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AN OUTLOOK TO THE BAHRAIN MARINE ENVIRONMENT WITH SPECIAL REFERENCE TO THE IMPACT OF POWER AND DESALINATION PLANT OUTLETS

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CHALLENGES ON NEW HORIZON TOWARDS MANAGING THE GLOBAL ENVIRONMENT AND WATER RESOURCES.

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Abstract

The presence of petroleum hydrocarbon and trace metals was confirmed in seawater and sediment in the marine environment of the Kingdom of Bahrain . Results of nearshore monitoring during the period 1993-1998 indicated , in general, that concentration of the trace metals were higher in water columns than sediments and the contrary was with the petroleum hydrocarbon. However , trace metals in industrial transected sediments collected from the coastal areas during the monitoring period 2001-2002 showed that Pb>Cd>Zn>Cu compared to the nearshore sediments monitored during the period 1993-1998 that showed Zn>Pb=Cu>Cd. This study confirms that the lead pollution is mainly concentrated in the vicinity of petroleum industry and that the Zinc and Cadmium in both the Sitra Power Plant(SPP) and the oil refinery of Bahrain Petroleum Company(Bapco) areas . SPP area showed higher pollution of Nickel, Copper and Chromium. The elevated concentration of trace metals; zinc, copper, nickel, chromium, in vicinity of SPP is perhaps attributed to the multi-flash stage operational system where it is expected that trace metals are coming off during clean up the distillers. The marine sediment collected from the neighborhood of Reverse Osmosis Plant (ROP) showed higher concentrations in lead and copper, where the marine sediment in immediate area of the oil refinery exhibited higher levels of zinc, copper, lead and cadmium.

Introduction

The first Marine Monitoring Programme around the Island Kingdom of Bahrain was started through the initiation of Marine Ecosystem Study in 1988 and 1989 where seven sites in three cruises were monitored for their physical, biological and chemical variations. At that time the sampling regime was insufficient to produce a substantial judgement on the state of the marine environment (1). Therefore, this study gives a more insight picture on the state of marine environment off the East Coast of the Kingdom of Bahrain during the monitoring period extended between 1993 to 1998, and complemented with transect study in 2001 and 2002 for industrial and developmental pollution identification and assessment.

Materials and methods

Four sampling sites (map 1 ; their coding is: 1 sailing club , 2 Alba , 3 Ras Abu Jarjour Desalination Plant (Reverse Osmosis Plant; ROP) , 4 Askar) were monitored for the trace metals (Cd, Cu, Pb , Zn) and petroleum hydrocarbons contaminants following the unified analytical procedures recommended by the Regional Organisation for the Protection of the Marine Environment, ROPME (2).

On brief, trace metals and petroleum hydrocarbons in seawater and sediments were analyzed volumetrically (VA processor) and spectroflorometrically respectively, during a six-year period (1993-1998) in the filtered fraction of nearshore surface seawaters sampled at monthly, seasonally and then biannually frequencies at 4 different sites off the East Coast of the Kingdom of Bahrain . Monitoring stations adopted after ROPME to evaluate the degree of pollution in an area receiving industrial, agricultural and urban wastes.

The monitoring programme for the year 2001and 2002 was adjusted to evaluate the impact of the industry (refer to table 1 for details), and to illustrate the zonations(0,500,1000 metres from the outfalls) of such impact. The monitored industries included in the year 2001 were BAPCO (representing oil refining industry) and both Sitra (SPP) and Reverse Osmosis Plant(ROP) desalination and power plants and in the year 2002 , the Addur Desalination Plant (ADP).

Both SPSS and Minitab statistical packages were used ,and One way Analysis of Variance (ANOVA) statistical analysis was employed on the data sets to examine temporal and spatial variations. This was further supported with time series trend analysis to elucidate the overall trend dominated on each monitored contaminant. In addition descriptive statistics were provided for comparisons with other studies.

Results and discussion

Petroleum Hydrocarbons in Seawater and Sediment

Figure 1: illustrates the overall trend in petroleum hydrocarbons in seawater for 112 samples .The trend shows a slight increase and that the Mean is 2.53 μg/l with a minimum 0 μg/l and maximum 11.40 μg/l. Figure 2 shows

that the lowest mean value 1.48 μg /l is reported in 1995 , and the maximum value 3.28 μg/l is reported in 1998 .ANOVA test among years indicated non significance [f(5,111)= 0.045;NS]. Figure 3 demonstrates the petroleum hydrocarbons spatial variation where the maximum mean is 3.1 μg /l registered in station 1 and that the lowest is 2.1 μg/l found in station 4. ANOVA test showed non-significance among stations [f(3,111)= 0.164;NS]. Table 2 gives the concentrations of Petroleum hydrocarbons in seawater in this study which ranged from zero to 11.400 μg /l .Previous study showed the mean concentration ranges 22.4 - 43.3(3). In the NW ROPME the range is 0.10 - 16.8 μg /l (4), whereas in the Mediterranean Sea the range is 1-123 μg /l (cited in 5), and in Australia the range is 0.1 -22.6 μg /l (6). It is obvious that the reported results are within the previously reported values in the area and they are indeed far below the Bahrain Environmental affairs Standard that is 8 and with max 15 mg/l. (7).

Figure 4: gives the overall trend in petroleum hydrocarbons in sediment for 24 samples . The trend is sharply decreasing and that the Mean is 141.25 mg/kg with a minimum 30 mg/kg and maximum 266 mg/kg. Figure 5 shows the temporal variation in petroleum hydrocarbons in sediment for the period 1993 until 1998. The lowest mean value 107.15 mg/kg is reported in 1996 and the maximum mean value 182.17 mg/kg is reported in 1993. ANOVA test among years indicated non significance [f(5,23)= 0.243;NS]. Table 3 gives the concentrations of petroleum hydrocarbons in sediments in this study and other studies conducted on Bahrain Marine Environment and the ROPME region as well as other areas. In this study the concentration range is 30 - 266 mg/kg and this is higher than that found during the Gulf war which ranges from 14.6 - 182 mg/kg (8) and the mean is 14 mg/kg , or other study which showed that the range is 15-38 mg/kg (9) or before the war during the period extended from 1983- 1986 that ranged from 20.3 - 103 mg/kg (9) , and in the ROPME sea area ranged from 0.1- 950 mg/kg.(4) . In the Black Sea ranged from 2- 300 mg/kg (10), and in Cartagena Bay, Columbia ranged from below 10 - 1415 mg/kg (11). Lower concentrations represent background levels while the upper range demonstrates concentrations in areas under direct impact of pollution(4). The reported concentrations are higher than the previously described values for Bahrain but are within the range reported for the region. The reduced general trend found by Fowler et. al. (1993) for the ROPME Sea Area was attributed to the low oil tanker traffic during the Gulf war crises which resulted in a decreased release of contaminated ballast water that is estimated to be 2 million barrels per year.

Both crude and refined petroleum usually consist of hundreds of chemical substances. Chemically the components of crude petroleum can be divided into two classes: alkanes and aromatic hydrocarbons. The aromatic hydrocarbons include the environmentally suspect Polycyclic Aromatic Hydrocarbons (PAHs) which occur in relatively low concentrations in most petroleum substances. Refined petroleum products can contain the alkenes that are prepared synthetically and are somewhat similar to the alkanes in environmental properties (6).

All of these products are manufactured in Bahrain petrochemical plants. In addition 50% of the Global marine transport of crude petroleum is shipped from the ROPME sea area to the world from Inland and Marine oil fields (4). Most of these activities have generated discharges during production processes as well as accidental spills. Petroleum substances also occur in relatively low concentrations in sewage and urban run-off, but the total amount discharged is relatively high due to the large volumes involved. It is estimated that during the period from mid June 1996 until first week of March 1998, there were 7 oil tankers leaked 16400 metric tonnes or 4,823,529.27 US gallons of crude oil. It should be mentioned here that during the Nuwrouz oil well blow out in 1983 more than 68 000 tonnes leaked into the marine environment and that between 6-12 M barrels were poured into the area from Mina Al Ahmadi during the liberation of Kuwait in early 1991. In addition , during 1991 the Kuwait oil field fires emitted / ignited some 500 million barrels (67 million t) which could have potentially contaminated the Gulf environment with aerosols, soot, toxic combustion products and oil derived heavy metals (9).

A range of chemical, histopathological and ecological indicators can be used to evaluate the effects of petroleum in Bahrain waters. The most valuable chemical indicator is the occurrence of petroleum in sediments. Water is not a satisfactory medium for monitoring, since concentrations of petroleum are very low and that occurrence can be changed by weather conditions and seasonal changes. On the other hand sediments exhibit relatively high concentrations and are not affected by the factors mentioned previously.

