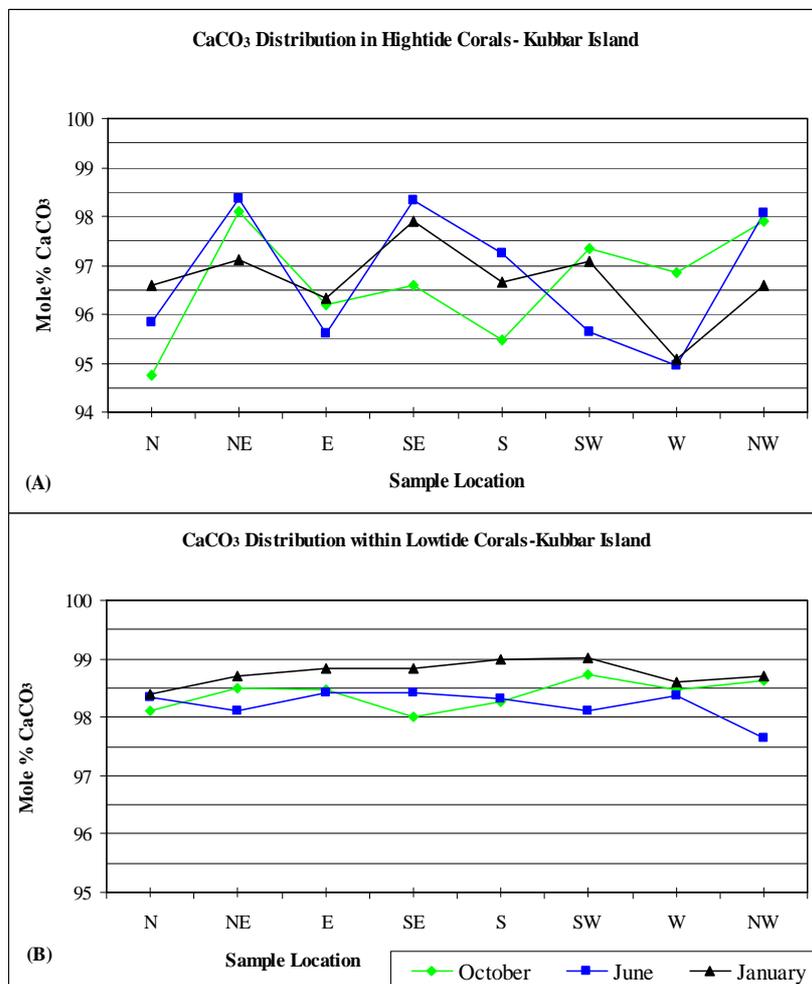
No.	Sample No.	Mole%					Element ppm								
		Ca	Mg	Na	Al	Si	K	Fe	Sr	Pb	Zn	Cu	Co	Cr	
1	KO1	97.350	2.650	10290	3150	4780	550	740	7100	0.945	BDL	2.221	0.378	0.662	
2	KO3	95.463	4.537	11730	6550	4740	1050	630	5680	BDL	BDL	1.347	0.549	0.848	
3	KO5	96.591	3.409	11140	1050	4800	610	590	6190	0.100	BDL	0.949	0.500	0.799	
4	KO7	96.194	3.806	9070	1200	4500	440	780	6470	BDL	BDL	0.949	0.500	0.749	
5	KO9	98.100	1.900	3921	302		336	516	7898						
6	KO11	94.759	5.241	10350	11970	7290	790	790	6310	BDL	BDL	0.500	0.550	0.800	
7	KO13	97.900	2.100	3835	256		373	375	7455						
8	KO15	96.855	3.145	9690	1370	3970	510	860	6850	BDL	BDL	1.050	0.500	0.700	
9	KJ1	95.628	4.372	8310	830	4210	570	680	6240	2.008	2.510	1.004	0.452	0.904	
10	KJ3	97.249	2.751	2780	1560	1680	790	640	5640	1.932	1.932	0.966	0.483	1.063	
11	KJ5	98.320	1.680	3884	251		182	353	7031						
12	KJ7	95.605	4.395	8560	1350	5120	440	660	6430	1.978	0.495	0.989	0.445	0.940	
13	KJ9	98.350	1.650	4130	354		574	429	7215						
14	KJ11	95.851	4.149	11550	1080	4560	740	590	6010	0.988	BDL	0.988	0.543	0.954	
15	KJ13	98.080	1.920	3357	110		254	348	7644						
16	KJ15	94.963	5.037	23120	4490	6730	1380	830	6470	0.980	BDL	0.490	0.490	0.980	
17	KJA1	97.073	2.927	12740	620	4280	480	650	6200	0.346	BDL	2.962	0.395	0.740	
18	KJA3	96.641	3.359	7010	2120	5070	340	720	6240	1.500	BDL	4.500	0.450	0.700	
19	KJA5	97.900	2.100	3131	252		186	374	7219						
20	KJA7	96.317	3.683	6150	1180	4860	380	620	5640	0.478	BDL	2.871	0.574	0.766	
21	KJA9	97.122	2.878	6920	1310	5380	570	660	6560	2.495	0.449	5.489	1.497	1.996	
22	KJA11	96.589	3.411	5380	970	4590	290	750	6080	0.147	BDL	2.153	0.538	0.881	
23	KJA13	96.590	3.410	3328	376		250	754	7102						
24	KJA15	95.087	4.913	13770	1460	5980	980	830	6300	BDL	BDL	0.988	0.445	0.939	
	<b>Average</b>	96.691	3.309	8089	1840	4855	544	632	6582	1.158	1.347	1.789	0.546	0.907	
	<b>St-dev</b>	1.10	1.10	4702	2614	1199	293	159	631	0.813	1.037	1.428	0.251	0.303	
	<b>Maximum</b>	98.350	5.241	23120	11970	7290	1380	860	7898	2.495	2.510	5.489	1.497	1.996	
	<b>Minimum</b>	94.759	1.650	2780	110	1680	182	348	5640	0.100	0.449	0.490	0.378	0.662	

**Table 3. Statistical data for all the major and trace elements, and heavy metals within high-tide and low-tide coral samples—Kubbar Island.**

