Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.23316

143 (2019) 102–110
March

Distribution of salinity and trace elements in surface seawater of the Arabian Gulf surrounding the State of Qatar

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Received 15 March 2018; Accepted 18 October 2018

ABSTRACT

This study reports a preliminary survey of salinity variations and trace element concentrations in seawater collected from the coastal areas of Qatar. The concentrations of trace elements in seawater were determined by inductively coupled plasma atomic emission spectroscopy. The concentrations of trace elements were less than 5 ppb for As, Cd, V, Ag, Cr, Mn, Co, Ni, Be, Cu, Tl, and Sn; less than 15 ppb for Pb, Zn, Fe, and Se; less than 50 ppb for Sb, Al, and Ba; and less than 15 ppm for Si, Sr, and B. The average salinities of eastern and western coasts were 42 and 51 ppt, respectively. This salinity variation across the coastal regions is due to the marginal enclosed nature of the sea and brine discharge from desalination plants of the Gulf region. Among analyzed elements, Al, Ba, Fe, Zn, Sb, and Pb were significantly higher at some specific locations than their general average concentrations in the region. These site-specific variations in trace element concentrations may be related to anthropogenic inputs from industrial activities. Strong correlations were obtained for Al–Fe, Sb–Pb, and Sr–B combinations confirming their coexistence from common pollution sources. The trace element average concentrations in Qatari seawater are within the national and environmental protection agency seawater quality standards, they and exhibited similar concentrations to that of Red Sea. Outcomes of this study can be applied to mitigate pollution, improve water management efficiencies and assist sustainable operations of desalination plants.

Keywords: Seawater quality; Arabian Gulf; Anthropogenic activities; Salinity; Trace elements; Correlation coefficient

1. Introduction

Water is the new oil of the 21st century due to its increased consumption and demand. The amount of available water resources is decreasing due to (i) an increase in the population, (ii) strict health regulations, and (iii) competing demands from a variety of users, for example, agricultural, industrial, and urban development [1]. This huge water demand is not only attributed to the increase in the world population (and the corresponding increase in the per capita water consumption), but also to global warming (which results in climatic changes, desertification, and gas emissions). The desalination of seawater and brackish water is currently used to augment the supply of freshwater [2]. Both potable and non-potable water are supplied through desalination of seawater. Seawater quality is the key parameter for building up any new desalination plants.

There is a growing evidence of enormous anthropogenic disruption of seawater quality over the past few decades.

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Sustainability indicators for seawater quality include eutrophication, fishing pressure, regional developments, discharges of trace elements (TEs), wastewaters, and oil pollution. Among these, pollution of TEs is the potential threat to the environment through bioaccumulation and to seawater reverse osmosis (SWRO)-based desalination plants. Previous studies have reported the impact of TEs on fish, shrimp, oyster, bivalve species, phytoplankton, zooplankton, and water birds in coastal areas [1–16]. Importantly, higher levels of bioaccumulation of tin, cadmium, copper, mercury, and chromium were reported for some specific marine species [1,5,10,15].

While the population of the Gulf countries constitutes about 6% of the world's population, their total available freshwater resources account for less than 1% of world available freshwater [17]. The line of water poverty as reported by WHO is estimated at 1,000 m^3 per capita per year [18]; however, the average annual capacity of renewable freshwater is reported at 453 per year per capita [19]. Except for some parts in Saudi Arabia, UAE, and Oman, the bulk of the Gulf Cooperation Council countries are arid areas with no surface freshwater resources and scarce rainfall throughout the year. The situation in Qatar is even worse. Qatar is one of the world's lowest rainfall areas throughout the year (the average rainfall is about 80 mm per year), with an estimated evaporation rate of about 2,000 mm [20]. This high evaporation rate exerts higher pressure on the natural freshwater resources in Qatar and limits the socioeconomic development in the country. Not only the freshwater resources in Qatar are limited but also the consumption is very high. According to Qatar general electricity and water company (Kahramaa), the average consumption rate of water in Qatar was estimated at 595 L/d per capita in 2014 [21]. Furthermore, about 437 million cubic meters (MCM) of freshwater was produced from Qatari thermal desalination plants in 2012. In 2008, the annual production of freshwater was estimated at 312 MCM. This indicates an increase in the consumption rate of about 40% in 4 years. Moreover, during the same period, the numbers of customers have jumped from 167,540 in 2008 to 241,204 in 2014 with an annual growth rate of about 9.3% [22]. This means that the current freshwater consumption can be doubled in about 7–8 years, which is one of the world's highest growth rates. Not only the current consumption of water is high but also the prospective consumption is expected to keep increasing as a result of the boom in the economic and industrial sectors in Qatar. According to the Qatar National Development Strategy (QNDS) 2030, the demand on freshwater in Qatar is expected to keep growing until it exceeds the supply, and the current desalination plants will not be able to supply freshwater to fill the gap. The forecasted demand on freshwater production from 2009 to 2030 is shown in Fig. 1. As depicted, in 2020, there will be a water deficiency of about 40 MCM. As explained in the QNDS 2030, the main reason behind the gap between supply and demand at 2020 is the decommissioning of Ras Abu Fontas plant which is anticipated to reach the end of its technical life in 2020. Beyond 2020, the supply will remain unchanged whereas the demand will keep increasing, until it reaches a deficiency level of about 70 MCM (which is about 15% of the water production) in 2030 [23].