Trace metals in seawater and sediment

Figure 6 shows the overall trend in zinc in seawater for 108 samples . The trend is slightly decreasing and that the Mean is 15.20 μg /l with a minimum 1 and maximum 124 μg /l . Figure 7 demonstrates the temporal variation in zinc in seawater for the period 1993 until 1998. The lowest mean value 8.30 μg /l is reported in 1998 and the maximum mean value 24.48 μg /l is reported in 1994 . ANOVA test among years indicated non significance [f(5,107)= .017;NS]. Figure 8 exhibits the spatial variation in zinc in seawater where the maximum mean 18.37 μg /l is registered in station 2 and that the lowest 11.85 μg/l is found in station 4. ANVOVA test showed non-significance among stations [f(3,107)=0.444;NS]. Figure 9 presents the overall trend in zinc in sediment for 24 samples . The trend is dropping and that the Mean is 41.30 mg/kg with a minimum 21 mg/kg and maximum 110.07 mg/kg. Figure 10 gives the temporal variation in zinc in sediment for the period 1993 until 1998. The lowest mean value 23.75 mg/kg is reported in 1995 and the maximum mean value 53.58 mg/kg is reported in 1993 . ANOVA test among years indicated non significance [f(5,23)= .069;NS]. Figure 11 characterises the overall trend in cadmium in seawater for 104 samples . The trend is slightly declining and that the Mean is 0.12μg /l with a minimum 0.001μg /l and maximum 0.71μg /l. Figure 12 describes the temporal variation in cadmium in seawater for the period 1993 until 1998. The lowest mean value 0.095μg /l is reported in 1994 and the maximum mean value 0.156μg /l is reported in 1995 .ANOVA test among years indicated non significance [f(5,103)= 0.589;NS]. Figure 13 demonstrates the spatial variation in cadmium in seawater where the maximum mean 0.133μg /l is registered in station 1 and that the lowest 0.108μg /l is found in station 2. ANVOVA test showed non-significance among stations [f(3,103)=0.855;NS]. Figure 14 shows the overall trend in cadmium in sediment for 15 samples . The trend is falling and that the Mean is 0.09 mg/kg with a minimum 0.01 mg/kg and maximum 0.10 mg/kg. Figure 15 shows the temporal variation in cadmium in sediment for the period 1994 until 1998. The lowest mean value 0.01 mg/kg is reported in 1996 and the means are equal for the other years. Figure 16 pictures the overall trend in lead in seawater for 107 samples . The trend is slightly decreasing and that the Mean is 16.25μg /l with a minimum 1.20 and maximum 87.60μg /l. Figure 17 shows the temporal variation in lead in seawater for the period 1993 until 1998. The lowest mean value 10.71μg /l is reported in 1998, and the maximum mean value 23.03μg /l is reported in 1994 .ANOVA test among years indicated non significance [f(5,106)= .004;NS]. Figure 18 demonstrates the spatial variation in lead in seawater where the maximum mean 20μg /l is registered in station 2 and that the lowest 13.05 μg /l is found in station 4. ANVOVA test showed non-significance among stations [f(3,106)=0.144;NS]. Figure 19 shows the overall trend in lead in sediment for 24 samples . The trend is abruptly decreasing and that the Mean is 48.75 mg/kg with a minimum 24 mg/kg and maximum 76.95 mg/kg. Figure 20 shows the temporal variation in lead in sediment for the period 1993 until 1998. The lowest mean value 28 mg/kg is reported in 1995 and the maximum mean value 62.56 mg/kg is reported in 1993 .ANOVA test among years Indicated significant differences[f(5,23) = 0.001] between 1993 and both 1994 and 1995(mean=42). Figure 21 depicts the overall trend in copper in seawater for 107 samples . The trend is slightly descending and that the Mean is 3.04μg /l with a minimum 0.10μg /l and maximum 17.60μg /l. Figure 22 illustrates the temporal variation in copper in seawater for the period 1993 until 1998. The lowest mean value 2.08μg /l is reported in 1995,and the maximum mean value 3.63μg /l is reported in 1993 . ANOVA test among years indicated non significance [f(5,106)= 0.368;NS]. Figure 23 demonstrates the spatial variation in copper in seawater where the maximum mean 3.52μg /l is registered in station 4 and that the lowest 2.56μg /l is found in station 3. ANVOVA test showed non-significance among stations [f(3,106)=0.450;NS]. Figure 24 shows the overall trend in copper in sediment for 24 samples . The trend is declining and that the Mean is 28.73 mg/kg with a minimum 11 mg/kg and maximum 76.95 mg/kg. Figure 25 gives the temporal variation in copper in sediment for the period 1993 until 1998. The lowest mean value 16.67 mg/kg is reported in 1994 and the maximum mean value 37.45 mg/kg is reported in 1993 .ANOVA test among years indicated non significance [f(5,23)= 0.173;NS].

Trace metals are a major anthropogenic contaminant of estuarine and coastal waters. Their inputs include urban run-off, industrial effluents, mining operations and atmospheric depositions, and may be in particulate or dissolved forms. Although many are essential biological elements, all have the potential to be toxic to organisms above certain threshold concentrations, and for the protection of aquatic biota it is important that these limits not be exceeded in aquatic environments (4).

Because most heavy metals tend to accumulate in sediments , their presence in the water column is usually the result of recent inputs. Metal concentrations can vary significantly over short distances and as a function of tide. Single measurements at a given site may indicate contamination.

Table 4 gives the ranges of seawater trace metals reported in this study that are determined to be Zn (1 - 124), Cd (0 - 0.71) , Pb (1.20 - 87.6) , and Cu (0.10 - 17.60) μg /l . The State of the Environment Report did include trace metals in the ROPME seawater environments for 3 states only, for Bahrain, Kuwait and Qatar . However, In Australia, open ocean concentrations are estimated to be in the ranges for zinc (0.003-0.6), cadmium (0.0001-0.12

), lead(0.001-0.04), copper (0.03-0.4 µg /l), . In Houston Ship Channel, USA, the range values were determined to be for zinc (30-280) , cadmium (0.3 - 3.3) , copper (0.3-25) and the lead average value is 0.68 µg /l.

Notwithstanding the fact that the reported values in this nearshore study (years 1993-1998) are below the Bahraini effluent standard, nevertheless the lead level reported in this study is exceptionally high compared with other areas and this may indicate that the area is under recent pollution loads and this will be dealt with in the sediment section.

Table 5 shows the ranges of sediment trace metals reported in this study for the nearshore (1993 until 1998) ranged for Zn (21-117.07), Cd (0.01 - 0.10), Pb (24.00 - 76.95), and Cu (11.00 - 76.95) mg/kg , and during the period January 1983 until June 1991 ranged for Bahrain for Zn (2.34-3.79), Cd (0.011), Pb 0.64-24), and Cu (1.16-17.6).

The pollution zonations studies for both years 2001 and 2002 for Zn(figures 26,27) ranged (12-451) and (3.6-29) respectively, Cd(figures 28,29) ranged (71-587) and (19-147) respectively, Pb(figures 30,31) ranged (0-846) and (0-12) respectively, Cu(figures 32,33) ranged (9.4-257) and (4-60) respectively, Ni (Figures 34,35) ranged (10-181) and (4-60) ,respectively, for Cr(Figures 36,37) ranged (34-436) and (11-46) respectively, for Mn for year 2002 only(figure 38) ranged (23-64)) Mg/kg.

Comparing these results with other parts in the ROPME region ranged for Zn(0.7-410.3) Cd (0.01- 4.5), Pb (0.2 - 64.3), and Cu (1.3 - 142) mg/kg , and in the outside the region , in the Antarctic the mean values and the standard errors of the mean are determined to be for the Zn(42.3±10.4) Cd(0.26±0.16), Pb (20.7±2.8) mg/kg. In Semarang , Indonesia, the mean values Zn(1257) Cd (< 0.03), Pb (2666), and Cu (448) mg/kg with the reference values Zn (132.2), Pb (25.6), and Cu (40.7). DelValls *et. al.*(1998; (reference23)) evaluated heavy metal sediment toxicity in littoral ecosystem using juveniles of fish. He suggested the following site-specific sediment quality values; Cd ≥ 1.24, Pb ≥52.5, and Cu ≥ 71.2 mg/kg of dry sediment.

Trace metals sediments in industrial and developmental projects

The monitored industries included in the year 2001 were BAPCO (representing oil refining industry) and both Sitra Power Plant (SPP) and Reverse Osmosis Plant(ROP) , and in the year 2002 , the Addur Desalination Plant(A.D.P).

Figure 26 shows the ranking comparison of the zinc in a transected sediments sampled in 2001. The range is 451-12 mg/kg with the maximum in the vicinity of the SPP outfall. Both SPP and Bapco showed exceedances above 124 mg/kg of the Canadian guidelines. Figure 27 gives the zinc in the transected sediments sampled in 2002. The range is 29-4 mg/kg and all values are within the accepted limit.