	Average	St-dev	Maximum	Minimum		Average	St-dev	Maximum	Minimum
<b>High-tide coral samples—October</b>					<b>Low-tide coral samples—October</b>				
<b>CaCO<sub>3</sub></b>	96.65	1.16	98.10	94.76	<b>CaCO<sub>3</sub></b>	98.40	0.25	98.73	98.01
<b>MgCO<sub>3</sub></b>	3.35	1.16	5.24	1.90	<b>MgCO<sub>3</sub></b>	1.60	0.25	1.99	1.27
<b>Na</b>	8753.25	3116.47	11730.00	3835.00	<b>Na</b>	1432.75	550.52	2504.00	842.00
<b>Al</b>	3231.00	4091.23	11970.00	256.00	<b>Al</b>	197.38	48.44	246.00	122.00
<b>Si</b>	5013.33	1158.44	7290.00	3970.00	<b>Si</b>	1865.13	268.53	2197.00	1505.00
<b>K</b>	582.38	237.14	1050.00	336.00	<b>K</b>	179.00	42.80	245.00	112.00
<b>Fe</b>	660.13	162.77	860.00	375.00	<b>Fe</b>	357.13	57.48	437.00	276.00
<b>Sr</b>	6744.13	724.83	7898.00	5680.00	<b>Sr</b>	6556.75	151.00	6765.00	6317.00
<b>Pb</b>	0.52	0.60	0.95	0.10	<b>Pb</b>	0.24	0.08	0.31	0.15
<b>Zn</b>			0.00	0.00	<b>Zn</b>			0.00	0.00
<b>Cu</b>	1.17	0.58	2.22	0.50	<b>Cu</b>	1.63	0.50	2.62	1.00
<b>Co</b>	0.50	0.06	0.55	0.38	<b>Co</b>	0.04		0.04	0.04
<b>Cr</b>	0.76	0.07	0.85	0.66	<b>Cr</b>				
<b>High-tide coral samples—January</b>					<b>Low-tide coral samples—January</b>				
<b>CaCO<sub>3</sub></b>	96.66	0.80	97.90	95.09	<b>CaCO<sub>3</sub></b>	98.76	0.21	99.02	98.39
<b>MgCO<sub>3</sub></b>	3.34	0.80	4.91	2.10	<b>MgCO<sub>3</sub></b>	1.24	0.21	1.61	0.98
<b>Na</b>	7303.63	3961.41	13770.00	3131.00	<b>Na</b>	1178.75	260.80	1714.00	953.00
<b>Al</b>	1036.00	618.56	2120.00	252.00	<b>Al</b>	202.38	28.25	251.00	169.00
<b>Si</b>	5026.67	601.92	5980.00	4280.00	<b>Si</b>	2256.00	421.69	2889.00	1566.00
<b>K</b>	434.50	252.58	980.00	186.00	<b>K</b>	168.50	30.96	224.00	125.00
<b>Fe</b>	669.75	137.41	830.00	374.00	<b>Fe</b>	363.63	37.05	423.00	304.00
<b>Sr</b>	6417.63	526.75	7219.00	5640.00	<b>Sr</b>	6427.75	133.40	6596.00	6215.00
<b>Pb</b>	0.99	0.99	2.50	0.15	<b>Pb</b>	0.21	0.15	0.31	0.10
<b>Zn</b>	0.45		0.45	0.45	<b>Zn</b>			0.00	0.00
<b>Cu</b>	3.16	1.62	5.49	0.99	<b>Cu</b>	4.60	3.96	12.30	1.56
<b>Co</b>	0.65	0.42	1.50	0.40	<b>Co</b>			0.00	0.00
<b>Cr</b>	1.00	0.49	2.00	0.70	<b>Cr</b>				
<b>High-tide coral samples—June</b>					<b>Low-tide coral samples—June</b>				
<b>CaCO<sub>3</sub></b>	96.76	1.39	98.35	94.96	<b>CaCO<sub>3</sub></b>	98.21	0.26	98.42	97.64
<b>MgCO<sub>3</sub></b>	3.24	1.39	5.04	1.65	<b>MgCO<sub>3</sub></b>	1.79	0.26	2.36	1.58
<b>Na</b>	8211.38	6782.26	23120.00	2780.00	<b>Na</b>	1306.63	308.84	1814.00	953.00
<b>Al</b>	1253.13	1409.63	4490.00	110.00	<b>Al</b>	177.75	32.04	222.00	124.00
<b>Si</b>	4460.00	1829.58	6730.00	1680.00	<b>Si</b>	2626.50	683.14	3749.00	1463.00
<b>K</b>	616.25	374.85	1380.00	182.00	<b>K</b>	203.38	59.99	336.00	145.00
<b>Fe</b>	566.25	172.89	830.00	348.00	<b>Fe</b>	365.50	44.12	413.00	283.00
<b>Sr</b>	6585.00	665.18	7644.00	5640.00	<b>Sr</b>	6404.50	187.78	6638.00	6021.00
<b>Pb</b>	1.58	0.54	2.01	0.98	<b>Pb</b>	0.10	0.09	0.20	0.04
<b>Zn</b>	1.65	1.04	2.51	0.50	<b>Zn</b>	0.45		0.45	0.45
<b>Cu</b>	0.89	0.22	1.00	0.49	<b>Cu</b>	1.10	0.21	1.53	0.86
<b>Co</b>	0.48	0.04	0.54	0.45	<b>Co</b>	0.01	0.01	0.02	0.01
<b>Cr</b>	0.97	0.06	1.06	0.90	<b>Cr</b>				

**Table 4. Major, trace and heavy elements concentrations in the coral debris from low-tide mark around Kubbar Island.**

No.	Sample No.	Mole%					Element ppm							
		Ca	Mg	Na	Al	Si	K	Fe	Sr	Pb	Zn	Cu	Co	Cr
1	KO2	98.729	1.271	912	122	1870	112	357	6765	BDL	BDL	2.620	BDL	BDL
2	KO4	98.274	1.726	1091	222	2197	145	276	6545	BDL	BDL	1.487	BDL	BDL
3	KO6	98.013	1.987	2504	246	2136	228	437	6317	BDL	BDL	1.566	BDL	BDL
4	KO8	98.464	1.536	1762	130	1505	183	332	6579	0.150	BDL	0.998	BDL	BDL
5	KO10	98.497	1.503	842	230	1650	245	367	6460	BDL	BDL	1.342	0.035	BDL
6	KO12	98.117	1.883	1458	188	2099	166	420	6427	BDL	BDL	2.046	BDL	BDL
7	KO14	98.639	1.361	1194	198	1566	166	287	6655	0.259	BDL	1.400	BDL	BDL
8	KO16	98.466	1.534	1699	243	1898	187	381	6706	0.309	BDL	1.543	BDL	BDL
9	KJ2	98.101	1.899	1450	222	3090	145	378	6427	BDL	BDL	1.529	0.020	BDL
10	KJ4	98.319	1.681	1261	201	3749	336	413	6021	0.050	BDL	1.040	BDL	BDL
11	KJ6	98.422	1.578	1651	180	2996	166	346	6393	BDL	BDL	0.983	BDL	BDL
12	KJ8	98.409	1.591	998	206	2431	187	402	6596	0.200	0.450	1.151	BDL	BDL
13	KJ10	98.119	1.881	1224	148	2510	237	371	6443	BDL	BDL	0.862	0.005	BDL
14	KJ12	98.332	1.668	1102	172	2646	170	402	6638	BDL	BDL	1.052	BDL	BDL
15	KJ14	97.644	2.356	1814	124	1463	199	329	6325	0.040	BDL	0.946	BDL	BDL
16	KJ16	98.358	1.642	953	169	2127	187	283	6393	BDL	BDL	1.220	BDL	BDL
17	KJA2	99.020	0.980	1013	177	1566	125	329	6215	BDL	BDL	2.305	BDL	BDL
18	KJA4	99.002	0.998	953	233	2365	191	360	6503	BDL	BDL	2.571	BDL	BDL
19	KJA6	98.845	1.155	1714	212	2108	224	423	6300	0.313	BDL	9.388	BDL	BDL
20	KJA8	98.834	1.166	994	191	2127	166	378	6342	0.101	BDL	3.339	BDL	BDL
21	KJA10	98.708	1.292	1421	169	2646	174	367	6553	BDL	BDL	1.557	BDL	BDL
22	KJA12	98.388	1.612	1168	251	2449	145	395	6596	BDL	BDL	12.297	BDL	BDL
23	KJA14	98.692	1.308	1091	185	2889	145	353	6503	BDL	BDL	2.756	BDL	BDL
24	KJA16	98.604	1.396	1076	201	1898	178	304	6410	BDL	BDL	2.608	BDL	BDL
	<b>Average</b>	98.458	1.542	1306	193	2249	184	362	6463	0.178	0.450	2.442	0.020	
	<b>St-dev</b>	0.327	0.327	391	37	565	47	45	167	0.110		2.710	0.015	
	<b>Maximum</b>	99.020	2.356	2504	251	3749	336	437	6765	0.313	0.450	12.297	0.035	
	<b>Minimum</b>	97.644	0.980	842	122	1463	112	276	6021	0.040	0.450	0.862	0.005	



