

Concentration of Heavy Metals in the Territorial Sea Water of the Kingdom of Bahrain, Arabian Gulf

تراكيز العناصر الثقيلة في مياه البحر الإقليمية لمملكة البحرين

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ABSTRACT: This is the first investigation for the analysis of heavy metal covering the territorial water of Kingdom of Bahrain. For the purpose of establishing baseline, as well as the assessment of marine contamination due to heavy metals, sea waters were collected from 23 different sites known as fishing areas of the territorial water of the Kingdom of Bahrain in the year 2007. The heavy metals analyzed were Arsenic, Cadmium (Cd), Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni), Lead (Pb), Vanadium (V), Zinc (Zn) and Mercury (Hg), using Inductively Coupled Plasma Emission Spectroscopy (ICP-OES). The concentrations of As, Cd, Cu, Fe, Mn, Ni, Pb, V, Zn and Hg were in the range of 0.85-2.75, 0.06-5.20, 4.53-119.00, 1.03-28.62, 0.06-1.24, 0.71-20.1, 1.13-2.01, 1.13-9.93, 0.96-2.32, 4.06-118.00, and 0.13-0.38 $\mu\text{g/l}$, respectively, representing the baseline trace metal concentrations of sea water in the Kingdom of Bahrain. The results suggest that the Kingdom of Bahrain's marine waters seem to be of good quality as the concentrations of the metals reported in the studied areas are far below the United Kingdom Water quality standards and United States Environmental Protection Agency recommended water quality criteria, with the exception of copper in all sites, and Mercury (Hg) in Msoor site. In general, concentrations of trace elements in sea water were similar to those of other areas worldwide, and were deemed not to be of any toxicological significance.

Keywords: Trace metals, Seawater, Bahrain, Quality, Standards.

المستخلص: تعتبر هذه الدراسة الأولى من نوعها التي تسلط الضوء على تراكيز العناصر الثقيلة بصورة شاملة في المياه الإقليمية لمملكة البحرين. ورغبة في تأسيس وإنشاء الخط المرجعي، وتقويم وقياس قيم الملوثات البحرية ذات الصلة بالعناصر الثقيلة، فقد تم جمع عينات من مياه البحر من ثلاثة وعشرين (23) موقعا، تتمركز في مناطق صيد الأسماك المهمة في المياه الإقليمية للبحرين، وذلك خلال العام 2007م. والعناصر الثقيلة التي تم قياسها هي الزرنيخ، والكاديوم، والنحاس، والحديد، والمنجنيز، والنيكل، والرصاص، والفاناديوم، والزرنيق، وبواسطة جهاز Inductively Coupled Plasma Emission Spectroscopy (ICP-OES) ومن خلال الدراسة، تبين بأن تراكيز كل من الزرنيخ (As)، والكاديوم (Cd)، والنحاس (Cu)، والحديد (Fe)، والمنجنيز (Mn)، والنيكل (Ni) والرصاص (Pb)، والفاناديوم (V)، والزرنيق (Zn)، والزرنيق (Hg)، قد تراوحت بين 0.85-2.75، و0.06-5.20، و4.53-119.00، و1.03-28.62، و0.06-1.24، و0.71-20.1، و1.13-2.01، و1.13-9.93، و0.96-2.32، و4.06-118.00، و0.13-0.38 مايكروجرام/لتر، على التوالي، وهو ما يمثل الخط المرجعي لتراكيز هذه العناصر في مياه البحر المحيطة بمملكة البحرين. ومن خلال هذه النتائج يمكن اعتبار جودة مياه البحر

في مملكة البحرين جيدة، حيث أن معظم القيم المسجلة في هذه الدراسة تقل بصورة ملحوظة عن معايير جودة المياه للمملكة المتحدة والوكالة الأمريكية لحماية البيئة أيضاً، فيما عدى تركيز النحاس في جميع مواقع الدراسة، وكذلك تركيز الزئبق في موقع مسور. وبصورة عامة، فإن تراكيز العناصر الثقيلة في البحرين تقارب مثيلاتها في باقي بحار العالم غير الملوثة، ويعتقد بأن مستويات التلوث بهذه العناصر قد لا تشكل سمية خطيرة على مكونات البيئة البحرية.

كلمات مدخلية: المعادن الثقيلة، مياه البحر، البحرين، الجودة، المعايير البيئية.

INTRODUCTION

Trace metals are important in aquatic systems because of their demonstrated effects as both essential and toxic agents for biota. Many metallic elements, e.g., Iron (Fe), Manganese (Mn), Cobalt (Co), Copper (Cu), Nickel (Ni), Molybdenum (Mo) and Zinc (Zn), are considered essential for biological processes in a variety of natural ecosystems, but are generally present only in trace amounts. Although the essential function of such trace metals in terrestrial ecosystems has been known for many decades, it is only in recent years that scientific methodology has improved to the point that the biogeochemical behavior of trace metals can be adequately studied in aquatic ecosystems. The concentration of trace metals in the marine life is influenced by several mechanisms. The physical and chemical nature of the marine environment is one of the important factors that determine the level of the elements. Because most heavy metals tend to accumulate in sediments, their presence in the water column is usually the result of recent inputs. The analysis of saline samples has always been challenging, even with today's modern instrumentation, due to the high total dissolved salts and the presence of several elements at very high levels (e.g. Chloride, Sodium, Magnesium, Sulphur, Calcium and Potassium), whilst many of the elements of interest exist at miniscule concentrations.

Many of the elements of primary environmental concern are present in sea water at exceptionally low levels and background monitoring to these levels requires sampling and analysis conditions that are not economically and logistically viable on a routine basis. The practical problems involved in the chemical analysis of trace metals in aquatic systems are now widely known (Turekian, 1977; Hunter, 1982; Bruland, *et al.* 1991). The concentrations of most trace metals in aquatic systems are so low in comparison to

those prevailing in the materials and flotsam of the average chemistry laboratory (dust, skin and paint flakes, and chocolate vapor) that without special precautions, a seawater sample is quickly overwhelmed by external, spurious sources of trace metals.

Much of the progress in developing sample collection and analysis methods appropriate to the very low concentrations found in environmental samples can be traced to the pioneering efforts of Clair Patterson at the California Institute of Technology, whose painstaking work on the measurement of Pb and stable Pb isotopes (Patterson and Settle, 1976) has been the inspiration for those who have followed.

Reliable measurements of trace metals in natural waters requires scrupulous attention to all steps in the analytical protocol from sample collection to analysis: the preparation of trace metal-clean sample containers, rigorously-controlled collection and handling of the sample; carefully-designed analytical techniques, including the preparation of specially-purified reagents, and the strict control throughout of external sources of contamination by use of specialized clothing and clean-room working conditions (Patterson and Settle, 1976; Bruland, *et al.* 1979; Ahlers *et al.* 1990).