Figure 28 depicts the cadmium in the transected sediment in 2001.The range is 587-71 ug/kg. The highest value was reported at 500m distance from Bapco discharge and the lowest was in the 500m distance from the ROP outfall. Figure 29 gives the cadmium in transected sediment in 2002. The range is 147-19 ug/kg. The reported values in both years are below the Canadian ISQG= 700 ug/kg.

Figure 30 demonstrates the spatial variation in the lead in the transected sediments sampled in 2001. The lowest background is zero value in both Jasra(west coast of Bahrain) and north Meridien(north coast of Bahrain) areas. The highest concentrations reported in the Bapco oil refinery area and extends to the Ras Abu Jarjour Reverse Osmosis Plant maximum values 846-37 mg/kg were reported and they are above the 30.2 mg/kg of the Canadian guidelines. Figure 31 shows the lead in the transected sediment in 2002. The range is 12-0 mg/kg. The highest was in Askar and zero values were reported in Askar and north Meridien and addur zero and 500 metre distance from the discharge points.

Figure 32 exhibits the spatial variation in copper in a transected sediments sampled in 2001. The range is 257- 9 mg/kg with the maximum in the vicinity of both the SPP and Bapco outfalls . SPP, Bapco and Ras Abu Jarjour Reverse Osmosis Plant showed exceedances above 18.7 mg/kg of the Canadian guidelines, while the figure 33 shows the copper variation in the transected sediments sampled in 2002. The range is 60-4 mg/kg and that exceedances confined only to addur 1000 metre distance from the discharge point, Askar and north Meridien.

Figure 34 characterises the overall comparison in nickel in transected sediments sampled in 2001 . The range is 180-10 mg/kg. Only SPP at zero and 500 metre distances from the discharge point showed exceedances above 35 mg/kg of the Dutch standard. Figure 35 gives the nickel in transected sediment in 2002. The range is 9-0 mg/kg. The highest value was reported in north Meridien and the lowest value was in Jasra and the range is below the Canadian guidelines value.

Figure 36 shows the spatial variation in chromium in transected sediment in 2001.The range is 436-34 mg/kg. Exceedances above the 52.3 mg/kg of the Canadian guidelines were reported in SPP, north Meridien, Jasra and Askar areas. However , north Meridien, Jasra and Askar areas showed no exceedances in 2002(figure 37).

Figure 38 gives the manganese in transected sediment in 2002. The range is 64-23 mg/kg . The highest value was reported at zero distance from the ADP discharge point and the lowest was reported in Jasra.

As above mentioned in the seawater section, the lead level reported in this study is exceptionally high compared with other areas in the ROPME Sea Area. This observation was further noted by Fowler *et. al.* (1993) who found 37.7 mg/kg Pb in rock scallop from Askar and the range between the period 1983-1986 was (1.2 - 7.2 mg/kg). They suggested that pollution with Pb is relatively higher than values reported from other areas in the ROPME Sea Area and could be attributed to the effluent discharges form industries located on the east coast of Bahrain . In addition, They registered the mean lead concentration in the pearl oysters collected from Askar , the mean value was 3.9 mg/kg compared with 2.1 mg/kg in 1986, and at Al Malikiya was 0.32 mg/kg compared with the range for the period from 1983-1986 for Az Zallaq (0.8-2.4 mg/kg). However, Al-Sayed *et. al.* (1994; reference (12)) found that nearshore pearl oysters collected from Holiday Inn had lower concentration of lead compared with those collected from offshore Bal Yaal site, (means 5.1, 7.6 mg/kg respectively). They maintained that illegal discharges from ships are attributable for this elevated pollution. Fowler *et. al.* (1993) believed that during the Gulf war the general trend of the concentrations of petroleum hydrocarbons related heavy metals found in sediment and biota were not differed from that measured in earlier years in the same sites studied in the UAE, Oman and Bahrain. Linden & Larsson (2002-Reference (13)) carried out the Bapco's marine environmental assessment studies and demonstrated that the concentrations of lead were 152 mg/kg, 447 mg/kg and 1010 mg/kg in years 2002, 1997 and 1992, respectively and claimed that the decrease of pollution is due to the company's environmental improvements. Bapco plan 2000-2009 includes control of Pb in refinery tank farm effluent(mid 1999-mid 2000), lead sulphide in the refinery effluent system(mid 1999-2002) and Pb in refinery effluent(mid 2001-2004).

The elevated concentration of trace metals; zinc, copper, nickel, chromium, in vicinity of SPP is perhaps attributed to the multi-flash stage operational system where it is expected that trace metals are coming off during clean up the distillers. The marine sediment collected from the neighborhood of Reverse Osmosis Plant (Ras Abu Jarjour) showed higher concentrations in lead and copper, where the marine sediment in immediate area of the oil refinery exhibited higher levels of zinc, copper, lead and cadmium. The rejected water in SPP is about 70,000 tonnes per hour with a salinity range 50-55 ppm. ROP rejects 1050 cubic metre per hour with approximate salinity of 36,000 milligram per litre. Bapco uses 1905 million cubic metre per month of cooling water, and this is rejected after being mixed with pollutants during the cooling operations(National Environmental Strategy).

To conclude the presence of petroleum hydrocarbon and trace metals was confirmed in seawater and sediment in the marine environment of the Kingdom of Bahrain . Results of nearshore monitoring during the period 1993-1998 indicated , in general, that concentration of the trace metals were higher in water columns than sediments and the contrary was with the petroleum hydrocarbon. However , trace metals in transect sediments collected from the coastal areas during the monitoring period 2001-2002 showed that Pb>Cd>Zn>Cu compared to the nearshore sediments monitored during the period 1993-1998 that showed Zn>Pb=Cu>Cd. This study confirms that the lead pollution is mainly concentrated in the vicinity of petroleum industry and that the Zinc and Cadmium in both the Sitra Power Plant(SPP) and Bapco areas . SPP area showed higher pollution of Nickel, Copper and Chromium.

Table 1: The impact of 6 species of trace metal pollutants monitored in this study (adapted from the reference listed below).

Species	Point Sources	Fate and Behavior	Persistence	Effect on Biota
Lead	Industrial discharges Sewage discharges	Likely to be associated with sediments	Water: Variable Sediment: High	**Bioaccumulation** Likely to Bioaccumulate **Toxicity** Algae: very toxic Invertebrates: very toxic
CHROMIUM	Industrial discharges	Likely to be associated with sediments	Water: Variable Sediment: High	**Toxicity** Invertebrates: toxic Fish: toxic
NICKEL	Industrial discharges Sewage discharges Waste disposal	Likely to be associated with sediments. Can be present in complexes in the water column.	Water: Variable Sediment: High	**Bioaccumulation** Not likely to Bioaccumulate **Toxicity** Algae: very toxic Invertebrates: very toxic Fish: very toxic
ZINC	Industrial discharges Sewage discharges Waste disposal	Likely to be associated with sediments	Water: Variable Sediment: High	**Bioaccumulation** Likely to Bioaccumulate **Toxicity** Algae: very toxic Invertebrates: very toxic Fish: very toxic
COPPER	Industrial discharges Sewage discharges Waste disposal	Likely to be associated with sediments. Can be present in complexes in the water column	Water: Variable Sediment: High	**Bioaccumulation** Likely to Bioaccumulate **Toxicity** Invertebrates: very toxic Fish: very toxic

Source: Guidelines for managing water quality impacts within UK European marine sites (Eds. Cole, S., Codling, I.D., Parr, W. and Zabel, T., 1999). WRc Swindon, Frankland Road, Blagrove, Swindon,Wiltshire SN5 8YF, U.K.

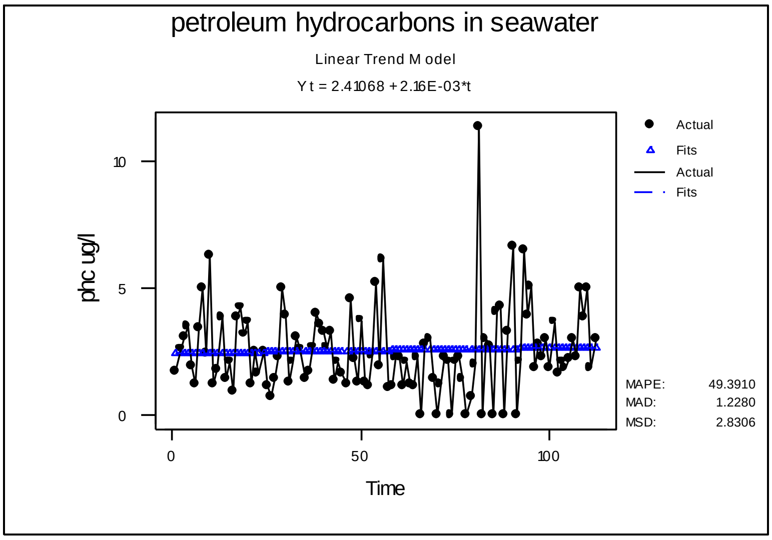


Figure 1: illustrates the overall trend in petroleum hydrocarbons in seawater for 112 samples .