**Figure 4. Distribution of calcium carbonate Mole% in corals collected from Kubbar Island.**

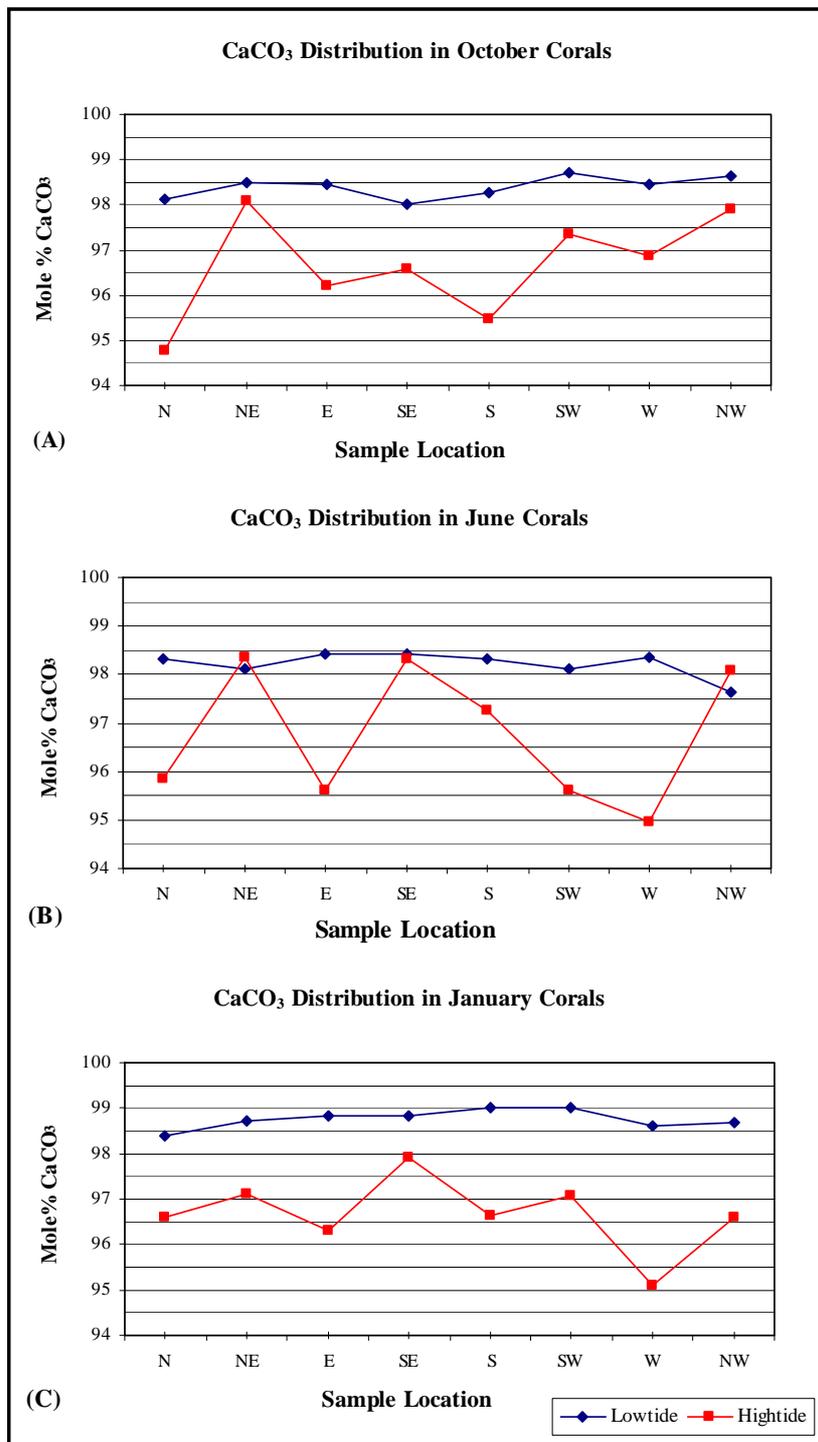
corals gathered from the NW direction during all the seasons (**Figure 6(A)**).

**Sodium** range in all low-tide coral samples from 842 - 2504 ppm with an average mean equals to  $1306 \pm 391$  (**Table 4**).

Corals samples gathered during October from low-tide mark include **Na** concentrations that range from 842 - 2504 ppm with an average mean value equals to  $1432.75 \pm 550.52$  ppm (**Table 3**). Coral samples gathered during June from low-tide mark include **Na** concentrations that range from 953 - 1814 ppm with an average mean value equals to  $1306.63 \pm 308.84$  ppm (**Table 3**). Coral samples gathered during January from low-tide mark include **Na** concentrations that range from 953 - 1714 ppm with an average mean value equals to  $1178.75 \pm 260.80$  ppm (**Table 3**). **Sodium** concentration in corals gathered during June and January share a sympathetic relationship at all locations (**Figure 7(A)**). Corals gathered during October show an antipathetic relationship to corals gathered during June and January, except for the South and the Southeast directions (**Figure 7(A)**).

**Aluminum** concentration in all coral samples gathered from high-tide mark range from 110 - 11970 ppm with an average mean equals to  $1840 \pm 2614$  (**Table 2**). Coral samples gathered during October from high tide mark include **Al** concentrations that range from 256 - 11970 ppm with an average mean value equals to  $3231 \pm 4091.23$  ppm (**Table 3**). Coral samples gathered during June from high tide mark include **Al** concentrations that range from 110 - 4490 ppm with an average mean value equals to  $1253.13 \pm 1409.63$  ppm (**Table 3**). Coral samples gathered during January from high tide mark include **Al** concentrations that range from 252 - 2120 ppm with an average mean value equals to  $1036 \pm 618.56$  ppm (**Table 3**). **Aluminum** concentration in corals gathered during October and June share a sympathetic relationship at all locations, except for the Western direction (**Figure 6(B)**). Corals gathered during January show an antipathetic relationship to corals gathered during October and June, except for the SE, S, SW, and NW directions (**Figure 6(B)**).

