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Monitoring of inorganic and organic pollutants in the desalinated water from thermal desalination plants

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ABSTRACT

Monitoring of inorganic and organic pollutants in the produced water from Saline Water Conversion Corporation (SWCC) seawater desalination plants was carried out over 20 y on the eastern coast and 8 y on the western coast of the Kingdom of Saudi Arabia. Water samples from SWCC plants were analyzed with an emphasis on toxic elements such as mercury, arsenic, lead, cadmium, selenium, chromium, and toxic disinfection by-products (DBPs) such as trihalomethanes (THMs) arising due to chlorination. Considering the Saudi Arabian Standards Organization (SASO) and World Health Organization (WHO) guidelines for drinking water, results show compliance with all the values for the components analyzed and found to be under the SASO and WHO regulations. Over the 20 y of the study, elevated THM concentrations were found for all plants located on the Arabian Gulf in the years 2001–2003, and elevated arsenic concentrations for the same plants in 2007. The fact that these increased levels were reported for all plants on the Arabian Gulf suggest they arise from systemic environmental effects impacting this restricted body of water.

Keywords: Toxic elements, Drinking water, Desalinated water, Heavy metals, Disinfection by-products, Saline Water Conversion Corporation

1. Introduction

Saudi Arabia is an arid country with limited fresh water resources. The major source of drinking water in the Kingdom of Saudi Arabia is desalination of seawater. The Saline Water Conversion Corporation (SWCC), a government agency responsible for producing desalinated water in the Kingdom, operates approximately 30 desalination plants along the coast of Red Sea and Arabian Gulf with a combined production capacity of close to 6 million m^3/d. Multi-stage flash (MSF) plants contribute the major share of the water being produced in the Kingdom, followed by reverse osmosis (RO), and multi-effect distillation (MED).

Providing safe and good quality drinking water is the highest priority of SWCC. Water produced by SWCC plants are regularly monitored for the water quality in compliance with national and international regulations, particularly for toxic heavy metals such as Hg, Se, Pb, As, Cd, Cr and toxic disinfection by-products (DBPs) such as THMs (trihalomethanes) arising from sea water chlorination (Table 1). SWCC's Desalination Technologies Research Institute (DTRI) has been entrusted with monitoring water

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quality control and has previously reported results of this ongoing monitoring, but no updates have appeared for several decades [1–4]. THMs have been reported at concentration of up to 90 µg/L in Arabian Gulf seawater near thermal desalination plant brine discharge points [5] and up to approximately 20 µg/L in similar environments in the Red Sea [6], the physical process of desalination means that they very much less concentrated in the produced water. Le Roux et al. [6] reported total THM concentration ≥ 0.38 µg/L in MSF distillate from a desalination plant located on the Red Sea.

2. Experimental methods

2.1. Sampling

Initially the sampling was done on monthly basis for only the plants located in the Eastern province (i.e., Jubail, Khobar and Khafji); from 2011 it was extended to all SWCC thermal plants on a bi-monthly basis. The collection of samples was carried out by DTRI staff in coordination with personnel at the respective desalination plants.

2.2. Analytical methods

2.2.1. Heavy metals

For the determination of heavy metals, samples were collected in polypropylene bottles. Their pH was set at 1.0 with the addition of a few drops of AR grade nitric acid.

Analyses were performed by Perkin Elmer Atomic Absorption Spectrometer-400 (AAS-400) with hydride generation for Hg, Se, and As. For the remaining metals (Cd, Cr, Pb) a Perkin Elmer (AAS-800) spectrometer with Graphite Tube Atomizer (GTA) was used [7].

2.2.2. Total trihalomethanes (TTHMs) analysis by GC/MS

According to the Standard Methods all samples were analyzed based on the described procedures in American Public Health Association (APHA) Standard Methods [7]. Based on the direct aqueous injection, an Agilent 5890 series, gas chromatography (GC) high performance quadrupole mass spectrometer (GC-MS) using a Purge and Trap technique was used for the identification and quantification of THMs.

The GC oven temperature was programmed from 40°C (4 min) to 140°C at 8°C/min. Other GCMS parameters were as follows:

- Column: J and W-DB5, 60 m × 0.25 mm × 0.25 µm thickness; Carrier gas: Helium at 1.2 ml/min.
- Injector temperature: 300°C;
- SIM mode (ions selected: 83, 85, 127, 129, 171 and 173); MS Quad. temperature: 150°C; MS source temp.