To meet the growing demand for freshwater in Qatar, there is a need to build up new desalination plants, where the seawater quality in Qatar is the major factor for new plants.

The purpose of this study is to understand the anthropogenic influence of the coastal activities on the physicochemical parameters of the near-shore waters.

2. Materials and methods

2.1. Sampling

Qatar is located on the north-eastern coast of the Arabian Peninsula. It has sole land border with Saudi Arabia to the south, while the rest of its territory is surrounded by the Arabian Gulf. The territory includes the mainland and a number of small islands. Coasts have always been the preferred areas for development around the world, and Qatar is no exception. The major cities of the State of Qatar are in close proximity to the coast. In recent times, there has been an increased structural/engineering development along the coastline leading to permanent changes in the shore-line configuration. These changes are more dominant along the east coast compared with the west coast of Qatar.

Keeping in view the settlements and densely populated areas, industrial and coastal engineering structures and fishing harbors along the coast and the sampling sites, as shown

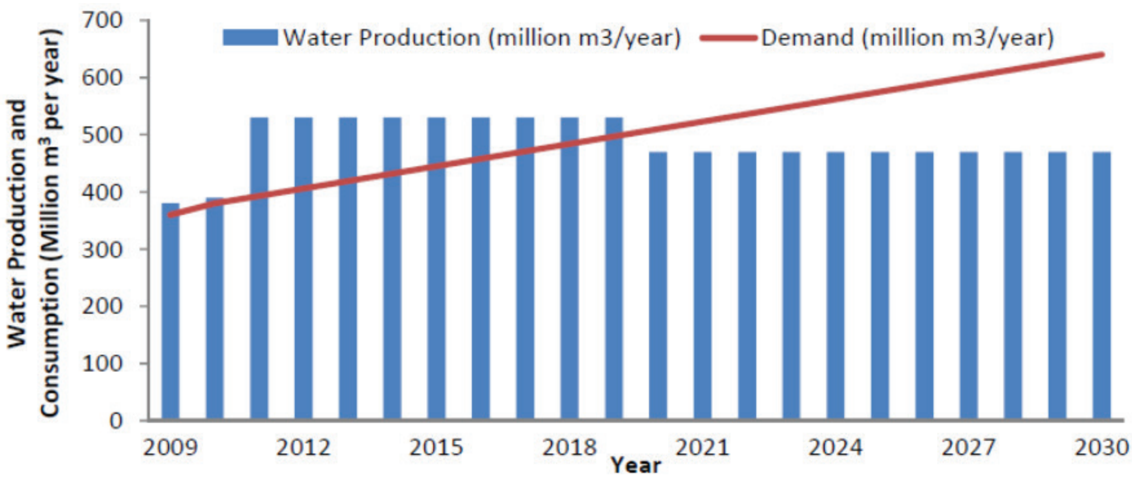


Fig. 1. Water production and demand in Qatar between 2009 and 2030 [17].

in Fig. 2, were selected within 2 km offshore from the shoreline along the coast. The detailed description of sample site coordinates and their associated anthropogenic activities are given in the following data.

2.2. Characterization

Surface seawater samples were collected manually in a pre-cleaned polyethylene and amber glass bottles from various locations as indicated in Fig. 2. Sample collections were performed in the front of the bow of boats, against the wind. Part of samples was acidified immediately after collection.

Trace metal analysis was performed using Thermo Fisher iCAP 6500 Duo (Thermo Electron Manufacturing Ltd., UK)—inductively coupled plasma atomic emission spectrometer instrument. Anions and cations in seawater were analyzed by Ion Chromatograph Dionex IC-5000+. Salinity of water samples was measured by electrical conductivity and gravimetric methods. Analysis was carried out in triplicates.

3. Results and discussion

3.1. Salinity distribution

The salinity distribution along the Qatar's coast is shown in Fig. 2 with values ranging between 39 and 58 ppt. Dissolved oxygen ranged from 4.5 to 7.5 mg/L in all samples were analyzed with an average of 6.2 mg/L The detailed list of salinity data is provided in Table 1. For the east coast region, lower salinity values of 39–43 ppt were observed in the sampling sites 1–7. For the sampling sites 15–17, salinity values extended from 44 to 45 ppt. For the west coast region, much higher values of 46–58 ppt were observed in the sampling sites 10–14 and 18–19.

The coastal water of Qatar is a shallow marginal semi-enclosed coast in the Arabian Gulf with a surrounding depth of ca. 20 m [18]. Due to the prevailing hot and arid conditions of its bordering lands, the salinity levels of the Arabian Gulf, in general, are higher than the Arabian Sea. Additionally, brine produced from desalination plants with a concentration of around 2.5 times of the seawater salinity is disposed of into the Arabian Gulf. Desalination plants in the west coast of Gulf dispose more than 3.4 MCM/d of the brine waste stream. Due to the marginal enclosed nature of the west coast and intense desalination activities in the region, salinity levels have reached a maximum of 58.2 ppt. In the east coast, the salinity levels are much lower compared with the west. Sample points 15–17 exhibited higher salinity values compared with other sites of the east coast. This slight increase in salinity values of southeast coastal region can be attributed to discharge of the brine waste stream from the major desalination plants of Qatar. The occurrence of hypersaline conditions along the coastal area would pose a negative impact on the marine species of the region and to SWRO desalination plant operations.