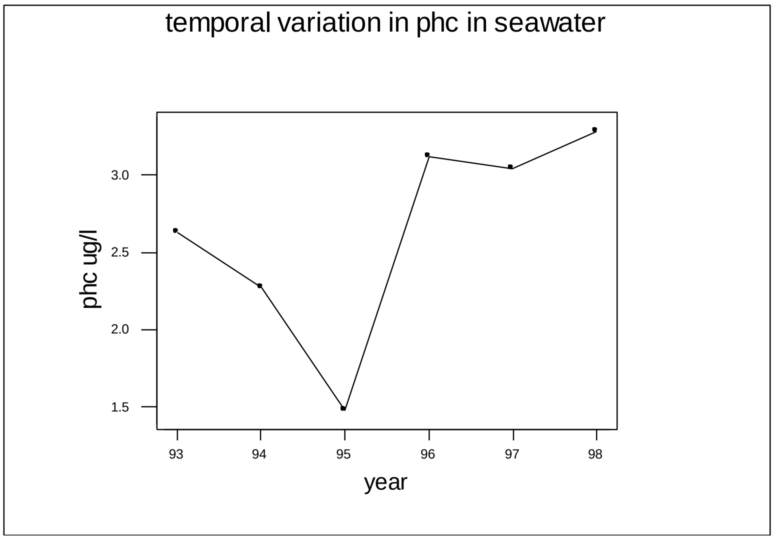


Figure 2 shows the temporal variation in petroleum hydrocarbons in seawater .

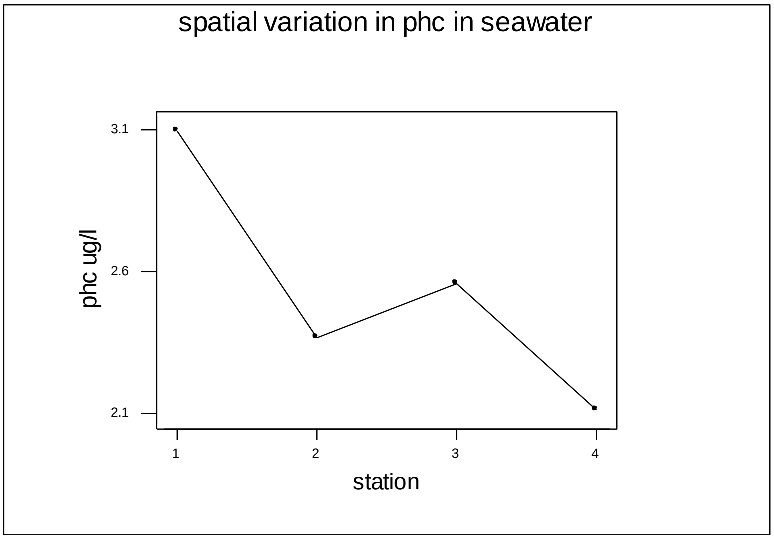


Figure 3 demonstrates the petroleum hydrocarbons spatial variation.

Table 2: Ranges of petroleum hydrocarbons in seawater in this study and other studies . Concentrations are ranges in μg/l.

Reference	Concentration
This study	0.000 - 11.400
Bahrain(3)	Means 22.4 - 43.3
ROPME(1)	0.10 - 16.8
Mediterranean(cited in 5)	1- 123
Australia(6)	0.1 - 22.6
Bahrain Std.(7)	8000(max. 15000)

Table 3 : Ranges of petroleum hydrocarbons in sediment reported in this study and other studies . Concentrations are ranges in mg/kg.

Reference	Concentration
This study	30.0 - 266.0
Bahrain before 1991(9)	20.3 - 103
Bahrain in 1991(8&9)	14.6 - 182
ROPME(4)	0.1-950
Black Sea(10)	2- 300
Cartagena Bay, Columbia(11)	below 10 - 1415

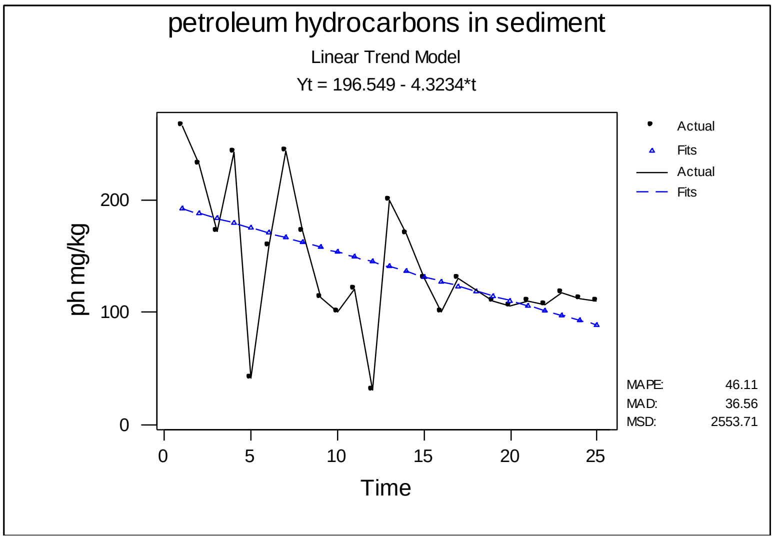


Figure 4: gives the overall trend in petroleum hydrocarbons in sediment for 24 samples .

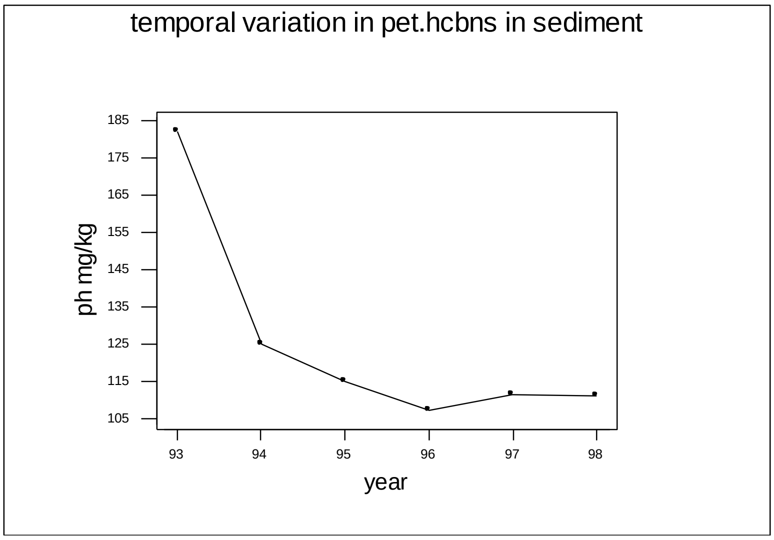


Figure 5 shows the temporal variation in petroleum hydrocarbons in sediment for the period 1993 until 1998.

Table 4: Ranges of seawater trace metal concentrations in µg /l reported in this study and other studies with their respective standards. Numbers in parentheses are the maximum allowable values, and the outer values are means.

Reference	Zn	Cd	Pb	Cu
This study-Nearshore(years 1993-1998)	1.00-124.00	0.00-0.71	1.2-87.60	0.10-17.60
Bahrain(12)	0.03-11.25	0.03 - 0.38	0.03-0.23	0.03 - 0.38
Kuwait(4)			<1	<10
Qatar(4)	0.9-130.3	Mean=0.8	0.1-15.6	Means=39.5-20.1
Australia (14)	0.003-0.6	0.0001-0.12	0.001-0.4	0.03-0.4
USA (15)	30-280	0.3-3.3	mean = 0.68	
Danube Delta(16)		0.04 - 1.54		0.30 - 2.30
North Aegean(16)		0.00 - 0.05		0.05 - 3.77
Bahrain Std (7)	2000 (5000)	10 (50)	200(1000)	200(500)
Int'nl Std (17)	2000	10	5000	500

Table 5: The ranges of marine sediment trace metals in mg/kg reported in this study and other areas. For Canadian guidelines, the Interim marine sediment quality guidelines, ISQGs; dry weight, and numbers in parentheses are probable effect levels, Pels; dry weight).