3. Results and discussion

The study assessed the concentrations of the toxic elements such as mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), selenium (Se), chromium (Cr) and toxic disinfection by-products (DBPs) such as THMs (trihalomethanes) arising due to sea water chlorination for a period of 20 y in the Eastern and 8 y in the Western provinces. Data are presented in Tables 2–15. Table 1 shows permissible limits according

Table 1
Relevant SASO limits for unbottled drinking water (2009), WHO limits for drinking water (2008), the detection limits of toxic elements and THMs, and previously reported values in desalination product water

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM*	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
SASO Limit	3	50	10	10	1	10	Note 1	200	60	100	100
WHO Limit	3	50	10	10	1	10		300	60	100	100
Detection limit	0.002	0.004	0.030	0.050	0.009	0.030		0.03	0.05	0.05	0.10
Mayan Kutty et al. [1] (MAX)	1.0–1.3	ND	0.52–0.67	ND	0.3–2.8	0.77–1.8					
Gao et al. [10] MED	0.02		ND	0.01	ND	1.4					
Gao et al. [10] RO	ND		0.1	ND	0.01	ND					
Le Roux et al. [6] MSF									0.15	0.12	0.11
Le Roux et al. [6] RO										0.07	19.05

Note 1: TTHM*: The sum of the ratio of each to its respective guideline value should not exceed 1, as per the function:

$$\frac{C_{\text{bromoform}}}{GV_{\text{bromoform}}}+\frac{C_{\text{DBCM}}}{GV_{\text{DBCM}}}+\frac{C_{\text{BDCM}}}{GV_{\text{BDCM}}}+\frac{C_{\text{chloroform}}}{GV_{\text{chloroform}}}\leq 1$$

where *C*: concentration; GV: guideline value; BDCM: bromodichloromethane ($CHBrCl_2$); DBCM: dibromochloromethane ($CHBr_2Cl$).

Table 2
Occurrence of heavy metals and disinfection by-products in desalinated water of Khobar MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
1989 [3]	<0.002	<0.004	<0.03	<0.05	<0.009–0.25	<0.03–0.47	<3.50/5.29	<0.01/0.04	0.18/0.20	<0.01/0.10	3.30/4.95
1990 [3]	<0.002	<0.004	<0.03–0.37	<0.05	<0.009	<0.03					
1991 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	1.2–5.6					
1992 [3]	<0.002	<0.004	<0.03	<0.05	<0.009–0.3	<0.03–1.24					
1993 [3]	<0.002	<0.004	<0.03–0.60	<0.05	<0.009–0.3	<0.03–1.8					
1994 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03–0.70					
1998	0.2–0.3	0.3	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
1999	0.1–1.59	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2000	<0.002–0.1	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2001	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<7.8	<0.03	0.31	0.48	1.0–7.0
2002	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<4.1	<0.03	<0.05	0.3–0.5	1.0–3.5
2003	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<2.7	<0.03	<0.05	<0.05	2.0–2.6
2004	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2005	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2006	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2007	<0.002	<0.004	<0.03	<0.05	<0.009	0.1–0.2	<0.23	<0.03	<0.05	<0.05	<0.10
2008	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2009	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2010	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	2.0–10
2014	<1	<1	NA	<1	<1	<1	<0.23	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

to the Saudi Arabian Standards Organization (SASO) and World Health Organization (WHO) [8,9] and results previously obtained from MSF, MED, and RO desalination plants [1,6,10].

The data from the Tables 2–4 for the plants located in the Eastern Province (Khobar, Khafji and Jubail) showed that for the entirety of the study period the six toxic elements studied were either below the detection level (Table 1) or present in very low concentrations in the desalinated water. Average values for all the six elements analyzed were found to be well below the Saudi Arabian Standards Organization (SASO) and World Health Organization (WHO) permissible limits [8,9].

Traces of Cd were observed in desalinated water during the years 1998 and 1999 in Khobar (0.1–1.59 ppb) and in 1999 in Khafji (0.2–0.24 ppb). The origin of these elevated levels of Cd are not known.

Traces of As were observed during the same year (2007) in the samples of all three plants (Khobar, Khafji and Jubail). These observations are consistent with some activity of contamination with As in the source water during these periods in the Arabian Gulf, as it is highly unlikely that contamination associated with corrosion of metallic components of the MSF plants (for example) would coincidentally occur at all three plants. As the Arabian Gulf is a relatively shallow body of water with restricted connections to the Indian Ocean, it is more sensitive to events that could increase As levels systemically: significant extractive industries are located in and around the Arabic Gulf, and it receives relatively large volumes of freshwater discharge from the Tigris–Euphrates–Karun watershed.