**Aluminum** range in all low-tide coral samples from



**Figure 5. Correlation between calcium carbonate Mole% concentrations in corals collected from Kubbar Island according to the different seasons.**

122 - 251 ppm with an average mean equals to  $193 \pm 37$  (Table 4). Coral samples gathered during October from low-tide mark include Al concentrations that range from 122 - 246 ppm with an average mean value equals to  $197.38 \pm 48.44$  ppm (Table 3). Coral samples gathered during June from low-tide mark include Al concentra-

tions that range from 124 - 222 ppm with an average mean value equals to  $177.75 \pm 32.04$  ppm (Table 3). Coral samples gathered during January from low-tide mark include Al concentrations that range from 169 - 251 ppm with an average mean value equals to  $202.38 \pm 28.25$  ppm (Table 3). Aluminum concentration in corals

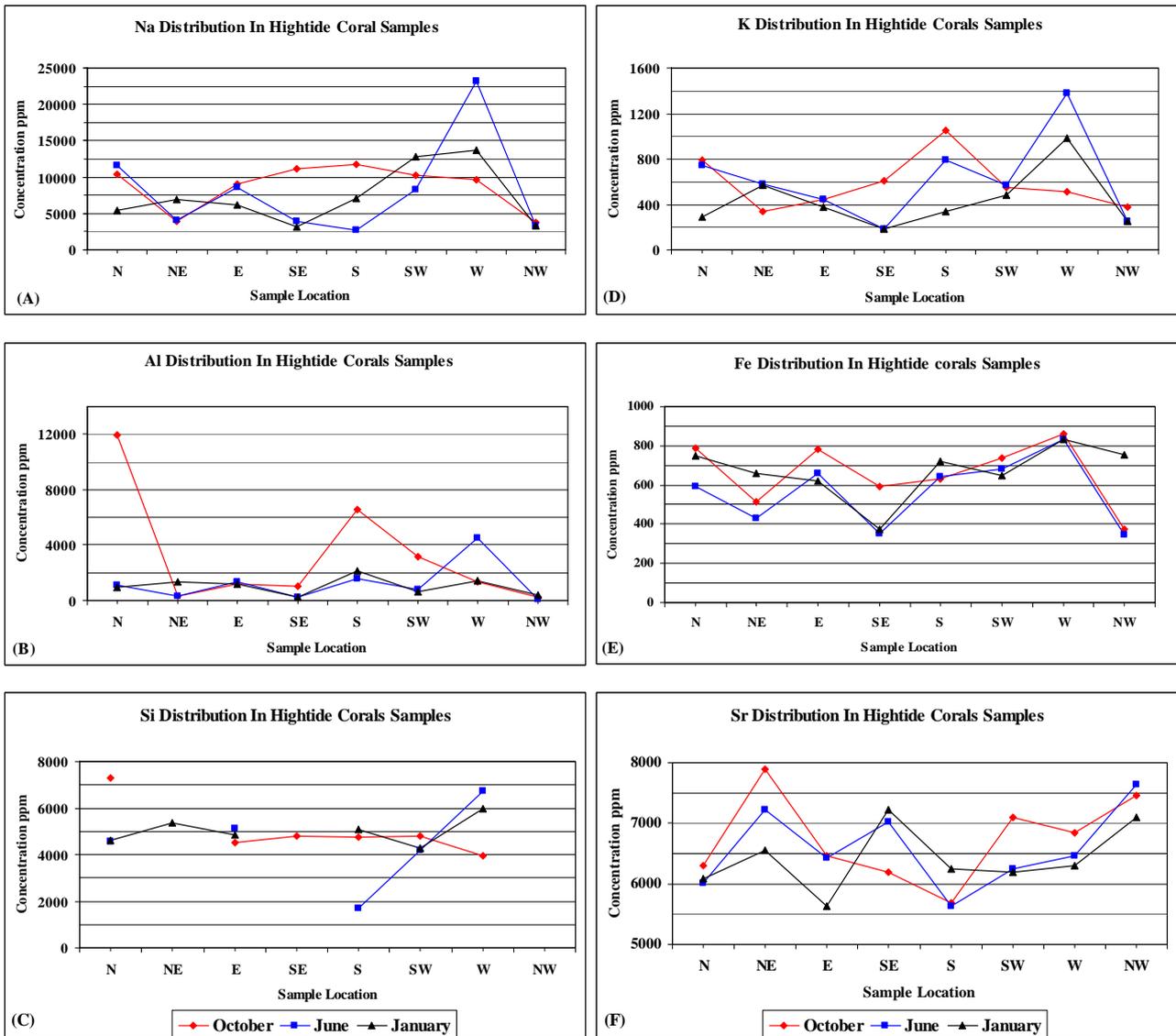


Figure 6. Trace elements distribution in coral gathered from high-tide mark from Kubbar Island—Kuwait.

gathered from low-tide mark during June and January share a sympathetic relationship at all locations, except the SE, SW, and W directions (Figure 7(B)). Corals gathered during October show an antipathetic relationship to corals gathered during June and January, except for the SE, SW and NW directions (Figure 7(B)).

**Silicon** concentration in all coral samples gathered from high-tide mark range from 1680 - 7290 ppm with an average mean equals to  $4855 \pm 1199$  (Table 2). Coral samples gathered during October from high-tide mark include **Si** concentrations that range from 3970 - 7290 ppm with an average mean value equals to  $5013.33 \pm 1158.44$  ppm (Table 3). Coral samples gathered during June from high-tide mark include **Si** concentrations that range from 1680 - 6730 ppm with an average mean value equals to  $4460 \pm 1829.58$  ppm (Table 3). Coral samples

gathered during January from high-tide mark include **Si** concentrations that range from 4280 - 5980 ppm with an average mean value equals to  $5026.67 \pm 601.92$  ppm (Table 3).

**Silicon** range in all low-tide coral samples from 1463 - 3749 ppm with an average mean equals to  $2249 \pm 565$  (Table 4). Coral samples gathered during October from low-tide mark include **Si** concentrations that range from 1505 - 2197 ppm with an average mean value equals to  $1865.13 \pm 268.53$  ppm (Table 3). Coral samples gathered during June from low-tide mark include **Si** concentrations that range from 1463 - 3749 ppm with an average mean value equals to  $2626.5 \pm 683.14$  ppm (Table 3). Coral samples gathered during January from low-tide mark include **Si** concentrations that range from 1566 - 2889 ppm with an average mean value equals to  $2256 \pm$