Recent studies (Ahlers, *et al.* 1990; Hunter and Tyler 1987) have reinforced the need for extreme care in the sampling of marine waters for trace metal analysis. The earliest concerns were raised by Patterson and Settle (1976) and Schaule and Patterson (1981). More recent analyses of open ocean water samples in which special precautions were taken in preparation of sample containers, sampling operation, and sample handling and analysis have shown metal concentrations to be lower than originally anticipated. For example, open ocean concentrations of zinc, lead, copper, cadmium and chromium are now estimated to be in the ranges 0.003-0.6, 0.001-0.04, 0.03-

0.4, 0.0001-0.12 and 0.1-0.3 $\mu\text{g L}^{-1}$, respectively (Bruland, *et al.* 1991; Bruland and Franks, 1983; Bruland, 1980).

MATERIALS AND METHODS

Seawater samples were collected in the Bahrain territorial seawater during 2007. In general, all sampling procedures were carried out according to internationally recognized methods and guidelines (Grashoff, *et al.* 1999). Teflon coated, metal free sampler was used for seawater sampling for trace metal analysis. The sampler was rinsed thoroughly with seawater before actual sampling. Seawater samples then were transferred to a new pre-washed (initial washing with DI water, then rinsing with 5% HNO_3 and then final rinse with the seawater) 5-L high density polythene containers. Filled bottles just above the shoulders of the bottles, screwed on the caps gently and firmly. The sampled seawaters were then put in ice cooled chest (4°C). The ice-chest transported to the lab within 3-hours of sampling. The water samples were filtered immediately with 0.45 μm membrane filtration. Then 2 ml of ultrapure HNO_3 per liter of sample were added to bring down the pH to < 2 .

All sampling sites are shown in Figure 1. Exact coordinates for sediment sampling are shown in Table 1. The analysis of seawater was performed using international analysis guidelines and approved test procedure. ASTM, USEPA and Methods of Seawater analysis (Grashoff, *et al.* 1999), (ASTM procedure for analysis of trace metals in salt water was modified to suit seawater for Bahrain samples. All samples were immediately filtered by 0.45 μm pore size and acidified to $\text{pH} < 2$. Collective procedure was adopted for chelating, pre-concentration and extraction of Cadmium, Cobalt, Copper, Iron, Manganese, Nickel, Vanadium and Zinc. Extracted and digested samples were analyzed by USEPA Method 200.7 on ICP-OEC. Seawater samples for arsenic determination were preserved with ultra pure low arsenic HCL. At the time of analysis, the samples were pre-reduced and arsenic determined using FIAS-ICPMS- Hydride accessory. Mercury samples were also preserved separately using ultra pure

low Mercury HCL. The analysis was performed by Hydride-Atomic Fluorescence analyzer. All analyses were performed in duplicate and results were averaged. Routine quality assurance/quality control procedures were performed to verify the authenticity of data.

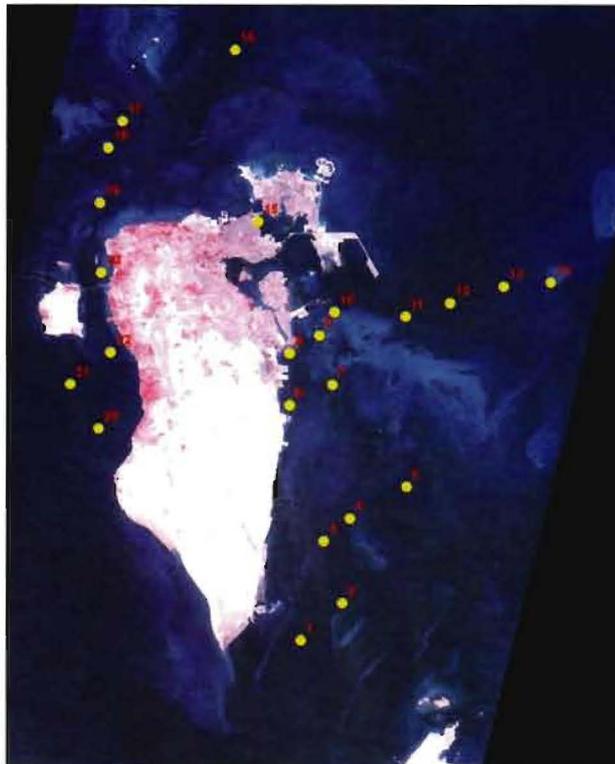


Fig. 1. Sampling Sites.

Series of parallels of blanks were taken through the procedure to measure background levels of the elements. Certified reference materials (CRM) were analyzed to assess the trueness and precision of the analyses. Parallels of CRM Near shore seawater reference material (CASS-4) (National Research Council –Canada Institute for Environmental Research & Technology; NRC-CNRC, Canada) were analyzed together with the seawater samples. The CASS-4 served as reference material for the analyses of Arsenic, Cadmium, Copper, Iron, Manganese, Nickel, Lead, Vanadium, and Zinc. Values obtained in both references seawater (CASS-4) demonstrated very good agreement with certified values (within 95% confidence limit) and a precision of 3–12% (1s) for all elements.

Table 1. Coordinates of Sampling sites and Concentrations ($\mu\text{g/l}$) of Trace Metal in Sea Water of Bahrain Marine Environment.