Chlorination of seawater containing organics results in the formation of disinfection by-products (DBPs) that are known to have adverse health effects [11,12]. The major DBPs are trihalomethanes (THMs), viz. chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$) and bromoform ($CHBr_3$) [11]. At most times no THMs could be detected, despite the fact that significant concentrations are expected to be produced in the discharged brine Elevated levels of THMs (though well within the acceptable limits) were found for all plants sampled on the Arabian Gulf in 2001–2002 and for two out of three plants sampled on the Arabian Gulf in 2003. It was found that bromoform was the predominant species formed, but

Table 3
Occurrence of heavy metals and disinfection by-products in desalinated water of Jubail MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
1989 [3]	<0.002–1.1	<0.004	<0.03–1.1	<0.05–1.2	<0.009	<0.03–0.50	>0.09/>0.40	0.05/0.08	0.02/0.13	0.01/0.08	0.01/0.13
1990 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03–0.60					
1991 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03					
1992 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03–0.49					
1993 [3]	<0.002–1.3	<0.004	<0.030–0.52	<0.05	<0.009	<0.03–0.77					
1994 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03–0.5					
1998	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
1999	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2000	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2001	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<7.1	<0.03	<0.05	<0.05	1.0–7.0
2002	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.6	<0.03	<0.05	<0.05	0.2–0.5
2003	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2004	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2005	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2006	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2007	<0.002	<0.004	0.1–0.2	<0.05	<0.009	0.08–0.09	<0.23	<0.03	<0.05	<0.05	<0.10
2008	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2009	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2010	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	<0.23	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 4
Occurrence of heavy metals and disinfection by-products in desalinated water of Khafji MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
1989 [3]	<0.002	<0.004	<0.03	<0.03–0.58	<0.009	NA	<1.10/<0.97	<0.01	0.12/0.01	<0.01/0.01	0.96/0.94
1990 [3]	NA	NA	NA	NA	NA	NA					
1991 [3]	NA	NA	NA	NA	NA	NA					
1992 [3]	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03–0.60					
1993 [3]	<0.002–1.0	<0.004	<0.03–0.67	<0.05	<0.009–2.8	<0.03–1.3					
1994 [3]	<0.002	<0.004	<0.03	<0.05	<0.009–0.6	<0.03–0.5					
1998	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
1999	0.22–0.24	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2000	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2001	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<1.1	<0.03	<0.05	<0.05	0.8–1.0
2002	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<1.1	<0.03	<0.05	<0.05	0.3– 1.0
2003	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.9	<0.03	<0.05	<0.05	0.3– 0.8
2004	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2005	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2006	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10

(Continued)

Table 4

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2007	<0.002	<0.004	<0.03	<0.05	<0.009	0.02–0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2008	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2009	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2010	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	<0.23	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 5
Occurrence of heavy metals and disinfection by-products in desalinated water of Jeddah MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	<0.23	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 6
Occurrence of heavy metals and disinfection by-products in desalinated water of Shoibah MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	<0.23	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	<0.23	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

at levels well below the regulated SASO and WHO values. Again, the similar result across three plants is consistent with a systemic event affecting the entire Arabian Gulf. In an earlier study, Mayan Kutty et al. [2] reported a similar clustering of elevated Hg results from these three plants on the Arabian Gulf in 1994, with the timing of the measurements consistent with a body of contaminated water apparently moving from north to south. It should be noted that overall, significantly higher levels of heavy metal contamination were measured in this earlier study than in the current work, perhaps unsurprisingly considering the unusually large amounts of pollutants generated in the Arabian Gulf as a result of armed conflict between 1984 and 1991.

For all the plants sampled in the Red Sea region, the concentration of the six target elements and the DBPs of interest were found to be below the detection level

Table 7
Occurrence of heavy metals and disinfection by-products in desalinated water of Yanbu MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 8
Occurrence of heavy metals and disinfection by-products in desalinated water of Shuqaiq MSF Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 9
Occurrence of heavy metals and disinfection by-products in desalinated water of Azizia MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 10
Occurrence of heavy metals and disinfection by-products in desalinated water of Wajeh MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 11
Occurrence of heavy metals and disinfection by-products in desalinated water of Farasan MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 12
Occurrence of heavy metals and disinfection by-products in desalinated water of Laith MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 13
Occurrence of heavy metals and disinfection by-products in desalinated water of Qunfudah MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 14
Occurrence of heavy metals and disinfection by-products in desalinated water of Rabigh MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