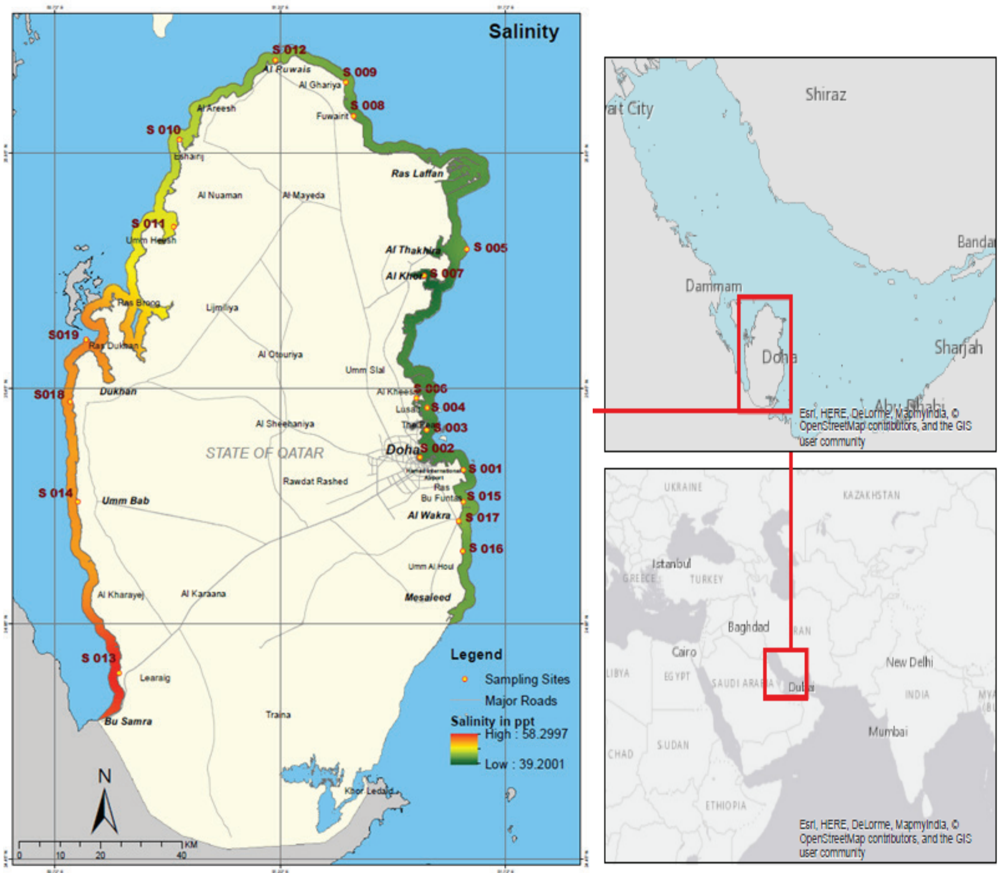


Fig. 2. Location map with sampling sites and salinity profile.

3.2. Distribution of TEs

Fig. 3 and Table 2 show the concentrations of TEs for all sampling sites. Concentrations of arsenic, cadmium, vanadium, silver, chromium, manganese, cobalt, nickel, beryllium, copper, tellurium, and tin varied from 0.1 to 5 ppb. TEs including lead, zinc, iron, and selenium exhibited concentrations ranging between 1.4 and 15 ppb. Concentrations of antimony varied between 0.1 and 28 ppb, and barium between 9 and 31 ppb. Aluminum concentrations varied between 0.1 and 50 ppb. For sample site 7, aluminum concentration in seawater was as high as 50 ppb. The average values of boron and strontium ranged between 6 and 11 ppm, respectively (Fig. 4). TEs with concentrations less than 5 ppb were within the environmental protection agency (EPA) and Qatari standard limits. Following discussion will focus on TEs with concentrations more than 5 ppb. A consolidated list of TEs pollution levels are given in Table 3.