Ser#	Site	Latitude	Longitude	As	Cd	Cu	Fe	Mn	Ni	Pb	V	Zn	Hg
1	Qassar Noon	N2548822	E5038559	1.51	0.47	20.22	2.63	0.52	0.72	4.78	1.77	19.44	ND*
2	Mashtan	N2551072	E5041057	1.27	0.09	16.65	5.47	0.35	1.35	2.00	2.23	14.13	ND
3	Jabbari	N2554806	E5039941	1.05	0.50	14.21	28.62	0.55	1.65	6.40	2.03	12.97	ND
4	Fasht Tighalib	N2556185	E5041515	2.02	0.81	14.79	7.78	0.29	1.21	2.88	1.38	13.19	ND
5	Ghumais	N2558127	E5044908	0.89	0.06	16.03	7.07	0.24	0.93	2.45	1.76	12.35	ND
6	Askar	N2603087	E5037876	1.11	0.30	13.33	4.65	0.42	0.77	1.66	1.39	10.62	ND
7	Msoor	N2604327	E5040449	0.99	0.12	15.02	9.44	0.09	0.89	1.76	1.48	11.17	0.38
8	Bapco	N2606233	E5037879	2.60	0.13	11.14	8.06	0.23	0.76	2.20	1.46	9.42	ND
9	Algaha	N2607316	E5039672	1.14	0.20	9.42	4.67	0.38	0.84	2.04	1.43	7.52	ND
10	Suhain	N2608731	E5040581	0.85	0.06	5.95	12.74	0.23	0.74	2.59	1.09	5.42	ND
11	Fa>ash	N2608468	E5044859	1.09	0.14	8.29	6.90	0.42	0.88	1.13	1.95	5.47	ND
12	Al Gazara	N2609286	E5047538	1.14	0.06	4.53	15.12	0.44	0.71	1.79	1.83	4.06	ND
12	Dam	N2610281	E5050761	1.15	0.18	29.47	7.78	0.18	1.37	5.30	2.02	23.17	ND
14	Qita'at Jaradah	N2610528	E5053587	1.29	5.20	27.99	8.48	0.40	1.91	4.48	1.87	69.41	ND
15	Marina club	N2614205	E5035955	1.30	0.15	38.41	4.92	0.42	1.60	4.62	2.32	29.96	ND
16	Al Jarim	N2624679	E5034558	1.33	3.50	34.57	6.03	0.71	1.19	5.22	1.70	47.43	ND
17	Khor Fasht	N2620306	E5027787	1.11	0.06	42.78	7.29	1.24	1.20	9.93	2.10	35.21	ND
18	Murwadah	N2618683	E5026925	1.01	0.65	39.81	5.08	0.23	1.29	3.39	2.08	37.56	ND
19	Bartafi	N2615320	E5026437	1.54	0.32	42.91	10.80	0.77	2.01	2.90	2.10	45.36	ND
20	Qassar	N2601663	E5026366	2.05	0.16	44.72	9.46	0.24	0.81	4.63	1.24	40.56	ND
21	Umm Al na'san	N2604370	E5024665	1.97	0.29	106.00	1.03	0.06	0.74	5.16	0.96	118.00	0.13
22	Jazirat Ya'suf	N2606290	E5027087	1.74	0.41	119.00	8.57	0.11	0.93	5.44	1.66	106.00	ND
23	Al Jasra	N2611113	E5026510	2.75	0.53	78.17	4.80	0.61	1.25	6.62	1.15	91.68	ND
	Minimum			0.85	0.06	4.53	1.03	0.06	0.71	1.13	0.96	4.06	0.13
	Maximum			2.75	5.20	119.00	28.62	1.24	2.01	9.93	2.32	118.00	0.38
	Average			1.43	0.63	32.76	8.15	0.40	1.12	3.89	1.70	33.48	0.26

* ND: means Not Detected.

RESULTS

In this study 10 trace elements, namely, As, Cd, Cu, Fe, Mn, Ni, Pb, V, Zn and Hg were determined in Bahrain territorial seawater. The concentrations and range for each element is shown in Table 1 on a site basis. With respect to interpretation of the results, average concentrations are compared firstly to the United States Environmental Protection Agency Recommended Water Quality Criteria, United Kingdom Water quality standards for the protection of saltwater Life, ASEAN Marine Water Quality Criteria, and Malaysian Interim Marine Water Quality Criteria as depicted in Table 2.

Arsenic average concentration is $1.43 \mu\text{g/l}^{-1}$, and in the range of $(0.85 - 2.75) \mu\text{g/l}^{-1}$, the highest value of $5.20 \mu\text{g/l}^{-1}$ was found in Al Jasra site, which is located West Coast of Bahrain, while the lowest value of $0.06 \mu\text{g/l}^{-1}$ was in Suhain. This study revealed that the Arsenic levels are far below the United Kingdom Water quality standards and United States Environmental Protection Agency recommended water quality criteria, and lower than in some other parts of the world, which is clearly depicted in Figure 2.

Cadmium average concentration is $0.63 \mu\text{g/l}^{-1}$, and in the range of $(0.06 - 5.20) \mu\text{g/l}^{-1}$, the highest value of $5.20 \mu\text{g/l}^{-1}$ was reported in Qita'at Jaradah fishing area located in the East of Bahrain, while the lowest value of $0.06 \mu\text{g/l}^{-1}$ was in Suhain. There are no sites in the studied areas with anomalous high levels, and the average concentration of Cadmium is less than the reported values elsewhere, as well as the standards and guidelines of some countries such as UK standards and USA recommended value as depicted in Figure 3. However, it has been considered that the concentration of Cadmium in the sea is less than $0.5 \mu\text{g/l}^{-1}$.

The Copper concentrations ranged from 4.53 to $119.00 \mu\text{g/l}^{-1}$, with an average of $32.76 \mu\text{g/l}^{-1}$. The lowest value of $4.53 \mu\text{g/l}^{-1}$ was in Al Gazara area, while the highest value was $119.00 \mu\text{g/l}^{-1}$ found in Jazirat Ya'suf fishing area. Like Cadmium, the Lead concentrations are not very high for most sites investigated in Bahrain Seawater. The average level of Lead in Bahrain Territorial seawater is about $3.89 \mu\text{g/l}^{-1}$, while

the maximum concentration of $9.93 \mu\text{g/l}^{-1}$ was found at Khor Fasht which is located in the North of Bahrain. Levels neither exceeded USA recommended value of $8.1 \mu\text{g/l}^{-1}$, nor UK standard value of $25.0 \mu\text{g/l}^{-1}$.

Nickel was detected in all water samples. The detected Nickel concentrations ranged from 0.71 to $2.01 \mu\text{g/l}^{-1}$ with a mean of $1.12 \mu\text{g/l}^{-1}$, and the highest concentrations were found at Bartafi site which is located in North West of Bahrain. The results indicated a significant positive relationship between Ni and V and were consistent among sampling sites which assume that petroleum oil is the sources of these two elements.

Figure 4 depicts the Nickel average concentration for all sites investigated in the studied area and some parts of the world. It is similar to that of Cadmium, reflecting the low natural background; hence, Nickel displays low concentrations in sea water throughout Bahrain territorial sea water. United States Environmental Protection Agency recommended water quality criteria ($610 \mu\text{g/l}^{-1}$) was never exceeded, and Nickel concentrations were also far below the United Kingdom Water quality standards of $30 \mu\text{g/l}^{-1}$.

Zinc was detected in all water samples. The detected Zinc concentrations ranged from 4.06 to $118.00 \mu\text{g/l}^{-1}$ with average of $33.48 \mu\text{g/l}^{-1}$, and the highest concentrations were found at Umm Al Na'san site which is located West of Bahrain. Figure 5 depicts the Zinc average concentration for all sites investigated in the studied area and some parts of the world. The average level neither exceed USA recommended value of $81.0 \mu\text{g/l}^{-1}$, nor UK standard value of $40.0 \mu\text{g/l}^{-1}$.

Figure 6 depicts the Mercury average concentration for the detected sites investigated in the studied area and some parts of the world. Mercury was detected in 2 of the 23 samples. The detected Mercury concentrations ranged from 0.13 to $0.38 \mu\text{g/l}^{-1}$ with a mean of $0.26 \mu\text{g/l}^{-1}$, and the highest concentration value of $0.38 \mu\text{g/l}^{-1}$ was found at Msoor site which is located East of Bahrain, and exceeded both United Kingdom Water quality standards and United States Environmental Protection Agency recommended water quality criteria.