Reference	Zn	Cd	Pb	Cu
This study-Nearshore(years 1993-1998)	21- 117.07	0.01- 0.10	24 - 76.95	11 - 76.95
This study-transect(year 2001)	12-451	71-587	0-846	9.4-257
This study-transect(year 2002)	3.6-29	19-147	0-12	4-60
Bahrain(9)	2.34-3.79	0.011-0.753	0.64-24	1.16-17.6
ROPME(4)	0.7 - 410.3	0.01 - 4.5	0.2 - 64.3	1.3 - 142
Arctic(18)	111		21	26
Antarctic(19)	42.3±10.4	0.26±0.16	20.7±2.8	
Indonesia (20)	1257	< 0.03	2666	448
Togo (21)	60-632	2-44	22-176	22-184
Australia(14)	4 - 1150	0.1 - 13	0.5 - 520	0.2 - 180
Indonesia Ref. value(20)	132.2		25.6	40.7
Canadian Guidelines(22)	124 (271)	0.7 (4.2)	30.2 (112)	18.7 (108)

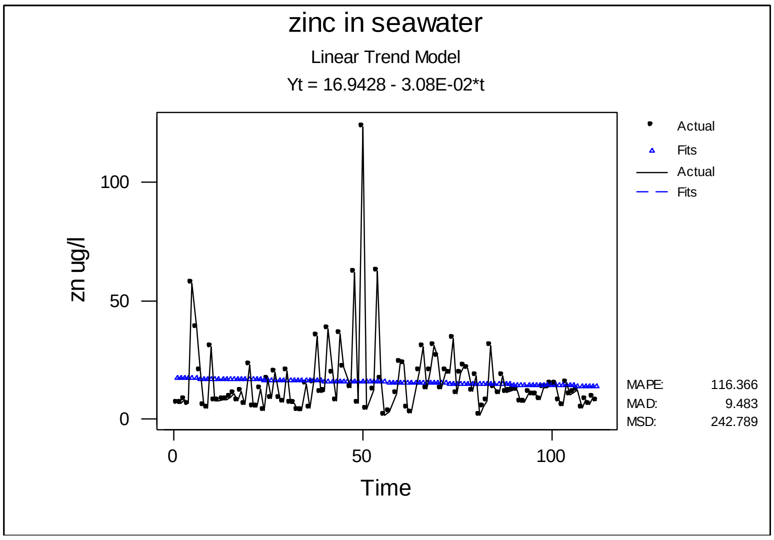


Figure 6: shows the overall trend in zinc in seawater for 108 samples .

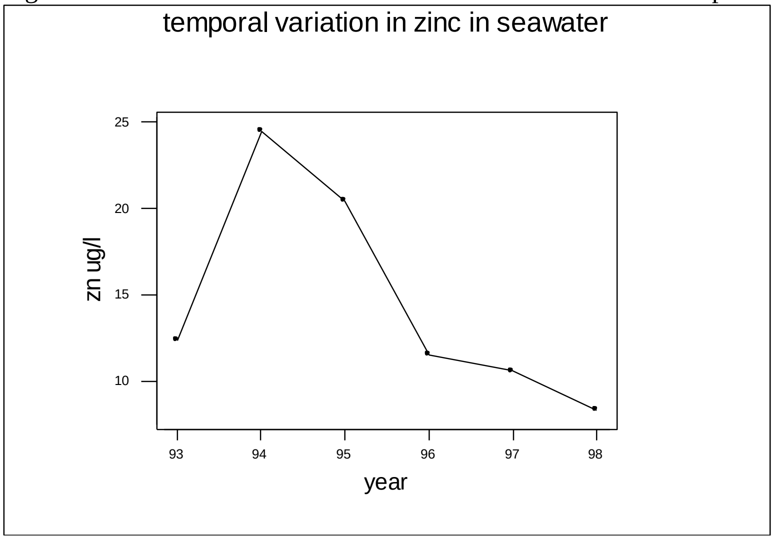


Figure 7: demonstrates the temporal variation in zinc in seawater for the period 1993 until 1998.

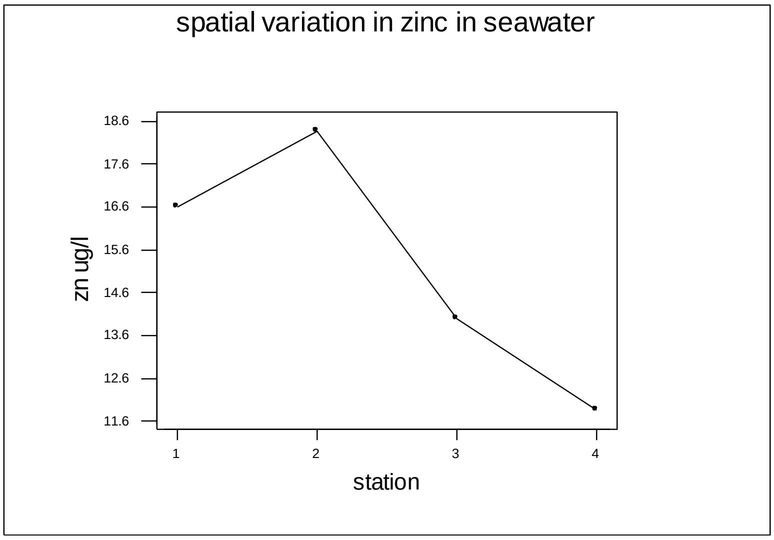


Figure 8: exhibits the spatial variation in zinc in seawater.

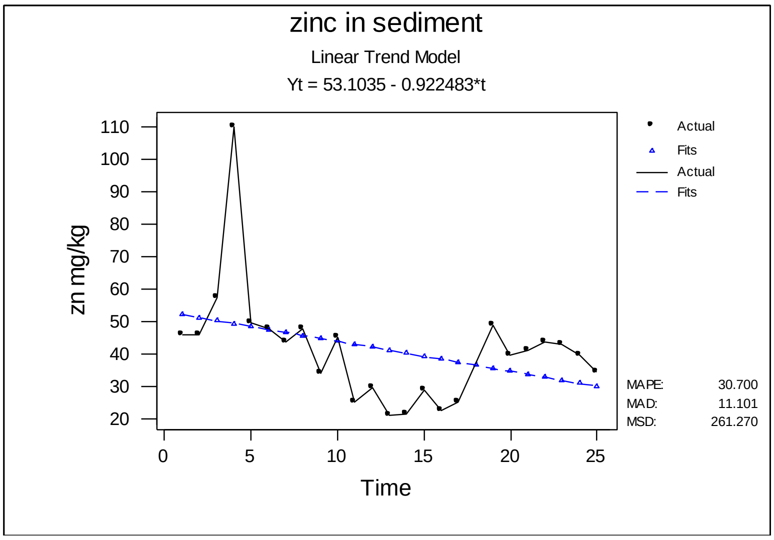


Figure 9: presents the overall trend in zinc in sediment for 24 samples .

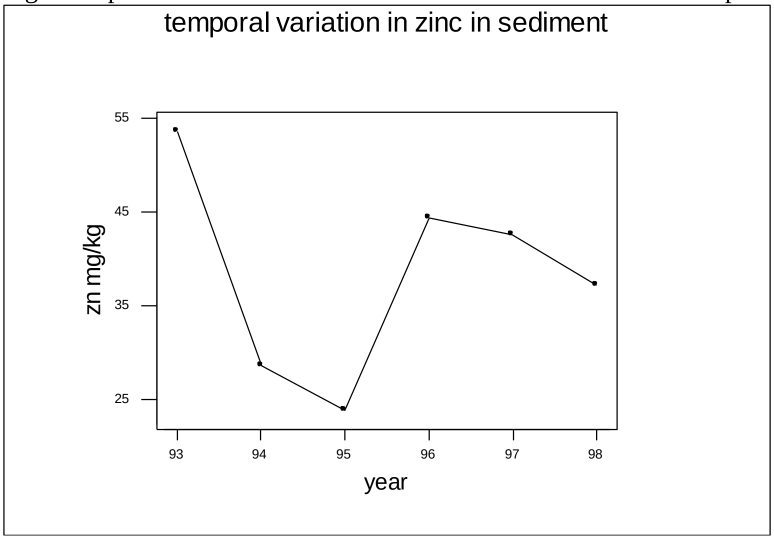


Figure 10: gives the temporal variation in zinc in sediment for the period 1993 until 1998.