Table 1
Seawater quality data

Sample	pH	Salinity, ppm	*T*, °C	Turbidity, NTU	TOC, ppm	Cl^-, ppm	SO_4^{2-}, ppm	Na^+, ppm	K^+, ppm	Mg^{2+}, ppm	Ca^{2+}, ppm
S 001	8.2	42,212.3	22	0.23	0.92	23,280.5	3,371.2	13,573.8	45.5	1,683.4	257.7
S 002	8.1	41,487.8	22	0.67	0.48	22,914.3	3,368.1	13,223.0	40.5	1,676.6	265.1
S 003	8.0	41,568.3	22	0.43	1.41	22,731.4	3,308.4	13,397.0	51.0	1,573.7	506.2
S 004	8.0	42,329.6	22	0.23	0.46	23,152.8	3,628.8	13,538.9	45.0	1,696.2	267.7
S 005	8.2	43,086.4	22	0.26	1.56	23,533.8	3,369.3	13,910.8	90.8	1,661.6	519.7
S 006	8.3	41,653.8	21	0.32	2.04	22,527.4	3,281.7	13,837.1	51.4	1,699.9	256.2
S 007	8.2	39,169.0	21	0.53	1.72	21,406.7	2,947.1	12,920.4	24.7	1,617.0	252.7
S 008	8.3	42,669.8	19	0.22	1.33	23,668.4	3,083.01	13,843.5	58.8	1,754.3	261.7
S 009	8.3	43,719.2	19	0.29	0.52	24,113.2	3,482.1	14,040.5	65.7	1,754.7	262.9
S 010	8.0	46,538.1	19	0.36	1.9	25,641.3	3,792.7	14,857.0	98.4	1,867.7	280.6
S 011	8.3	48,085.0	20	0.28	0.38	26,023.6	3,822.3	15,806.8	134.3	1,994.6	303.2
S 012	8.2	44,606.5	19	0.24	1.43	24,515.7	3,601.9	14,354.0	74.3	1,788.9	271.3
S 013	8.2	58,325.3	20	0.19	2.16	31,940.2	4,605.5	18,810.4	236.4	2,358.1	374.5
S 014	8.1	53,722.1	21	0.19	3.0	29,456.3	4,236.2	17,342.9	180.3	2,174.3	331.8
S 015	8.1	43,668.8	19	0.29	1.11	24,158.5	3,580.1	13,850.6	70.9	1,742.2	266.1
S 016	8.3	43,300.5	19	0.18	2.03	23,970.8	3,437.8	13,822.6	65.4	1,737.4	266.1
S 017	8.2	44,749.1	20	0.15	1.75	24,265.0	3,607.6	14,719.3	74.3	1,804.9	277.6
S018	8.1	53,776.5	18	0.21	2.52	29,477.2	4,344.2	17,237.2	186.3	2,195.7	335.6
S019	8.0	54,486.6	18	0.21	2.49	30,044.8	4,296.3	17,396.1	190.7	2,216.2	342.3

TOC — Total organic carbon.

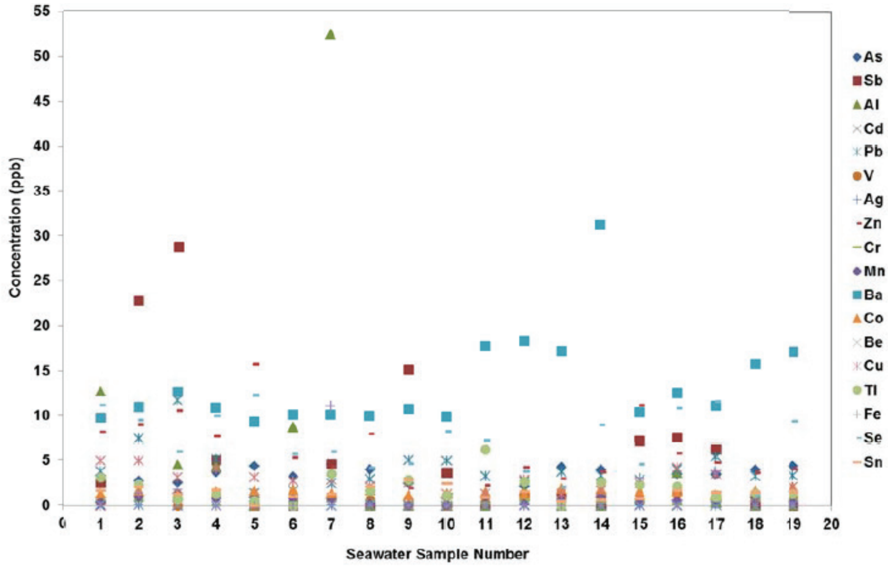


Fig. 3. Trace element concentrations of seawater in samples 1–19.