Manganese average concentration is $0.40 \mu\text{g/l}^{-1}$, and in the range of $(0.06 - 1.24) \mu\text{g/l}^{-1}$. The

Table 2. Trace metal average value ($\mu\text{g/l}^{-1}$) in sea water in Bahrain and other areas of the World.

Area	As	Cd	Cu	Fe	Mn	Ni	Pb	V	Zn	Hg	Reference
This study	1.430	0.626	32.757	8.147	0.397	1.120	3.886	1.696	33.483		
Canadian guidelines	12.500	0.120									CCME. (1999)
Uk standards	25.000	5.000	5.000	1000.000		30.000	25.000	100.000	40.000	0.300	Grimwood and Dixon (1997)
Malaysian interim standard	100.000	100.000	100.000				100.000			1.000	http://www.doe.gov.my/index.php?option=com_content&task=view&id=71&Itemid=445&lang=en
ASEAN criteria		10.000	8.000				8.500			0.160	http://www.doe.gov.my/index.php?option=com_content&task=view&id=v1&Itemid=110&lang=en
USA Recommended value	36.000	8.800	3.100	300.000	50.00	610.000	8.100		81.000	0.940	http://www.epa.gov/waterscience/criteria/wqcriteria.html
Kuwait		.04-3.4	0.7-16.0				0.7-16.0	2.600	.06-27.5	.01-0.7	Shunbo, <i>et al.</i> , (1986)
North Sea		16.000	140.0				31.000		10.000		Balls, PW (1986)
Greece		0.2-1.3	0.04-4.59	2.58-150.7		0.17-2.79	0.28-2.3		1.14-30.5		eleftheriadou and Skoullo (2003)
Saudi (Arabian Gulf)		1.692	2.678	37.260	3.652	2.166	2.116	3.828	14.284		SadiQ 1993
Baltic Sea		0.030	0.3 - 52						1 - 120		Baltic Marine Environment Protection Commission, (1987)
Atlantic water		8.000	70.000				30.000		10.000		Balls, PW (1986)
South-East Spain	1.500			1.500							Navarro <i>et al.</i> (1993)
Pakistan		54	504	1114	124	181	476		226		Qari and Siddiqui (2005)

highest value of $1.24 \mu\text{g l}^{-1}$ was reported in Khor Fasht fishing area, while the lowest value of $0.06 \mu\text{g l}^{-1}$ was in Umm Al Na'san. However, there are no sites in the studied areas with high levels, and the average concentration of Manganese was less than the reported values ($2.1 \mu\text{g l}^{-1}$) of Saudi Arabia (Sadiq and McCain, 1993), and far below United States Environmental Protection Agency recommended water quality criteria, as depicted in figure 7.

Iron average concentration is $8.15 \mu\text{g l}^{-1}$, and in the range of $(1.03 - 28.62) \mu\text{g l}^{-1}$, the highest value of $28.62 \mu\text{g l}^{-1}$ was reported in Jabbari fishing area which is located East of Bahrain, while the lowest value of $1.03 \mu\text{g l}^{-1}$ was in Umm Al Na'san.

Figure 8 shows the Iron average concentration for all sites investigated in the studied area and some parts of the world, and it displays low concentrations in sea water throughout Bahrain territorial sea water.

Vanadium average concentration is $1.70 \mu\text{g l}^{-1}$, and in the range of $(0.96 - 2.32) \mu\text{g l}^{-1}$, the highest value of $5.20 \mu\text{g l}^{-1}$ was reported in Marina Club resort area, while the lowest value of $0.06 \mu\text{g l}^{-1}$ was in Umm Al Na'san Fishing area. Vanadium displays low concentrations throughout Bahrain territorial sea water, and its concentrations were also far below the United Kingdom Water quality standards of $100 \mu\text{g l}^{-1}$.

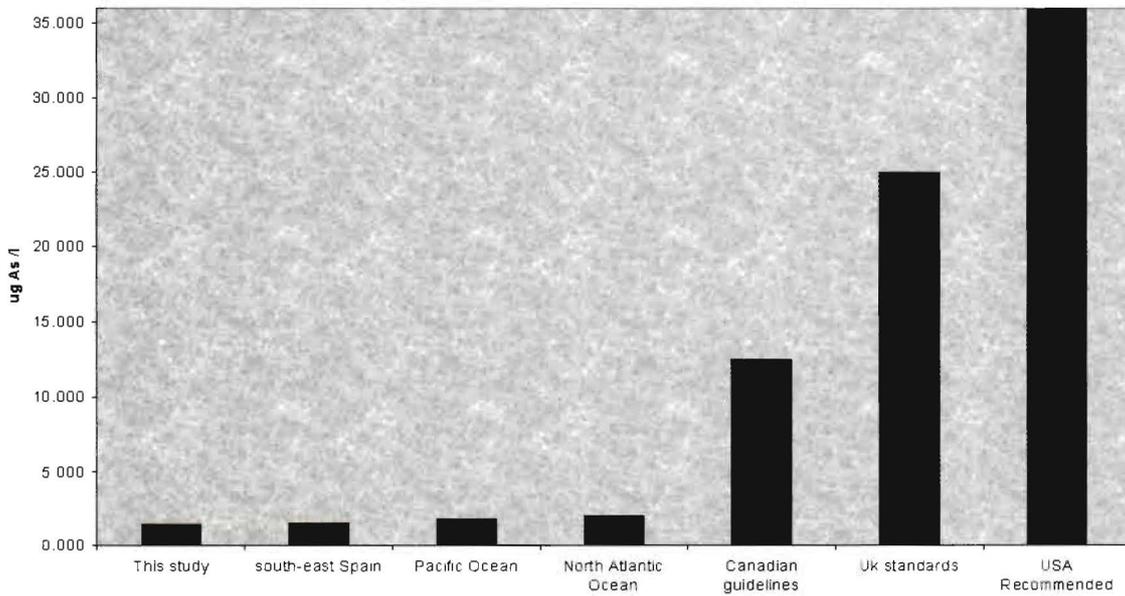


Fig. 2. Arsenic Concentration $\mu\text{g/l}$.