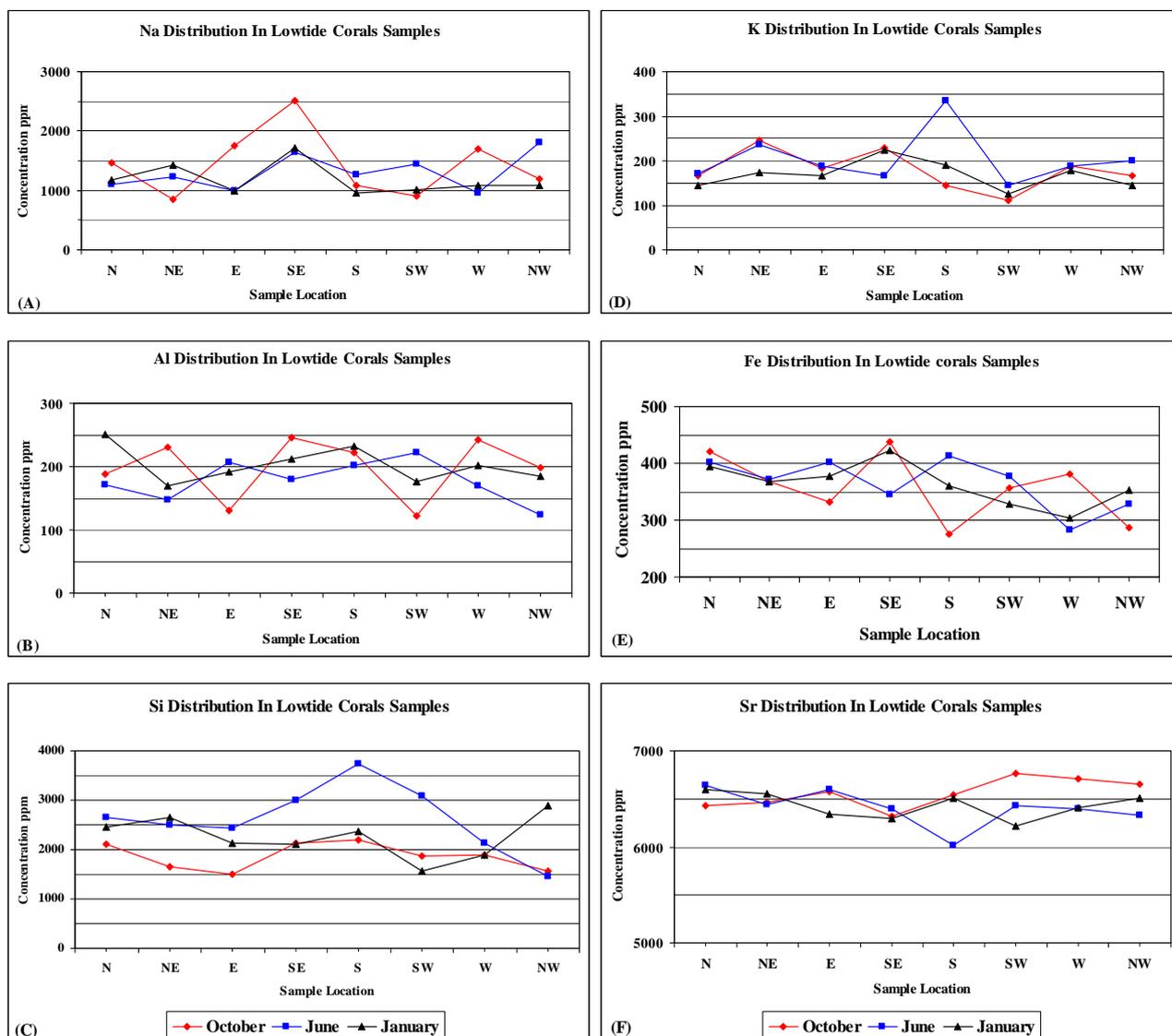


Figure 7. Trace elements distribution in coral gathered from low-tide mark from Kubbar Island—Kuwait.

421.69 ppm (Table 3). **Silicon** concentration in corals gathered during October and June share a sympathetic relationship at all locations, except for the western direction (Figure 7(C)). Corals gathered during January show a sympathetic relationship to corals gathered during October and June at all locations, except for the E, S and SW directions (Figure 7(C)).

**Potassium** concentration in all coral samples gathered from high-tide mark range from 182-1380 ppm with an average mean equals to  $544 \pm 293$  (Table 2). Coral samples gathered during October from high-tide mark include **K** concentrations that range from 336 - 1050 ppm with an average mean value equals to  $582.38 \pm 237.14$  ppm (Table 3). Coral samples gathered during June from high-tide mark include **K** concentrations that range from 182 - 1380 ppm with an average mean value equals to

$616.25 \pm 374.85$  ppm (Table 3). Coral samples gathered during January from high-tide mark include **K** concentrations that range from 186 - 980 ppm with an average mean value equals to  $252.58 \pm 434.5$  ppm (Table 3). **Potassium** concentration in corals gathered during the entire seasons share a sympathetic relationship at all locations, except for the N, NE and E directions (Figure 6 (D)).

**Potassium** range in all low-tide coral samples from 112-336 ppm with an average mean equals to  $184 \pm 47$  (Table 4). Coral samples gathered during October from low-tide mark include **K** concentrations that range from 112 - 245 ppm with an average mean value equals to  $179 \pm 42.80$  ppm (Table 3). Coral samples gathered during June from low-tide mark include **K** concentrations that range from 145 - 336 ppm with an average mean value

equals to  $203.38 \pm 59.99$  ppm (**Table 3**). Coral samples gathered during January from low-tide mark include **K** concentrations that range from 125 - 224 ppm with an average mean value equals to  $168.5 \pm 30.96$  ppm (**Table 3**). **Potassium** concentration in corals gathered during October and January share a sympathetic relationship at all locations (**Figure 7(D)**). Corals gathered during June share a sympathetic relationship to corals gathered during October and January, except for the SE, S and NW directions (**Figure 7(D)**).

**Iron** concentration in all coral samples gathered from high-tide mark range from 348 - 860 ppm with an average mean equals to  $632 \pm 159$  (**Table 2**). Coral samples gathered during October from high-tide mark include **Fe** concentrations that range from 375 - 860 ppm with an average mean value equals to  $660.13 \pm 162.77$  ppm (**Table 3**). Coral samples gathered during June from high-tide mark include **Fe** concentrations that range from 348 - 830 ppm with an average mean value equals to  $566.25 \pm 172.89$  ppm (**Table 3**). Coral samples gathered during January from high-tide mark include **Fe** concentrations that range from 374 - 830 ppm with an average mean value equals to  $669.75 \pm 137.41$  ppm (**Table 3**). **Iron** concentration in corals gathered during October and June share a sympathetic relationship at all locations (**Figure 6(E)**). Corals gathered during January share a sympathetic relationship to corals gathered during October and June, except for the East and the Southwest directions (**Figure 6(E)**).

**Iron** range in all low-tide coral samples from 276 - 437 ppm with an average mean equals to  $362 \pm 45$  (**Table 4**). Coral samples gathered during October from low-tide mark include **Fe** concentrations that range from 276 - 437 ppm with an average mean value equals to  $357.13 \pm 57.48$  ppm (**Table 3**). Coral samples gathered during June from low-tide mark include **Fe** concentrations that range from 283 - 413 ppm with an average mean value equals to  $365.5 \pm 44.12$  ppm (**Table 3**). Coral samples gathered during January from low-tide mark include **Fe** concentrations that range from 304 - 423 ppm with an average mean value equals to  $363.63 \pm 37.05$  ppm (**Table 3**). **Iron** concentration in corals gathered during June and January share a sympathetic relationship at all locations, except for the Southeast and the South directions (**Figure 7(E)**). Corals gathered during October show an antipathetic relationship to corals gathered during June, except for the North and the Northeast directions (**Figure 7(E)**).