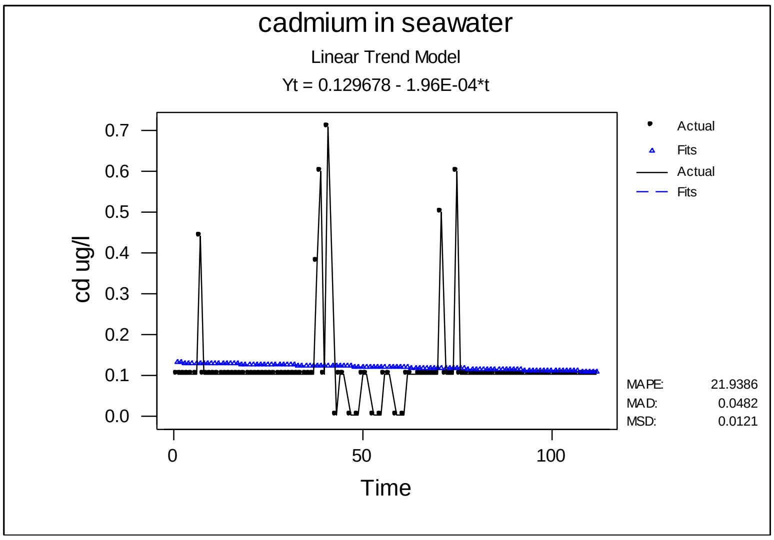


Figure 11: characterises the overall trend in cadmium in seawater for 104 samples .

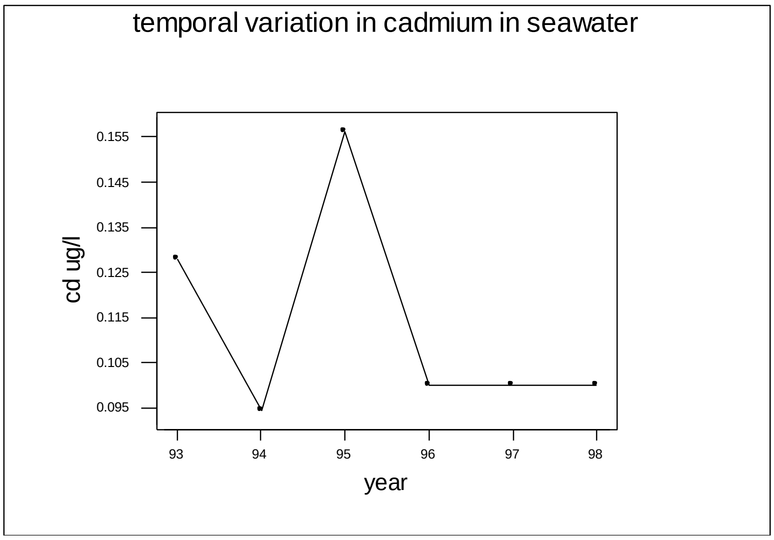


Figure 12: describes the temporal variation in cadmium in seawater for the period 1993 until 1998.

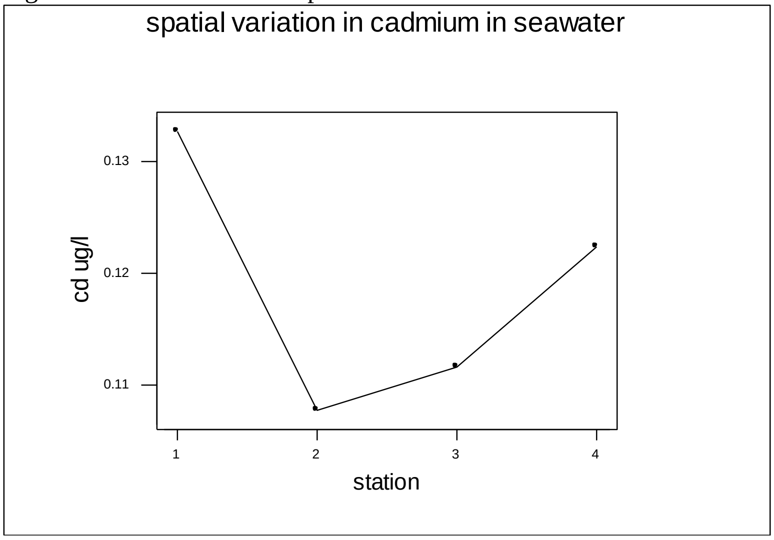


Figure 13: demonstrates the spatial variation in cadmium in seawater.

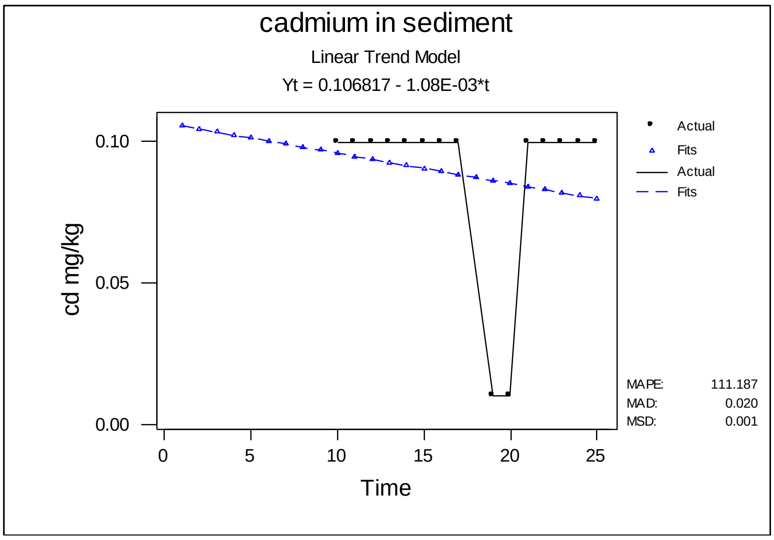


Figure 14: shows the overall trend in cadmium in sediment for 15 samples .

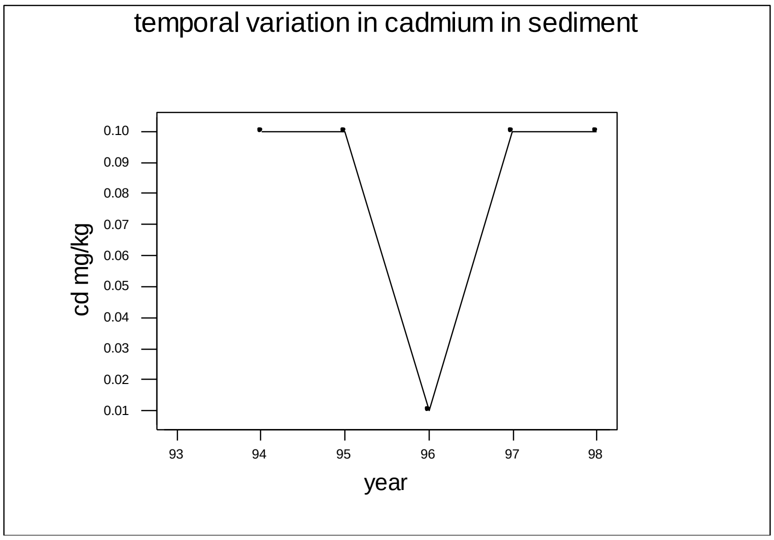


Figure 15: shows the temporal variation in cadmium in sediment for the period 1994 until 1998.

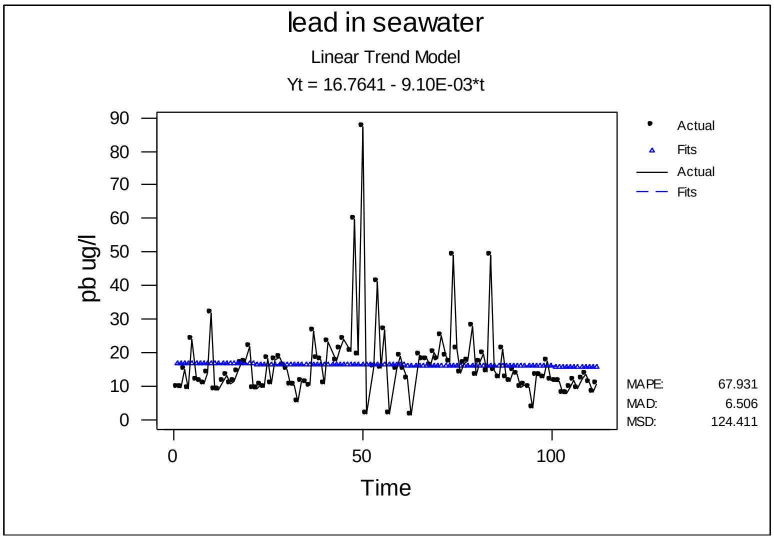


Figure 16: pictures the overall trend in lead in seawater for 107 samples .