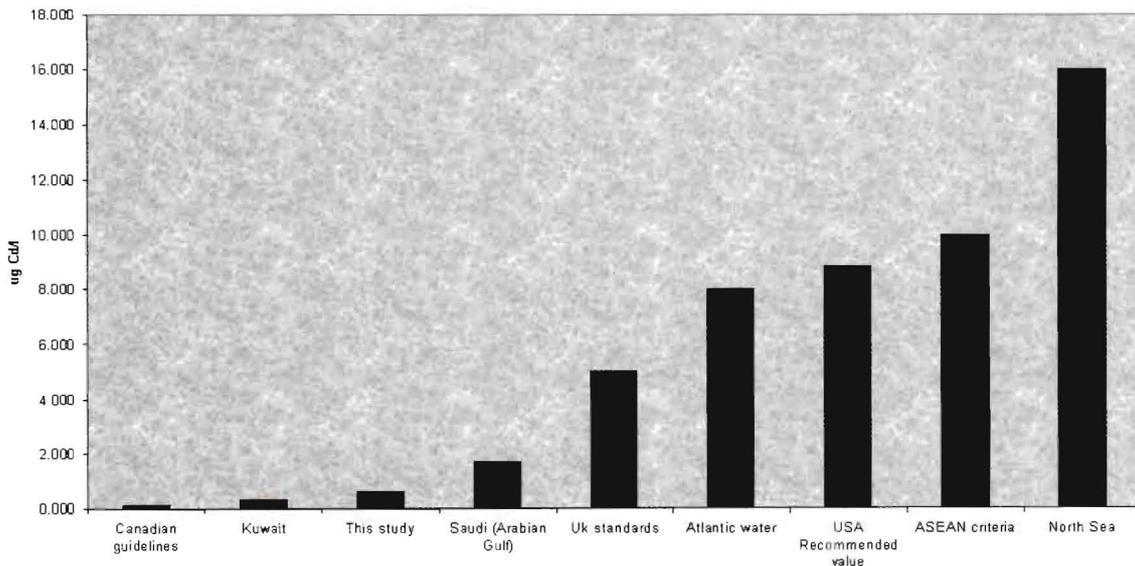


Fig. 3. Cadmium Concentration $\mu\text{g/l}$.

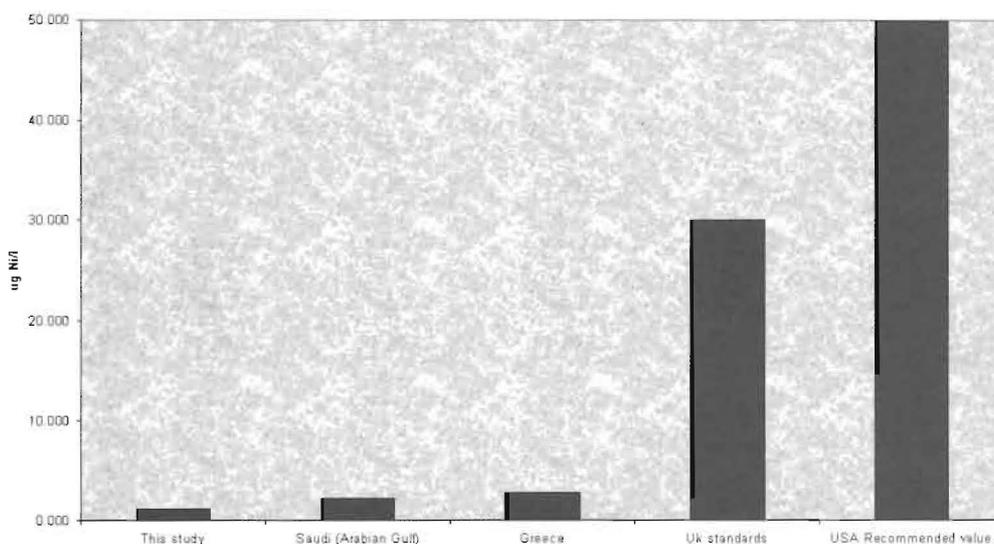


Fig. 4. Nickel Concentration $\mu\text{g/l}$.

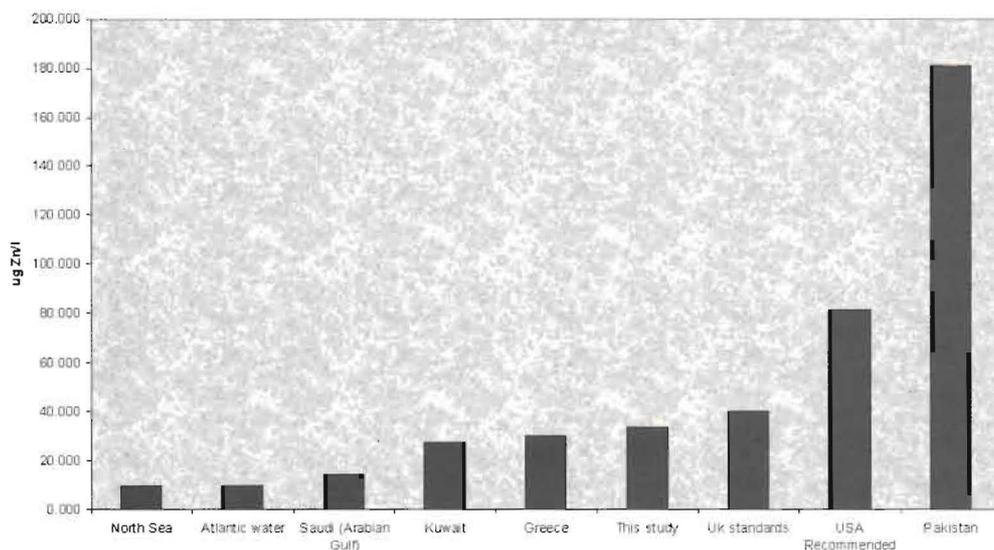


Fig. 5. Zinc Concentration $\mu\text{g/l}$.

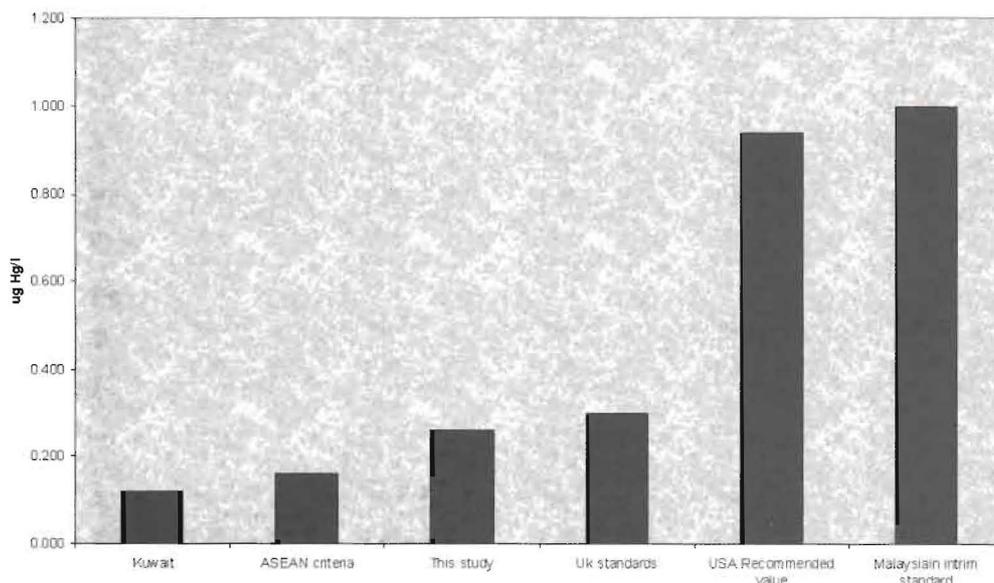


Fig. 6. Mercury Concentration $\mu\text{g/l}$.