Table 2
Trace element concentration in seawater

Sample	Trace elements concentration (ppb)																				
	As	Sb	Al	Cd	Pb	Si	V	Ag	Zn	Cr	Mn	Ba	Co	Ni	Sr	Be	Cu	Tl	B	Fe	Se	Sn
S 001	3.4	2.5	12.7	0	3.8	136.6	0.4	0.6	8.2	0.6	0.4	9.8	1.4	0	9,978	0.1	5	3.2	5,842	0	11.2	1.7
S 002	2.8	22.7	10.9	0.05	7.5	406.7	1.1	0.1	9	0.6	1	11	1.7	0	10,020	0.1	5	2.3	5,633	1.4	9.5	2.1
S 003	2.6	28.6	4.6	0	11.7	494.5	0	0.6	10.6	0.8	1.4	12.6	1.4	0	9,929	0.05	3.2	0.7	5,014	1.8	6.1	1.3
S 004	3.8	5.1	4.4	0	5.2	182.9	1.2	0	7.7	0.1	0.8	10.9	1.6	0	10,860	0	4.1	1.3	5,741	0	10	1.8
S 005	4.4	0	0	0.1	1.4	59.7	0	0.6	15.7	0.3	0.9	9.3	1.7	0	9,764	0.1	3.2	0.5	5,439	0	12.3	0
S 006	3.2	0	8.7	0	1.7	82.9	0.4	0	5.4	0.4	0.8	10.1	1.8	0	10,440	0	2.8	0	5,543	0	5.8	1
S 007	4.6	4.7	52.3	0	2.5	173.2	0.9	0.1	4.3	0.7	0.8	10.1	1.4	0	10,370	0	2.9	3.5	5,295	11.1	6.1	1.3
S 008	4	0	0	0.1	3	64.7	0.6	0.3	8	0.5	0.2	10	1.7	0	10,180	0.1	2.2	1.6	5,200	0	4.2	2.2
S 009	2.5	15.1	0	0.1	5.1	309.8	0.1	0.3	2	0.3	0	10.7	1.2	0	11,420	0	2.6	2.9	5,667	0	4.7	2.9
S 010	0.8	3.7	0	0	5	134.6	0	0.1	1.3	0.2	0	9.9	1.3	0	10,090	0	1.3	1.1	5,412	0	8.2	2.5
S 011	0.9	0	0	0	3.3	62.5	1	0	2.3	0.3	1	17.7	1.5	0	10,415	0	1.3	6.3	5,206	0	7.2	0.9
S 012	2.1	1.0	1.7	0.1	2.7	93.6	1.2	0.2	4.3	0.6	0.2	18.3	1.3	0	11,360	0	2.9	2.7	5,805	0	3.8	1.6
S 013	4.3	0.9	0	0.1	3.8	79.1	0.6	0.3	3.0	0.7	0.6	17.2	1.9	0	13,040	0	1.3	0	6,606	0	2.1	0.5
S 014	4.0	0.1	0	0	3.4	88.2	1.1	0	3.8	0.4	0.9	31.1	1.9	0	14,355	0	1.7	2.6	7,141	0	9	0.6
S 015	0.3	7.2	0.9	0	2.9	197.4	0.6	0.1	11.2	0.6	0.7	10.4	1.6	0	10,600	0.1	2.5	2.4	5,442	3.1	4.6	0.8
S 016	3.5	7.6	3.7	0	4	193.4	1.3	0.2	5.9	0.2	0.6	12.5	1.5	0	12,030	0.1	4.2	2.2	6,539	0	10.8	1.7
S 017	3.5	6.3	0.3	0	5.5	184.7	1	0.2	4.8	0.5	0.7	11.1	1.2	0	10,820	0	3.5	1	5,566	3.8	11.5	1.5
S018	4	0	0	0.1	3.3	70.8	1	0.4	3.7	0.7	0.9	15.7	1.7	0	12,820	0	1	1.4	6,418	0	1.05	1.5
S019	4.4	0	0.1	0.2	3.4	78.8	0.9	0.3	4.1	0.6	0.4	17.1	2.1	0	13,665	0.1	2.1	1.3	6,710	0	9.4	1.6

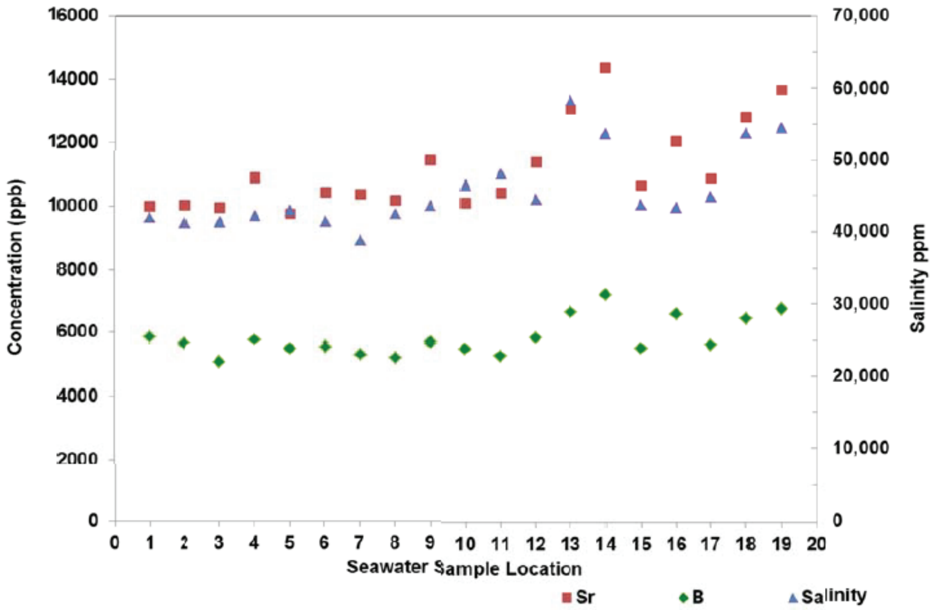


Fig. 4. Variations in boron and strontium concentrations with salinities of seawater in samples 1–19.