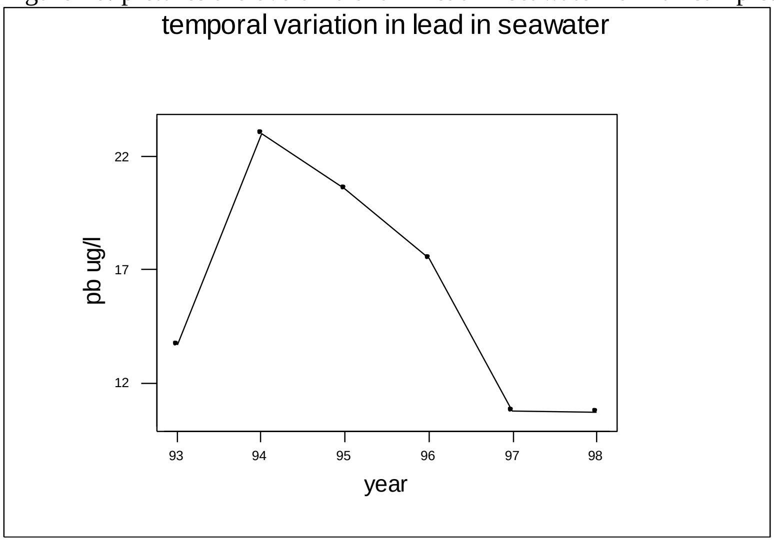


Figure 17: shows the temporal variation in lead in seawater for the period 1993 until 1998.

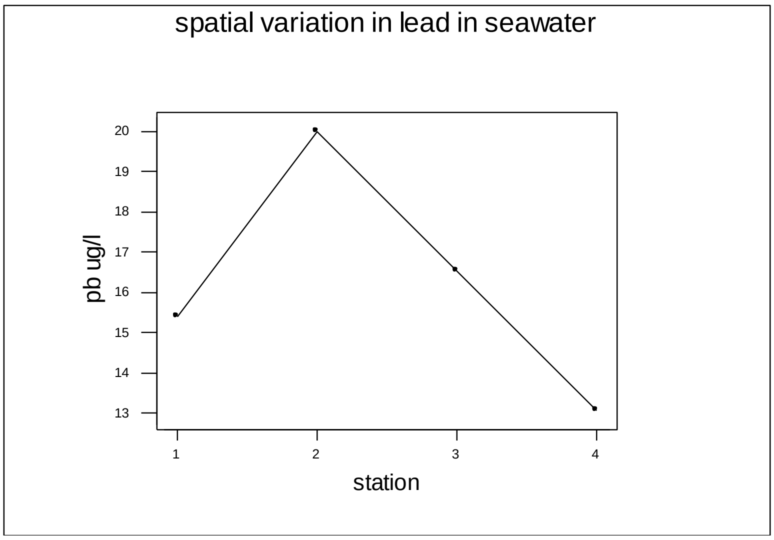


Figure 18: demonstrates the spatial variation in lead in seawater.

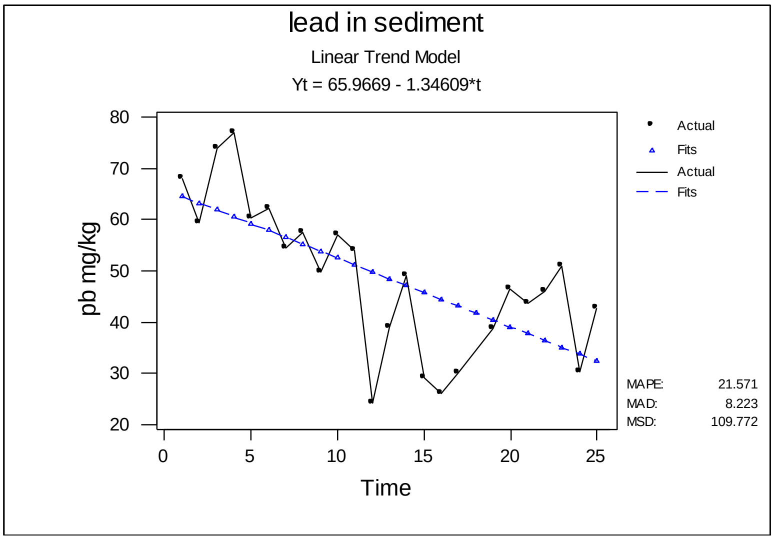


Figure 19: shows the overall trend in lead in sediment for 24 samples .

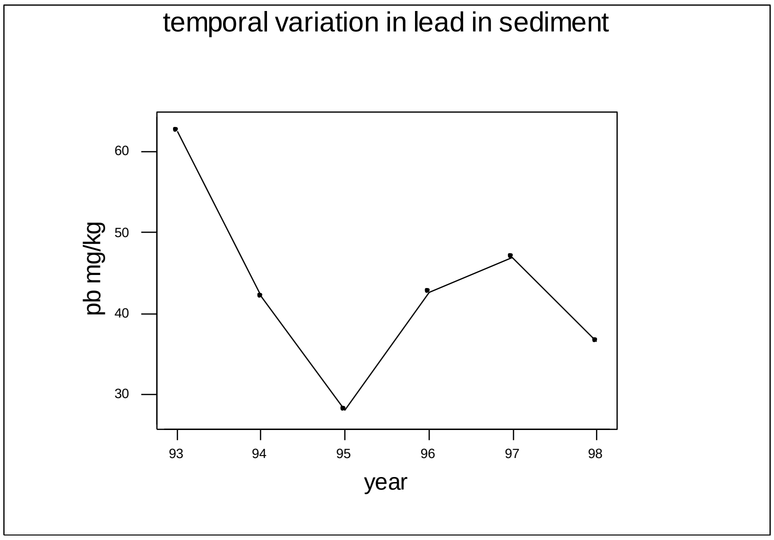


Figure 20: shows the temporal variation in lead in sediment for the period 1993 until 1998.

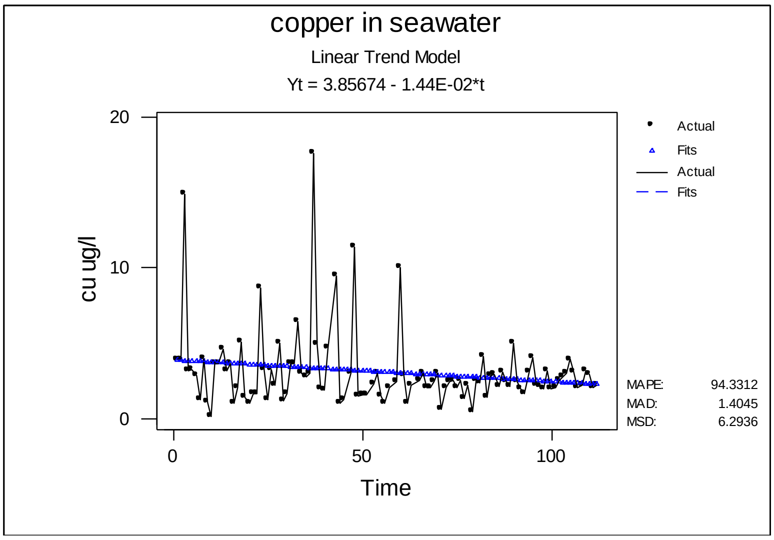


Figure 21: depicts the overall trend in copper in seawater for 107 samples .

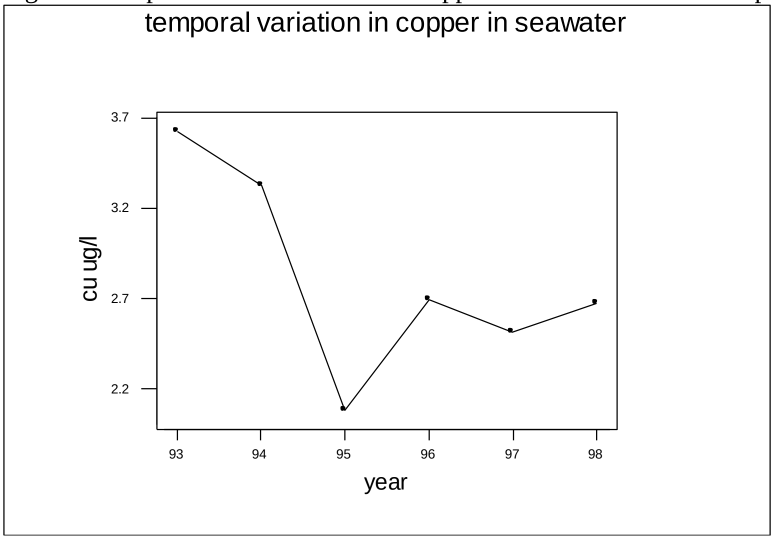


Figure 22: illustrates the temporal variation in copper in seawater for the period 1993 until 1998.