Table 15
Occurrence of heavy metals and disinfection by-products in desalinated water of Ummluj MED Plant

Year	Cd (ppb)	Cr (ppb)	Se (ppb)	Pb (ppb)	Hg (ppb)	As (ppb)	TTHM (ppb)	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)
2011	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2012	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2013	<0.002	<0.004	<0.03	<0.05	<0.009	<0.03	<0.23	<0.03	<0.05	<0.05	<0.10
2014	<1	<1	NA	<1	<1	<1	≤1	<0.03	<5	<5	<5
2015	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2016	NA	NA	NA	NA	<1	<1	≤1	<0.03	<5	<5	<5
2017	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA
2018	<1	<1	NA	<1	<1	<1	NA	<0.03	NA	NA	NA

NA = not analysed

(Tables 5–15). For THMs, this is somewhat surprising, considering the values were significantly above the detection limit reported from MSF produce water from the Red Sea by La Roux et al. [6].

4. Conclusions

Routine Monitoring of six toxic elements (As, Hg, Pb, Cd, Se and Cr) in produced water from SWC thermal desalination plants on the Arabian Gulf for 20 y and the Red Sea for 8 y indicated that at all times the concentrations of all the elements were either not detectable or far below the SASO and WHO regulated values.

Chlorinated disinfection by-products (THMs) monitored in produced water were also found to be well below the regulated SASO and WHO values, with bromoform as the predominant species. This monitoring of the potential toxic contaminants over two decades indicates that the desalinated water produced by SWCC Plants has been safe for human consumption over the study period.

Episodes of elevated heavy metals did not appear to be connected to local pollution events, but with larger scale events affecting the entire Arabian Gulf.

While this program was limited to only six toxic metals and the main THMs, the current quality monitoring program within the SWCC monitors 18 metals along with DBPs and other organic materials, as required to monitor adherence to the SASO and WHO regulations, and will be reported on in a future publication.

References

[1] P.C. Mayan Kutty, A.A. Nomani, S. Al-Sulami, A. Al-Rabeh, Monitoring of Trace Metals in Desalinated Drinking Water and their Permissible levels, Proc. IDA World Conference and Water Reuse, Abu Dhabi, 1995, pp. 1180–1190.

[2] P.C. Mayan Kutty, A.A. Nomani, T.S. Thankachan, Evaluation of Water Quality Parameters in Drinking Water from SWCC MSF Plants, Vol. 1, Proc. IDA World Conference and Water Reuse, Washington D.C., 1991, pp. 1–14.

[3] P.C. Mayan Kutty, A.A. Nomani, T.S. Thankachan, Trihalomethanes in Chlorinated Drinking Water from Seawater Desalination Plants in Saudi Arabia, Vol. 2, Proc. IDA World Conference and Water Reuse, Washington D.C., Aug. 25–29.

[4] P.C. Mayan Kutty, A.A. Nomani, T.S. Thankachan, Monitoring of organic compounds in feed and product water samples from MSF plants in the Eastern Coast of Saudi Arabia, Desalination, 74 (1989) 243–257.

[5] M.Y. Ali, J.P. Riley, The distribution of halomethanes in the coastal waters of Kuwait, Mar. Pollut. Bul., 17 (1986) 409–414.

[6] J. Le Roux, N. Nada, M.T. Khan, J.-P. Croué, Tracing disinfection by-products in full-scale desalination plants, Desalination, 359 (2015) 141–148.

[7] Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, American Water Works Association, Water Pollution Control, 1998.

[8] Guidelines for Drinking Water Quality, World Health Organization, Geneva, Switzerland, 2008.

[9] Guidelines for Unbottled Drinking Water, Saudi Arabian Standards Organization, Riyadh, Saudi Arabia, 2009.

[10] B. Gao, H.J. Yu, J.J. Gao, L.H. Liu, Q.W. Wang, C. Zhu, W.Q. Wu, Occurrence and health risk assessment of trace metals in desalinated seawater using two desalination technologies, Pol. J. Environ. Stud., 29 (2020) 3581–3588.

[11] E. Agus, N. Voutchkov, D.L. Sedlak, Disinfection by-products and their potential impact on the quality of water produced by desalination systems: a literature review, Desalination, 237 (2010) 214–237.

[12] W.Y. Wang, B.X. Ye, L.S. Yang, Y.H. Li, Y.H. Wang, Risk assessment on disinfection by-products of drinking water of different water sources and disinfection processes, Environ. Int., 33 (2007) 219–225.