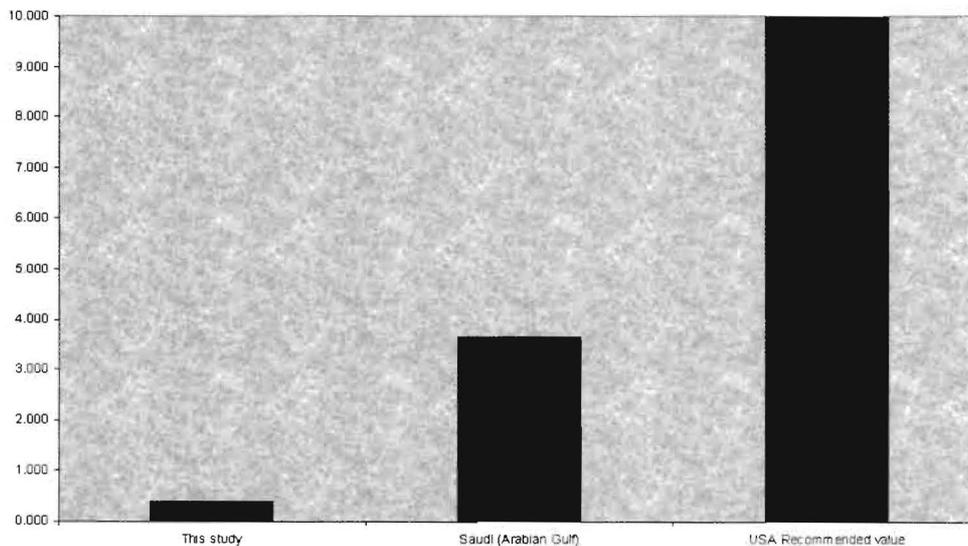


Fig. 7. Manganese Concentration $\mu\text{g/l}$.

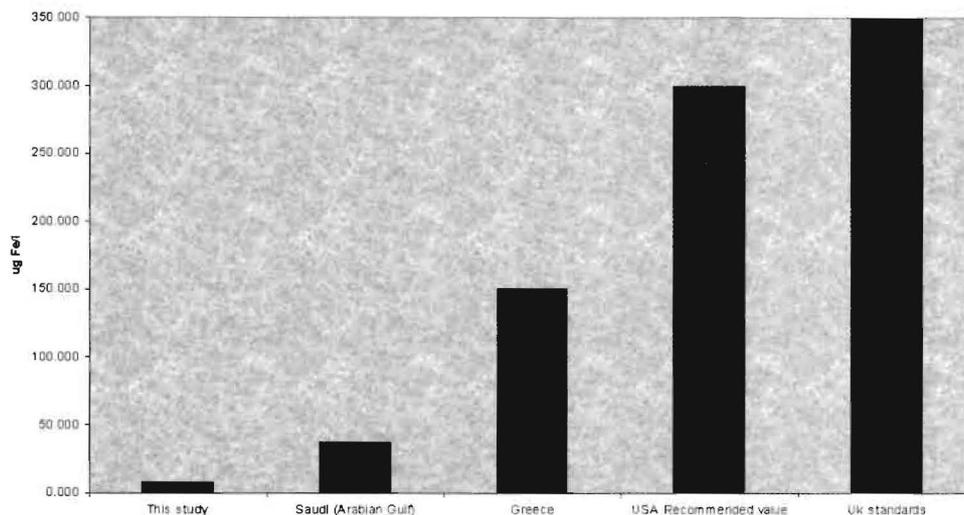


Fig. 8. Iron Concentration $\mu\text{g/l}$.

DISCUSSION

Arsenic concentration within the reported range of $(0.85 - 2.75) \mu\text{g/l}^{-1}$ is considered a typical value for the uncontaminated offshore waters as the concentrations of arsenic in open ocean seawater are typically $1-2 \mu\text{g/l}^{-1}$. Cutter and Cutter (1998) reported value of arsenic in sea water of $2 \mu\text{g/l}^{-1}$, in the North Atlantic Ocean. Navarro *et al.* (1993) reported mean value of $1.5 \mu\text{g/l}^{-1}$ for arsenic in coastal waters, South-East Spain. Bodewig, *et al.* (1982) also, found arsenic in Pacific Ocean with a mean of $1.8 \mu\text{g/l}^{-1}$. High levels of arsenic have been recorded in thermal waters. Tanaka (1990) found Arsenic with a mean concentration of $570 \mu\text{g/l}^{-1}$ in geothermal waters throughout Japan, with a maximum level of 25.7mg/l^{-1} .

The average Cadmium content in the world's

oceans has variously been reported as low as $<5 \text{ng/L}$ (WHO 1992) and $5-20 \text{ng/L}$ (OECD 1994, Jensen and Bro-Rasmussen, 1992) to as high as 110ng/L (CRC 1996), 100ng/L (Cook and Morrow 1995) and 10 to 100ng/L (Elinder 1985). Higher levels have been noted around certain coastal areas (Elinder 1985) and variations of cadmium concentration with the ocean depth, presumably due to patterns of nutrient concentrations, have also been measured (WHO 1992, OECD 1994). It is worth mentioning that on the basis of the cadmium average value, sea waters within the studied areas are comparable to those found in unpolluted worldwide areas. The results of Copper suggest that the value of all sites sampled were higher than the reported value in Saudi Arabia (Sadiq and McCain, 1993) and Kuwait (Shunbo *et al* 1986) as illustrated in figure 9. They also exceed

UK standard and USA recommended value for copper. However, the average value is less than the reported value of other areas such as North Sea and Baltic Sea as depicted in figure 9.

Balls (1985) reported average levels of 140.00 $\mu\text{g/l}$ in the Northern North Sea and the average in Atlantic water was 70.00 $\mu\text{g/l}$. WHO (1998) stated that Copper is widely distributed in water because it is a naturally occurring element, Copper levels in seawater of 0.15 $\mu\text{g/l}$ is found in uncontaminated areas. The results assumed that the high concentrations of Copper stem from its high rate of natural occurrence in the territorial seawater of the Kingdom of Bahrain

Lead (Pb) average value of 3.89 $\mu\text{g/l}$ is higher than the reported value (2.1 $\mu\text{g/l}$) of Saudi Arabia, (Sadiq and McCain, 1993) and Kuwait (2.2 $\mu\text{g/l}$, (Shunbo, *et al.* 1986) in the Arabian Gulf. The slight high level of Pb in compared to other Gulf States could be attributed to the fishing pattern where by lead is used in most of fishing materials such as nets and hooks, also suspension or mobilization of the sediment into the water column as a result of extensive reclamation activities being taking place in coastal areas and shallowness of territorial sea water could contribute to Pb results.