Sources of TEs in the sea include both natural and anthropogenic activities. The primary natural inputs of TEs are continental runoff and atmospheric deposition [19]. There are a multitude of anthropogenic sources of TEs from a variety of industrial, agricultural, and urban activities along the coastline of Qatar and in the Gulf region. The sample site 7 is one of the key and busiest fishing ports of the country. For the sample site 7, the aluminum level was about 25 times higher than that observed for other sites with minor boating and fishing activities (Table 2 and Fig. 3). Aluminum is a preferred material in ship building industry because of lightweight, economical, high performance, and nearly maintenance free. However, under hypersaline conditions, aluminum has a tendency to dissolve in water. Hence, higher aluminum levels in the busiest port location can be attributed to material corrosion by shipping industry.

Barium in seawater primarily comes from natural sources. Barium level in seawater for the site location 14 was found to be three times higher than the average values for other sampled locations. Site location 14 is the offshore industrial city dominated by aggregate and cement industry. Barium compounds are used as a mineralizer in cement industry and hence the pollution caused through the outflows from cement industry.

Antimony is a naturally occurring element. Its presence in seawater may be due to the natural erosions and/or anthropogenic activities (Table 2). Naturally occurring antimony compounds such as stibnite, antimonite, and valentinite are commonly found in ores of copper, silver, and lead [20]. Antimony concentrations at sites 2 and 3 showed higher values compared with that in other locations. Similar observations of lead levels were noted in sample locations 2 and 3. Lead is the highly toxic element concerned with human health. The major sources of lead in seawater are corrosion of plumbing systems through discharge lines and erosion of natural deposits. Its concentration in seawater, especially in sampling sites 2 and 3 exceeded the EPA standard and attained the maximum limit set by Qatar.

Zinc is naturally present in seawater with average concentration of less than 5 ppb [14,21]. Samples from sites 1–5 and 15 indicated three times higher concentrations of Zn than the average values for other sampled locations. Site activities such as cooling water discharge of the main desalination and power generation plant were predominant for these sites. Zinc is commonly used as a corrosion inhibitor for cooling water systems. Vessels using zinc-based paint are another anthropogenic source of zinc in seawater. Hence, the increase in zinc levels in seawater for sites 1–5 and 15 can be attributed to corrosion inhibitors from the industrial discharge lines and shipping vessels of the region.

Typically, the iron content in seawater is less than 3 ppb [21]. The main source is from naturally occurring iron minerals such as magnetite, hematite, goethite, and siderite. For the sample site 7, the observed iron level was 11 ppb, and for the other sampled locations iron levels were below 3 ppb. As mentioned earlier, site 7 is located in the key and busiest fishing ports of the country, and hence the pollution level can be related to material corrosion. The average concentration of selenium along the coastline of Qatar was found to be 7 ppb. Common anthropogenic sources of selenium in seawater include mining and smelting of sulfide ore [22]. Moreover, the Arabian Gulf is subject to intense and frequent dust storms which represent an important source of trace metals to seawater in this region [23].

The average concentrations of strontium and boron in seawater were found to be 11.2 and 5.8 ppm, respectively. These elements typically are released from natural sources by weathering and erosion of rocks and soil [24]. Some of the common pre-treatment technologies for removing TEs from seawater are listed in Table 3 [25,26].

TEs concentrations in surface waters of Qatar coastal sites, Red Sea, and Gulf of Aqaba are given in Table 4. The average concentrations of TEs in Qatari coastal waters are comparable with their concentrations observed in Red Sea and Gulf of Aqaba samples for the sampling year 2013 [27,28].

Table 3
Trace element levels (TEs) in seawater, pollution source, EPA standards, and recommended purification technologies for TE removal

TEs (<5 ppb)	TEs (<15 ppb)	TEs (<50 ppb)	TEs (<15 ppm)
As, Cd, V, Ag, Cr, Mn, Co, Ni, Be, Cu, Tl, and Sn	Pb, Zn, Fe, and Se	Sb, Al, and Ba	Si, Sr, and B

Trace elements (TEs) Sampling site (SS)	Potential sources of TEs in Qatar's coastal waters	EPA and Qatar Standards (QS)	Purification technologies
Aluminum: SS 1,2, and 6 (10±2 ppb); SS 7 (52 ppb)	Recreational boat activity, busiest fishing ports, and discharge of surface water from the mainland	Seawater EPA: no guideline Seawater QS: no guideline Drinking water: MCL 0.05–0.2 ppm	Ion exchange and coagulation–flocculation
Barium: SS 14 (30±2 ppb)	Discharges from aggregate and cement industry	Seawater EPA: CMC no guideline Seawater QS: no guideline Drinking water: MCL 2 ppm	Ion exchange, lime softening, electrodialysis, and distillation
Antimony: SS 2 and 3 (25±3 ppb); SS 9 (15 ppb)	Erosion of natural deposits, discharge from petroleum refineries, fire retardants, ceramics, solder electronics, and contaminants from pipes and fittings	Seawater EPA: CMC nil Seawater QS: no guideline Drinking water: MCL 6 ppb	Coagulation–filtration and reverse osmosis
Lead: SS 2 and 3 (10±2 ppb)	Erosion of natural deposits, leaded gasoline, high-temperature industrial activities, and plumbing contamination	Seawater EPA: CMC 210 and CCC 8.1 ppb Seawater QS: 12 ppb Drinking water: MCL 0 Action level: 15 ppb	Reverse osmosis, carbon, ion exchange resins, and activated alumina
Zinc: SS 1–5 and 15 (11±4 ppb)	Effluent discharge from desalination plant and paints	Seawater EPA: CMC 90 ppb Seawater QS: no guideline Drinking water: MCL 5 ppm	Coagulation, sand filtration, ion exchange, and active carbon
Iron: SS 7 (11 ppb)	Busiest fishing ports and dust storms	Seawater EPA: no guideline Seawater QS: 90 ppb Drinking water: MCL 0.3 ppm	Chemical treatment and ion exchange
Selenium: 10±5 ppb	Coal burning, and the mining and smelting of sulfide ores	Seawater EPA: CMC 290 ppb Seawater QS: no guideline Drinking water: MCL 0.05 ppm	Activated alumina, coagulation–filtration, lime softening, and reverse osmosis
Boron: 5–7 ppm	Released from rocks and soil by weathering	Seawater EPA: no guideline Seawater QS: no guideline Drinking water: HRL 0.5 ppm	Ion exchange
Strontium: 10–14 ppm	Released from rocks and soil by weathering	Seawater EPA: no guideline Seawater QS: nil Drinking water: MCL 1.5 ppm	Membrane filtration, ion-exchange resins, activated alumina, and softening