**Strontium** concentration in all coral samples gathered from high-tide mark range from 5640 - 7898 ppm with an average mean equals to  $6582 \pm 631$  (**Table 2**). Coral samples gathered during October from high-tide mark include **Sr** concentrations that range from 5680 - 7898 ppm with an average mean value equals to  $6744.13 \pm$

$724.83$  ppm (**Table 3**). Coral samples gathered during June from high-tide mark include **Sr** concentrations that range from 5640 - 7644 ppm with an average mean value equals to  $6585 \pm 665.18$  ppm (**Table 3**). Coral samples gathered during January from high-tide mark include **Sr** concentrations that range from 5640 - 7219 ppm with an average mean value equals to  $6417.63 \pm 526.75$  ppm (**Table 3**). **Strontium** concentration in corals gathered during June and January share a sympathetic relationship at all locations, except for the Southwest direction (**Figure 6(F)**). Corals gathered during October share a sympathetic relationship to corals gathered during June and January, except for the Southeast and the West directions (**Figure 6(E)**).

**Strontium** range in all low-tide coral samples from 6021 - 6765 ppm with an average mean equals to  $6463 \pm 167$  (**Table 4**). Coral samples gathered during October from low-tide mark include **Sr** concentrations that range from 6317 - 6765 ppm with an average mean value equals to  $6556.75 \pm 151$  ppm (**Table 3**). Coral samples gathered during June from low-tide mark include **Sr** concentrations that range from 6021 - 6638 ppm with an average mean value equals to  $6404.5 \pm 187.78$  ppm (**Table 3**). Coral samples gathered during January from low-tide mark include **Sr** concentrations that range from 6215 - 6596 ppm with an average mean value equals to  $6427.75 \pm 133.4$  ppm (**Table 3**). **Strontium** concentration in corals gathered during October and June share a sympathetic relationship at all locations, except for the North, Northeast and South directions (**Figure 7(F)**). Corals gathered during January share an antipathetic relationship to corals gathered during October and June, except for the N, NE, SE, and S directions (**Figure 7(E)**).

### 5.3. Heavy Metals Concentrations

**Lead** concentration in all coral samples gathered from high-tide mark range from 0.100 - 2.495 ppm with an average mean equals to  $1.158 \pm 0.813$  (**Table 2**). All the coral samples which were gathered during October from high-tide mark include **Pb** concentrations that are below the detection limit, except for two: SE = 0.10 ppm and SW = 0.95 ppm. Coral samples gathered during June from high-tide mark include **Pb** concentrations that range from 0.98 - 2.01 ppm with an average mean value equals to  $1.58 \pm 0.54$  ppm (**Table 3**). Coral samples gathered during January from high-tide mark include **Pb** concentrations that range from 0.15 - 2.5 ppm with an average mean value equals to  $0.99 \pm 0.99$  ppm (**Table 3**).

**Lead** concentrations range in all low-tide coral samples from 0.040 - 0.313 ppm with an average mean equals to  $0.178 \pm 0.110$  (**Table 4**). Coral samples gathered during October from low-tide mark include **Pb** concentrations that range from 0.15 - 0.31 ppm with an

average mean value equals to  $0.24 \pm 0.08$  ppm (**Table 3**). Coral samples gathered during June from low-tide mark include **Pb** concentrations that range from 0.04 - 0.2 ppm with an average mean value equals to  $0.1 \pm 0.09$  ppm (**Table 3**). Coral samples gathered during January from low-tide mark include **Pb** concentrations that range from 0.1 - 0.31 ppm with an average mean value equals to  $0.21 \pm 0.15$  ppm (**Table 3**).

**Zinc** concentration in all coral samples gathered from high-tide mark range from 0.449 - 2.510 ppm with an average mean equals to  $1.347 \pm 1.037$  (**Table 2**). All the coral samples which were gathered during October from high-tide mark include **Zn** concentrations that are below the detection limit. Coral samples gathered during June from high-tide mark include **Zn** concentrations that range from 0.50 - 2.51 ppm with an average mean value equals to  $1.65 \pm 1.04$  ppm (**Table 3**). All the coral samples which were gathered during January from high-tide mark include **Zn** concentrations that are below the detection limit, except for one: NE = 0.449 ppm (**Table 2**).

All the low-tide corals have **Zinc** concentrations below the detection limit except for one which was gathered during June from the East direction and it is equal to 0.450 ppm (**Table 4**).

**Copper** concentration in all coral samples gathered from high-tide mark range from 0.49 - 5.489 ppm with an average mean equals to  $1.789 \pm 1.428$  ppm (**Table 2**). Coral samples gathered during October from high-tide mark include **Cu** concentrations that range from 0.5 - 2.22 ppm with an average mean value equals to  $1.17 \pm 0.58$  ppm (**Table 3**). Coral samples gathered during June from high-tide mark include **Cu** concentrations that range from 0.49 - 1.00 ppm with an average mean value equals to  $0.89 \pm 0.22$  ppm (**Table 3**). Coral samples gathered during January from high-tide mark include **Cu** concentrations that range from 0.99 - 5.49 ppm with an average mean value equals to  $3.16 \pm 1.62$  ppm (**Table 3**).

**Copper** range in all low-tide coral samples from 0.862 - 12.297 ppm with an average mean equals to  $2.442 \pm 2.71$  ppm (**Table 4**). Coral samples gathered during October from low-tide mark include **Cu** concentrations that range from 1.00 - 2.62 ppm with an average mean value equals to  $1.63 \pm 0.5$  ppm (**Table 3**). Coral samples gathered during June from low-tide mark include **Cu** concentrations that range from 0.86 - 1.53 ppm with an average mean value equals to  $1.10 \pm 0.21$  ppm (**Table 3**). Coral samples gathered during January from low-tide mark include **Cu** concentrations that range from 1.56 - 12.3 ppm with an average mean value equals to  $4.6 \pm 3.96$  ppm (**Table 3**).

**Cobalt** concentration in all coral samples gathered from high-tide mark range from 0.378 - 1.497 ppm with an average mean equals to  $0.546 \pm 0.251$  ppm (**Table 2**). Coral samples gathered during October from high-tide

mark include **Co** concentrations that range from 0.38 - 0.55 ppm with an average mean value equals to  $0.50 \pm 0.06$  ppm (**Table 3**). Coral samples gathered during June from high-tide mark include **Co** concentrations that range from 0.45 - 0.54 ppm with an average mean value equals to  $0.48 \pm 0.04$  ppm (**Table 3**). Coral samples gathered during January from high-tide mark include **Co** concentrations that range from 0.40 - 1.50 ppm with an average mean value equals to  $0.42 \pm 0.65$  ppm (**Table 3**).