Balls (1985) reported average levels of 31.00 $\mu\text{g/l}$ in the Northern North Sea, and the average in Atlantic water was 30.00 $\mu\text{g/l}$. The reported level of Pb (2.3 $\mu\text{g/l}$) in the Gulf of Astakos of Ionian Sea in Greece is also less than the average of the studied area. Nevertheless, compared to the lead levels in other parts of the World such as Atlantic and North seas (Figure 10).

Nickel concentrations of 0.228-0.693 $\mu\text{g/l}$, determined for a vertical open-ocean water profile, were considered to reflect the actual nickel concentration in this medium (Bruland, *et al.* 1979). Nickel levels usually tend to be elevated in areas subject to release of crude oil. However, it should be mentioned that another major source of input of nickel into the marine environment is the corrosion of copper/nickel pipes and fittings used extensively in this area whereas desalination/power plants and cooling system utilizing water. Despite all these factors, compared to the nickel levels in other parts of the World (see, Figure 4), the average level of Nickel

in studied area of Bahrain Territorial Sea water is one of the lowest among other.

The studied areas reported zinc average value of 33.48 $\mu\text{g/l}$ was higher than the reported value (14.28 $\mu\text{g/l}$) of Saudi Arabia (Sadiq and McCain, 1993) and Kuwait 27.5 $\mu\text{g/l}$ (Shunbo, *et al.* 1986), for the Arabian Gulf, while Balls, (1985) reported average level of 10.00 $\mu\text{g/l}$ in the Northern North Sea. However, it was far below the reported value of 181 $\mu\text{g/l}$ in Karachi of Pakistan (Qari and Siddiqui, 2005) Like Copper, the results suggest that the high concentrations of zinc stem from its high rate of natural occurrence in the territorial seawater of the Kingdom of Bahrain.

The Mercury average value of the studied areas of 0.26 $\mu\text{g/l}$ was higher than the reported value (0.12 $\mu\text{g/l}$) of Kuwait (Shunbo, *et al.* 1986), for the Arabian Gulf. Few measurements have been made of the concentration of Mercury in sea water and there are considerable differences in the values reported. Leatherland, *et al.* (1971) stressed that high values of 1.6 to 3.6 μg total Hg/l. for samples from Minamata Bay, Japan, probably reflect the serious pollution of that area. Ocean water from the North-Western Pacific has been reported to contain from 0.06 to 0.27 $\mu\text{g/l}$, with the highest concentrations in deep water. In the analysis of waters from the Solent and the English Channel, these were found to contain lower amounts of Mercury, from 0.014 to 0.021 $\mu\text{g/l}$, which are quite similar to that (0.03 $\mu\text{g/l}$) found for a single sample from off Heligoland. It is worth mentioning that these two detected sites of the studied area should be furthered investigated to explore the causes of these high values.

An average concentration of Manganese in seawater of 0.4 $\mu\text{g/l}$ was reported by Turekian (1969). In other studies on the manganese contents of sea water in the North Sea, the North-East Atlantic, the English Channel, and the Indian Ocean, concentrations ranged from 0.03 to 4.0 $\mu\text{g/l}$ with mean values of 0.06-1.2 $\mu\text{g/l}$. In estuarine and coastal waters of the Irish Sea and in waters along the North Sea shores of the United Kingdom, values ranging from 0.2 to 25.5 $\mu\text{g/l}$ have been reported with mean values of 1.5-6.1 $\mu\text{g/l}$ (Topping, 1969; Preston, *et al.* 1972; Jones, *et al.* 1973; Bouquiaux, 1974.

Concentration of iron in seawater up to

about 3mg l^{-1} (Armstrong, 1957). United States Environmental Protection Agency recommended water quality criteria ($1000\ \mu\text{g l}^{-1}$) was never exceeded, and Iron concentrations were also far below the United Kingdom Water quality standards of $300\ \mu\text{g l}^{-1}$.

Vanadium is present at $11.79\ \mu\text{g l}^{-1}$ concentrations in seawater, making it the most abundant transition metal in the aqua sphere. Figure 11 depicts the Vanadium average concentration for all sites investigated in the studied area and some parts of the world.

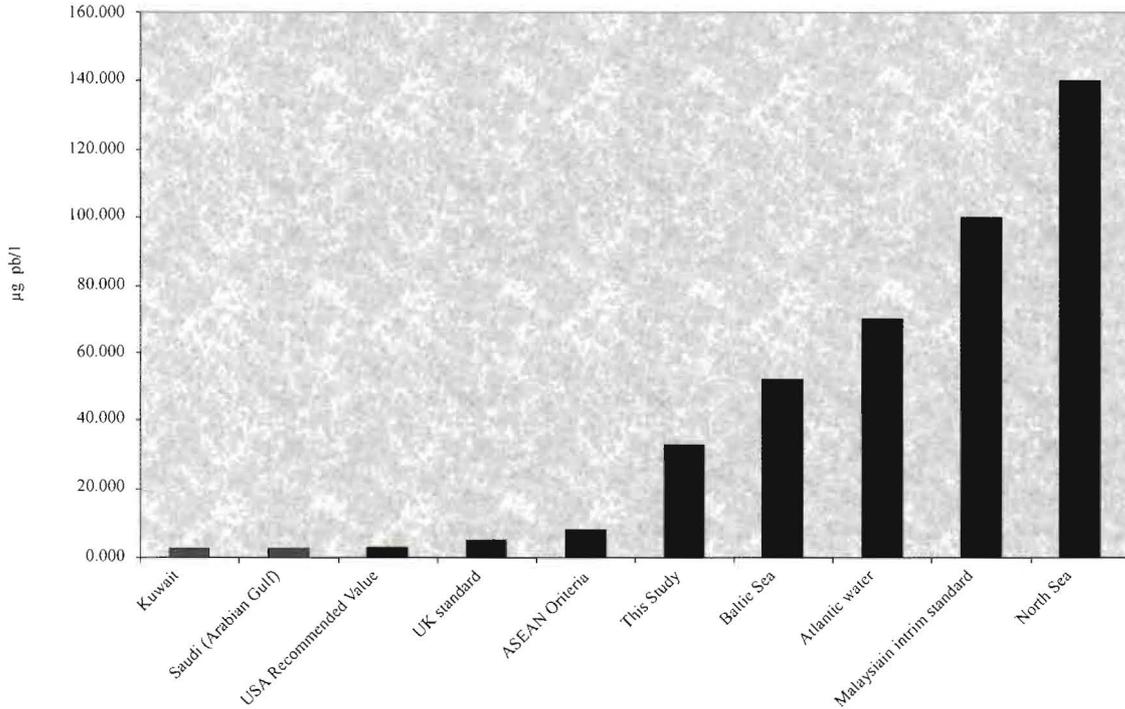


Fig. 9. Copper Concentration $\mu\text{g/l}$.