MCL, Maximum contamination limit; HRL, health reference level; CMC, criterion maximum concentration (aquatic life); CCC, criterion continuous concentration.

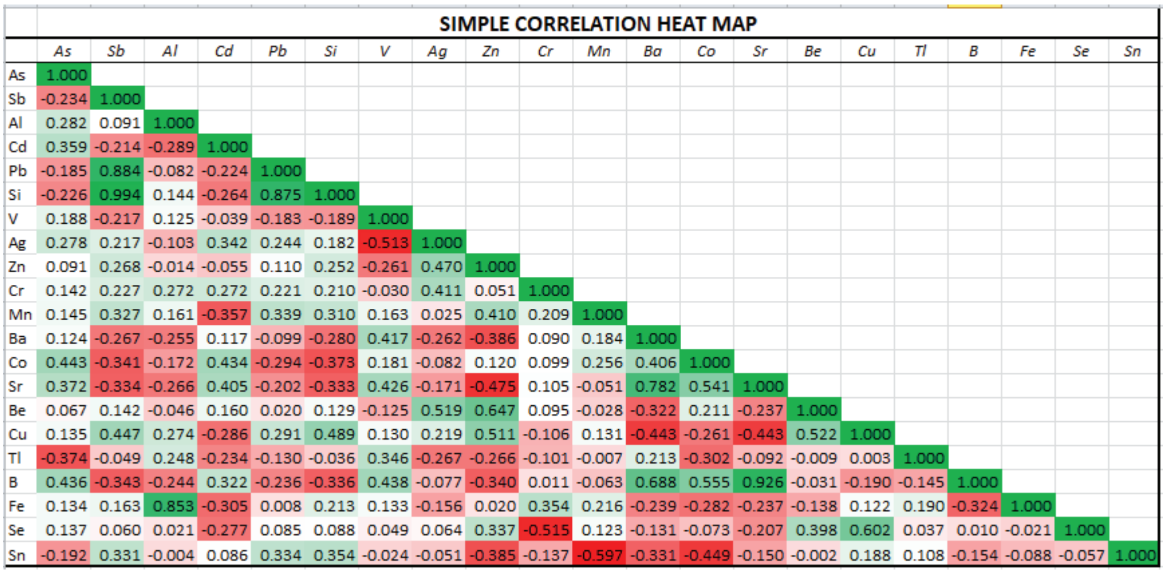
TEs concentrations showed 10-folds increase when compared with that of the Red Sea and Gulf of Aqaba samples reported for year 2001 [29]. For example, the average lead concentrations in Red Sea and Gulf of Aqaba samples were 0.36 ppb in 2001.

3.3. Interrelation between different TEs accumulated in seawater

Correlation heat map of TEs in seawater is shown in Fig. 5. It ranged between most positively correlated (+1) in Green to most negatively correlated value (–0.597) in Red. A significant correlation of Sr with B indicates the coexistence of these elements from their natural source. Moreover, it is clearly evident from Fig. 4 that Sr and B follow similar salinity variations to that of the seawater. Both Sr and B can be used as a fingerprinting elements/water quality indicators to detect the intrusion of seawater into groundwater resources. Positive correlations observed for Pb–Si and Sb–Si combinations indicate their existence in seawater is through erosion of natural deposits. A positive correlation of Pb and Sb indicates their coexistence and common pollution source. Clearly, concentrations of Sb and Pb were significantly high in the areas

Table 4
Concentrations (ppb) of trace elements in coastal water of different regions [27,28]

Trace metal	Qatar coastal area		Red Sea (2013)		Gulf of Aqaba (2013)	
	Maximum	Average	Maximum	Average	Maximum	Average
As	4.7	3.1	–	2.0	1.5	0.82
Cd	0.2	0.1	1.18	0.48	2.39	1.49
Pb	11.7	4.2	8.9	3.93	9.74	3.59
Zn	15.7	6.1	75.91	15.14	29.62	14.19
Cr	0.8	0.5	–	–	3.25	0.95
Mn	1.4	0.7	12.7	2.49	11.23	2.24
Co	2.1	1.6	–	–	0.4	0.2
Cu	5.0	2.8	14.12	4.34	13.41	3.44
Fe	11.1	1.1	65.62	36.59	63.25	34.1
Se	12.3	7.3	–	–	0.73	0.29
B	5,014.0	5,801.0	5,800	5,500	2,947	1,916