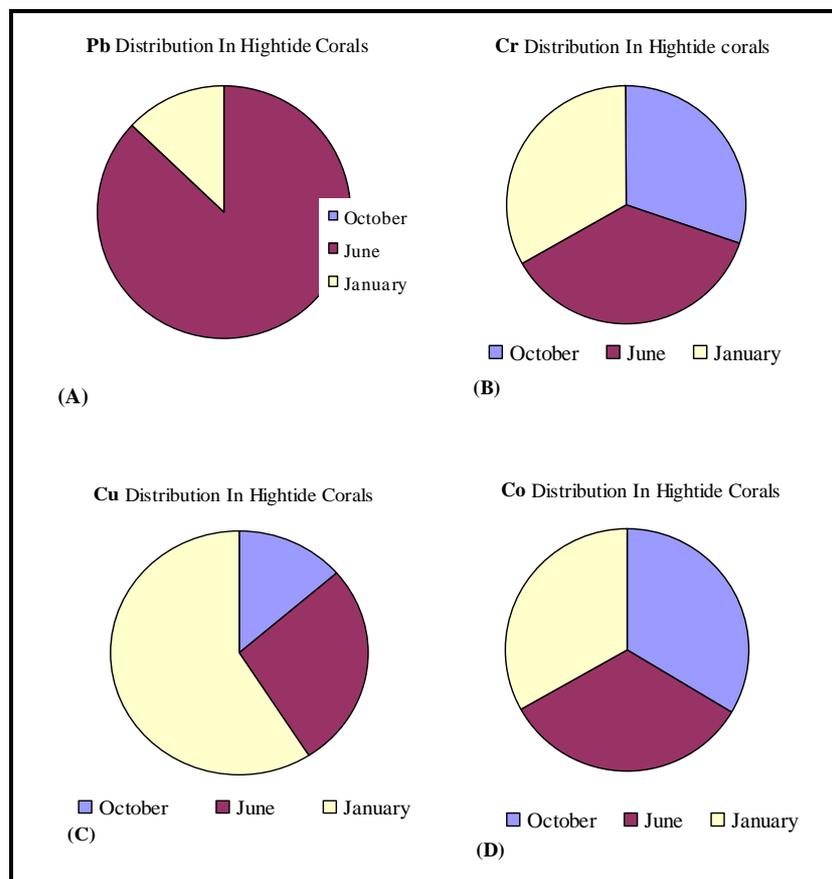
**Cobalt** range in all low-tide coral samples from 0.005 - 0.035 ppm with an average mean equals to  $0.02 \pm 0.015$  ppm (**Table 4**). All the coral samples which were gathered during October from low-tide mark include **cobalt** concentrations that are below the detection limit, except for one: NE = 0.035 ppm. Coral samples gathered during June from low-tide mark include **Co** concentrations that range from 0.01 - 0.02 ppm with an average mean value equals to  $0.01 \pm 0.01$  ppm (**Table 3**). All the coral samples which were gathered during January from low-tide mark include **cobalt** concentrations that are below the detection limit.

**Chromium** concentration in all coral samples gathered from high-tide mark range from 0.662 - 1.996 ppm with an average mean equals to  $0.907 \pm 0.303$  (**Table 2**). Coral samples gathered during October from high-tide mark include **Cr** concentrations that range from 0.66 - 0.85 ppm with an average mean value equals to  $0.76 \pm 0.07$  ppm (**Table 3**). Coral samples gathered during June from high-tide mark include **Cr** concentrations that range from 0.90 - 1.06 ppm with an average mean value equals to  $0.97 \pm 0.06$  ppm (**Table 3**). Coral samples gathered during January from high-tide mark include **Cr** concentrations that range from 0.70 - 2.00 ppm with an average mean value equals to  $1.00 \pm 0.49$  ppm (**Table 3**). All the low-tide corals which were gathered during all the seasons have **chromium** concentrations below the detection limit (**Table 4**).

**Figure 8**, pie charts for all heavy metals in high-tide coral debris which show contamination patterns according to the seasons. **Figure 8(B) and (D)** indicate that **Cr** and **Co** share the same relationship throughout the seasons with nearly equal number of contaminated coral samples. **Figure 8**, also shows that coral samples collected in January are the most contaminated by **Cu** and least contaminated by **Pb**, but **Pb** is the major contaminant in sediments gathered in June.

## 6. Discussion and Conclusions

Intertidal sediments in an arid to semi-arid environments are characterized basically by the following features: algal mats; crypt-algal laminates of irregular or even laminations initially bond by algae; birdseye or fenestral porosity; and desiccation features. Ref. [9] indicated



**Figure 8. Heavy metals distribution in coral fragments gathered from high-tide mark—Kubbar Island.**

that on the arid Trucial Coast-Arabian Gulf coarse lags of coral and shell debris are thickly encrusted with algae and bryozoans and infested by algal/faunal borers. Normally the beaches along the Arabian Gulf coasts are exposed to the strong north-westerly winds and the 2 m spring tides are composed of coarse sand with Aeolian quartz, ooids, shell debris, and intraclasts.

Modern coral reefs are rigid wave resistant structures produced and partially bound by organisms. The main biological and morphological zones of a reef complex have gradational boundaries and comprise the following zones: a) fore-reef (open deep-water side); b) reef-front (sloping reef in front of the deep-water side); c) reef-crest (highest-elevation point in the reef); reef-flat and back-reef (the area include the top of the coral colony and trapped lagoon-landward side). The main reef builders at the present time are corals and coralline algae, including others of limited importance such as; sponges, serpulids, oysters and vermetide gastropods [15]. Sponges provide framework for reefs and mounds, and that sclerosponges are the dominant reef-forming organism in some modern Caribbean reefs. Borers, such as worms, sponges, and bivalves produce high amount of mud, while predatory fish produce sand and silt size particles that filters into

the interstices of coral frame. Generally, the reef frames are organically bound, but pervasive early cements bind modern reefs. Specific types of ecological reefs include: 1) Patch reef which is small and circular in shape, 2) Pinnacle reef which is conical, 3) Barrier reef which is attached to a coast, and 4) Atoll which are enclosing a lagoon [15].

The main ecological requirements for the coral growth are: 1) Shallow water that are up to 80 m deep, but generally most growth takes place within 10 m of the surface; 2) warm waters (18°C - 36°C), optimum growth is around 25°C; 3) normal salinities (27‰ - 40‰); 4) strong sunlight; 5) abundant nutrients; 6) stable substrate for attachment; 7) intense wave action; and 8) low turbidity [9,15,16].

In the case of Kubbar Island it is surrounded by well developed coral reef. Therefore, the intertidal zone is considered part of back-reef zone that fringes the island. The petrographic study of the intertidal sediments revealed that all sediment samples have the same composition, which includes mainly of coral debris and coralline algae fragments of various sizes, molluscs specially bivalves and gastropods, and echinoderm spines and plates. The intertidal sediments also include in low amounts and

variations the following bioclasts: foraminifera, bryozoans, ostracodes, sponge spicules, annelids worm tubes, radiolarians, and coccoliths. Other clastic-non bioclastic components that exist in the sediments are oolitic grains and pellets as well as intraclasts. Therefore the carbonate constituents prevailed, indicated a back-reef depositional environment.