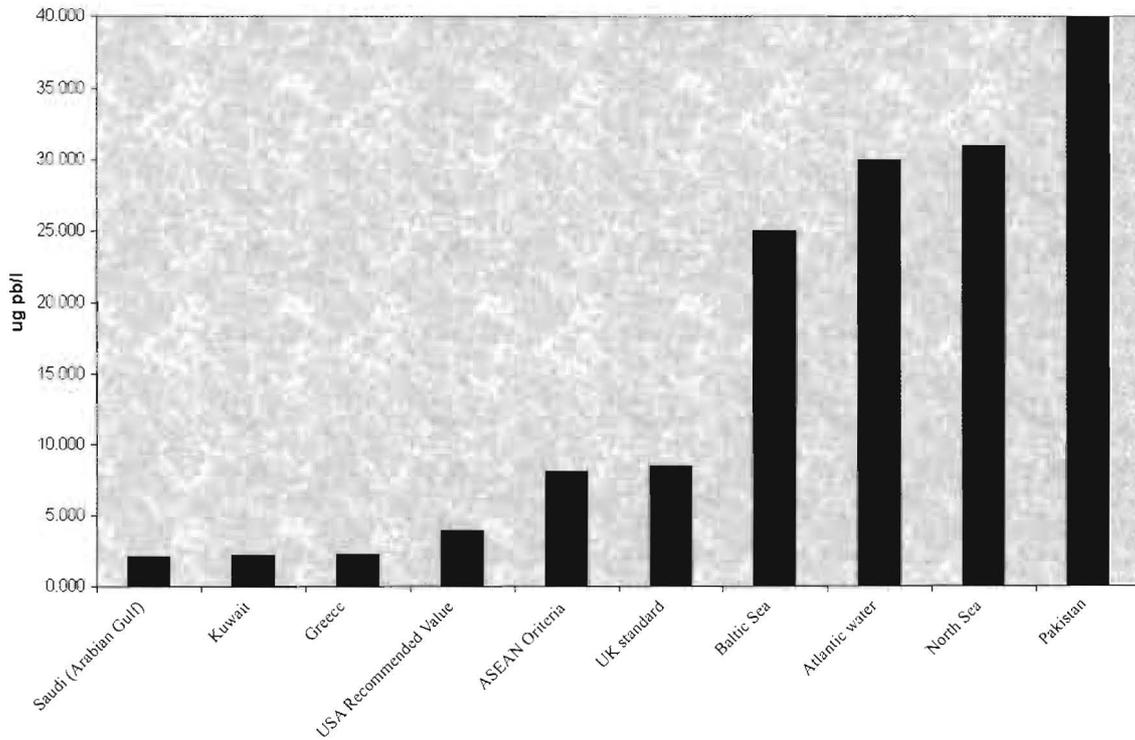


Fig. 10. Lead Concentration $\mu\text{g/l}$.

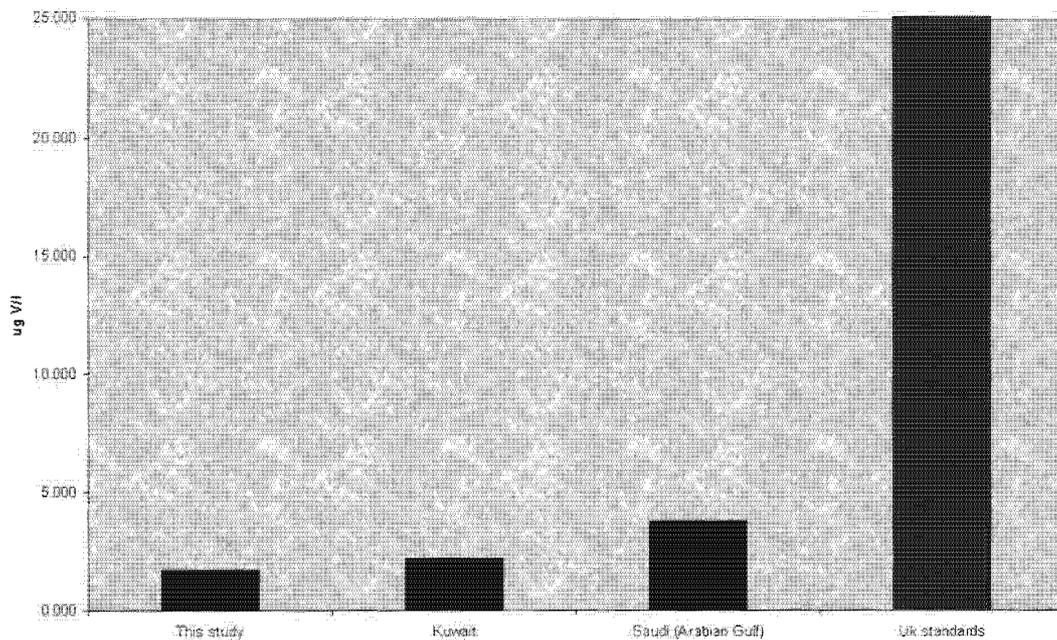


Fig. 11. Vanadium Concentration $\mu\text{g/l}$.

CONCLUSION

As no quality standards for trace metal for Bahrain marine waters are available, an overview United Kingdom Water Quality Standards and United States Environmental Protection Agency recommended water quality criteria value has been used. A comparison between these assessment levels shows that all the measured trace metals, with the exception of copper, remained within the specified limits.

It is worth mentioning that on the basis of the total elements concentrations, the Sea Water from the studied areas are comparable to those found in unpolluted worldwide areas, and reveal that the effect of anthropogenic enrichment upon concentration of the elements is nominal.

The results suggest that the Kingdom of Bahrain's marine waters seem to be of good quality as the concentrations of the metals reported in the studied areas are far below the United Kingdom Water quality standards and United States Environmental Protection Agency recommended water quality criteria, with the exception of Copper.

It is worth mentioning that, as far as Mercury is concern, the detected sites of the studied area should be furthered investigated to explore the causes of these high values.

It is difficult to draw any broad conclusion

regarding the trace metal levels in the territorial sea water of the Kingdom of Bahrain, because there is no comparable data available for Arabian Gulf region. Considering this fact, we feel that the data presented here can serve as a baseline for future studies in this area.

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