SIMPLE CORRELATION HEAT MAP

	As	Sb	Al	Cd	Pb	Si	V	Ag	Zn	Cr	Mn	Ba	Co	Sr	Be	Cu	Tl	B	Fe	Se	Sn
As	1.000																				
Sb	-0.234	1.000																			
Al	0.282	0.091	1.000																		
Cd	0.359	-0.214	-0.289	1.000																	
Pb	-0.185	0.884	-0.082	-0.224	1.000																
Si	-0.226	0.994	0.144	-0.264	0.875	1.000															
V	0.188	-0.217	0.125	-0.039	-0.183	-0.189	1.000														
Ag	0.278	0.217	-0.103	0.342	0.244	0.182	-0.513	1.000													
Zn	0.091	0.268	-0.014	-0.055	0.110	0.252	-0.261	0.470	1.000												
Cr	0.142	0.227	0.272	0.272	0.221	0.210	-0.030	0.411	0.051	1.000											
Mn	0.145	0.327	0.161	-0.357	0.339	0.310	0.163	0.025	0.410	0.209	1.000										
Ba	0.124	-0.267	-0.255	0.117	-0.099	-0.280	0.417	-0.262	-0.386	0.090	0.184	1.000									
Co	0.443	-0.341	-0.172	0.434	-0.294	-0.373	0.181	-0.082	0.120	0.099	0.256	0.406	1.000								
Sr	0.372	-0.334	-0.266	0.405	-0.202	-0.333	0.426	-0.171	-0.475	0.105	-0.051	0.782	0.541	1.000							
Be	0.067	0.142	-0.046	0.160	0.020	0.129	-0.125	0.519	0.647	0.095	-0.028	-0.322	0.211	-0.237	1.000						
Cu	0.135	0.447	0.274	-0.286	0.291	0.489	0.130	0.219	0.511	-0.106	0.131	-0.443	-0.261	-0.443	0.522	1.000					
Tl	-0.374	-0.049	0.248	-0.234	-0.130	-0.036	0.346	-0.267	-0.266	-0.101	-0.007	0.213	-0.302	-0.092	-0.009	0.003	1.000				
B	0.436	-0.343	-0.244	0.322	-0.236	-0.336	0.438	-0.077	-0.340	0.011	-0.063	0.688	0.555	0.926	-0.031	-0.190	-0.145	1.000			
Fe	0.134	0.163	0.853	-0.305	0.008	0.213	0.133	-0.156	0.020	0.354	0.216	-0.239	-0.282	-0.237	-0.138	0.122	0.190	-0.324	1.000		
Se	0.137	0.060	0.021	-0.277	0.085	0.088	0.049	0.064	0.337	-0.515	0.123	-0.131	-0.073	-0.207	0.398	0.602	0.037	0.010	-0.021	1.000	
Sn	-0.192	0.331	-0.004	0.086	0.334	0.354	-0.024	-0.051	-0.385	-0.137	-0.597	-0.331	-0.449	-0.150	-0.002	0.188	0.108	-0.154	-0.088	-0.057	1.000

Fig. 5. Correlation coefficients of trace elements in seawater.

dominated by discharge of surface waters. A strong correlation between Al and Fe was observed in Fig. 5 confirming the common pollution source for these two elements. They exhibited higher concentrations in the same sample location 7, a busiest shipping port.

Salinity and TEs distribution showed significant variations across east and west coast of Qatar. The average salinities of east and west coastal region were 42 and 51 ppt, respectively. High salinity in the west coast can be attributed to the marginal enclosed nature of the sea and also due to anthropogenic activities from desalination industries of the Gulf region. Site-specific sampling indicated high Al, Ba, Fe, and Zn concentrations that can be related to anthropogenic inputs from shipping, cement, desalination industries, and power plants. However, concentrations of Sb and Pb were significantly high in the areas dominated by discharge of surface waters. Strong correlations of the elements Al–Fe, Sb–Pb, and Sr–B confirm their common pollution source for these elements. Moreover, Sr and B followed the salinity variations of seawater, suggesting that these elements can act as water quality indicators to detect the intrusion of seawater into groundwater aquifers. Nevertheless, TE average concentrations in Qatari seawater are within the national and EPA seawater quality standards and exhibited a similar TE trends to that of Red Sea. This study provides a distribution and site-specific variations of TEs in seawater that can be applied to mitigate pollution improve water management efficiencies and assist sustainable operations of desalination plants.

Acknowledgments

This article was made possible by the NPRP grant (NPRP7-330-1-056) from the Qatar National Research Fund (a member of Qatar Foundation). Authors also thank Centre for GIS and the Information Systems Department of Ministry of Municipality and Environment, Qatar, for providing us the base data and mapping facility. The findings achieved herein are solely the responsibility of the authors.

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