The petrographic study of all the sediment samples indicated that samples collected during June and January have more diverse types of coral debris than sediment samples collected during October. This may be the affect of wind speed, wave action and water temperature on the coral reefs. Adding to this the affect of coral grazers; echinoderms and predatory fish, this will cause the breakdown of the corals, hence the accumulation of various diverse types of coral debris on the beaches after October. All these factors will result in the brake down and accumulation of diverse types of corals debris first by killing the coral polyps by low temperatures, and grazing by fish, echinoderms, algae and indolithic bacteria, then brake down by wave action of the fragile reefs. It should be mentioned that, high numbers of echinoderms has been seen living in the intertidal zones during October and June field trips. These echinoderms graze on the coral polyps, which tend to leave the coral reefs bare.

The petrographic description of samples gathered during the various seasons indicated that although all the sediment samples share the same composition, especially type of major and minor bioclasts, different sedimentological processes affect them. It is noted that cementation by cubic halite, aragonite and high-Mg calcite crystals prevailed during October and June, as well as to, the precipitation of free crystals of halite, high-Mg calcite and aragonite during these seasons.

The second major variation is that the accumulation of yellow, yellowish-brown and yellowish-orange precipitate on some grains which is composed of micritic crystals of calcite, gypsum, and halite. It is noted that this precipitate is absent from sediments collected during October and June from Kubbar Island.

The third important processes are micritization and burrowing of bioclasts. Normally these processes are performed on the seabed by indolithic bacteria or algae, which tend to graze on the calcium carbonate that these bioclasts are composed of. It is very important to indicate that, micritization and burrowing of bioclasts is more significant in sediment samples gathered during January. This may be due to the relative decrease in wind speed before January, hence low wave action and calming of the sea, and due to the moderate water temperature that boosts the growth and flourishing of algae.

The geochemical investigations on corals gathered from the high-tide mark of Kubbar Island show magnesium enrichment at the N, E, S, and W during all the

seasons, however, all the low-tide coral samples are Ca-rich at all locations and seasons. The maximum Mg concentrations are found at the Northern side during October and at the Western side during June and January, Which is due to higher agitation rates because of the prevailing north-westerly "Shamal" wind prior to October (July-September), and south-easterly winds prior to January (November and December) and June (April-May). The maximum Ca concentration is found at the NE direction during October and June, SE direction during June and January, and NW direction during October and June. It is important to mention that the SE and NW direction are the main locations affected by high wave action during all the seasons due to the effect of the prevailing wind directions throughout the year.

The geochemical work on Kubbar corals gathered from high-tide mark regarding trace elements show an antipathetic relationship between Ca concentration and Al, Fe, and K at all locations and all the seasons. Whereas, a sympathetic relationship is clear between Ca and Sr concentration in these corals, which indicate that when coral composition shift from Aragonite to high-Mg calcite it will be depleted in Sr. It is also concluded that when the corals are composed of Mg-calcite they are enriched in Al, Fe, and K, and when the composition is of Aragonite corals will be depleted in these elements.

As for the geochemical work on heavy metals, Kubbar Island corals which were gathered from the high-tide mark show a type of heavy metal contamination by the following elements: Pb, Cu, Co, and Cr during all the seasons. **Table 5** shows a comparison between heavy metal concentrations of Pb, Cu, Co, and Cr in corals from Kubbar Island with other parts of the world, and **Table 6** show comparison between heavy metal concentration in sediments from the Arabian Gulf. It is clear that corals from Kubbar Island are the least contaminated in respect to Pb, Cu, Co, and Cr in comparison to the other data. But we can not exclude that these corals show a type of contamination which is related to weather and human influence around the island at some locations. Zn contamination is encountered only in four coral samples which were gathered during June 3 and January 1. It is also concluded that the Northeast direction show the highest contamination levels of all heavy metals during January because it represent the calmest direction of wave action. Moreover, June and October coral samples show the highest contamination levels in heavy metals within corals gathered from the South and West and Southwest were wave action also is reduced. Whereas, the highest contaminant during all the seasons in corals gathered from low-tide mark copper and the second is lead. There is no contamination by chrome in corals gathered from low-tide mark.

**Table 5. Comparison of the concentration of Cu, Pb, Cd, Zn, and Cr in Coral fragments from Kubber Island and other areas of the World (ppm) [17-22].**

Trace Metals	Cu	Pb	Cd	Zn	Ni	Cr
South African Coast	298.7 - 1499.7		33.72 - 157.37		10.2 - 66.4	
	29750.96628	4282.824	290.0178	27779.96		
Sea of Japan	299.93712		110.1618		17.03	
China Sea	400.34 - 2300		44.96 - 123.65		11.9 - 85.2	
Gulf of Thailand	95.32 - 571.91	6.216 - 207.2	1.12 - 19.11		0.5 - 9.0	
Gulf of Thailand and East Coast of Peninsular Malaysia	184.28 - 1303	10.36 - 180.26	0.11 - 11.24		1.7 - 8.5	
Off Sabah, Sarawak and Brunei Darussalam	2.9 - 20.5	4.14 - 310.8	1.12 - 154		1.3 - 14.1	
Ocean	3001.91304	3002.328	100.045	9997	8.82	49.92
Pacific Ocean	149.96856	99.456	14.61	649.8772	21.5	
Atlantic Ocean		841.232	30.351	7917.52		
Baltic Sea	7104.4428	799.792	290.02	8197.34		
South China Sea	502.01 - 6355	497.28 - 5387	494.6 - 3372	497 - 42497		
Vietnamese Waters	4173.06582	2080.288	180.98	9324.49	2.69	1001.44
High-tide Coral Debris—Kubbar	0.490 - 5.489	0.100 - 2.495		0.449 - 2.51		0.662 - 1.996
Low-tide coral debris—Kubbar	0.862 - 12.297	0.040 - 0.313		0.450 - 0.450		BLD

**Table 6. Mean and range values of trace metal concentrations ( $\mu\text{g/g} = \text{ppm}$ ) in unpolluted marine sediments of different areas in the Arabian Gulf [23-29].**

Trace Metals	Cu	Pb	Cd	Zn	Ni	Cr
Kuwait [23]	15 - 30	20 - 30	0.5 - 2	30 - 80	300 - 600	
Kuwait [24]	27.5	4.7	0.21	60	115.9	
Kuwait [25]	34 - 50	-	-	91 - 127	150 - 209	
Northern Kuwait Bay [26]	24 - 33	-	-	25 - 123	75 - 139	72 - 121
Khor Al-Subiya Bubiyan—Kuwait [26]	10 - 33	-	-	13 - 88	15 - 130	25 - 116
Offshore Sediments—Kuwait [26]	11 - 27	-	-	18 - 67	25 - 109	17 - 105
Kuwait Coastal Area [27]	8 - 72	17 - 48	-	12 - 123	15 - 139	17 - 121
Sulaibikhat Bay—Kuwait [28]	17.7 - 37.7	1.9 - 7.96	-	48.4 - 112.98	2.1 - 23.5	30.5 - 69.9
Arabian Gulf [29]	0.2 - 18	0.2 - 64	0.4 - 1.0	0.7 - 40	2.3 - 89	-
Corals-Arabian Gulf [29]	0.70 - 3.6	3.6	Not Detected	0.70 - 8.00	5.5 - 9.9	-

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