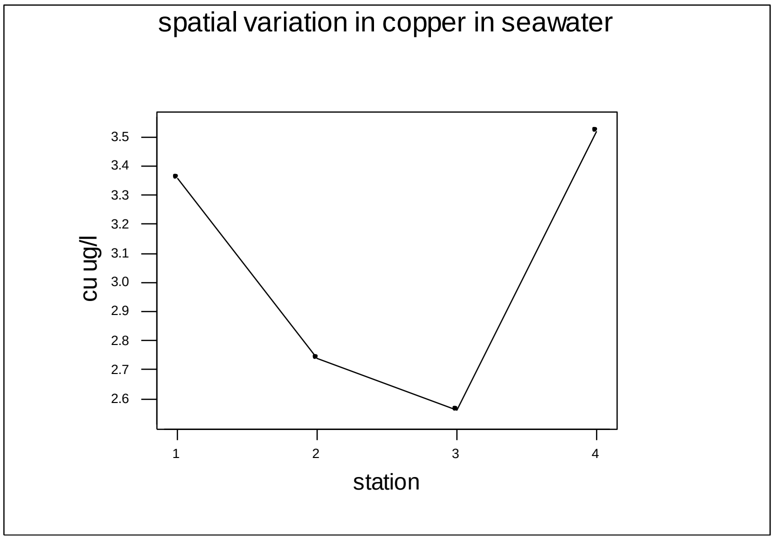


Figure 23: demonstrates the spatial variation in copper in seawater .

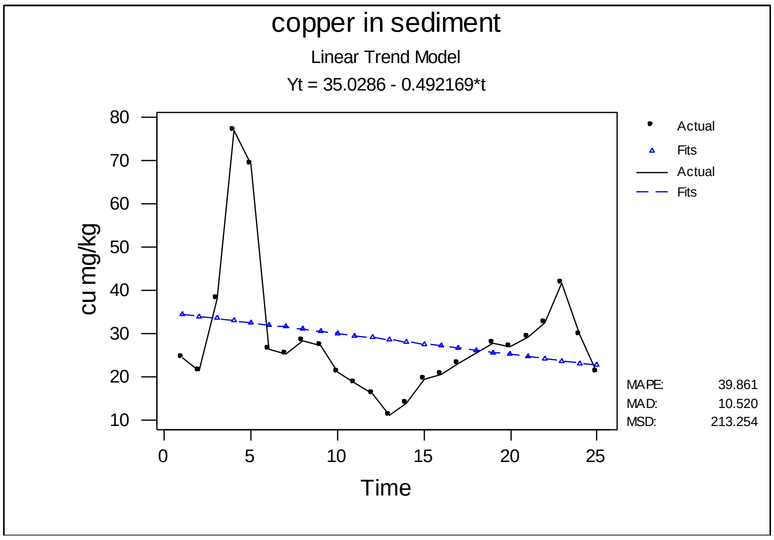


Figure 24: shows the overall trend in copper in sediment for 24 samples .

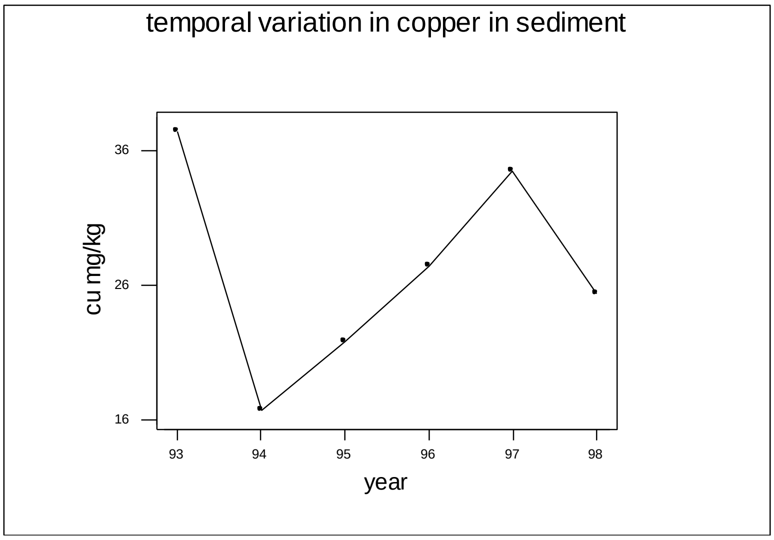


Figure 25: gives the temporal variation in copper in sediment for the period 1993 until 1998.

Figure 26: Zinc in sediment 2001

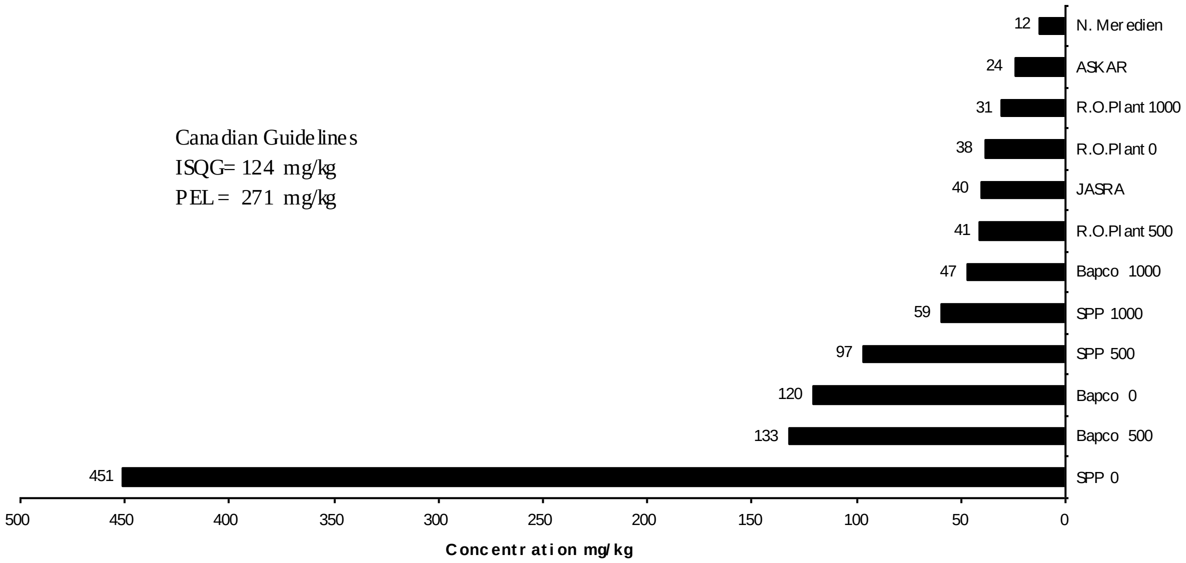


Figure 27: Zinc in sediment 2002

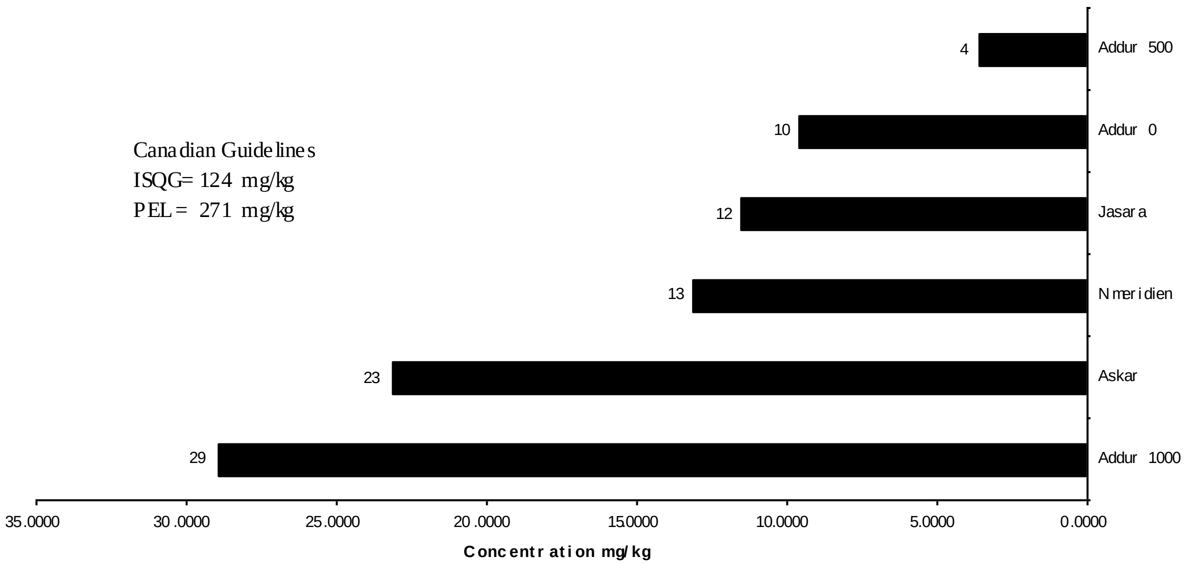


Figure 28: Cadmium in sediment 2001

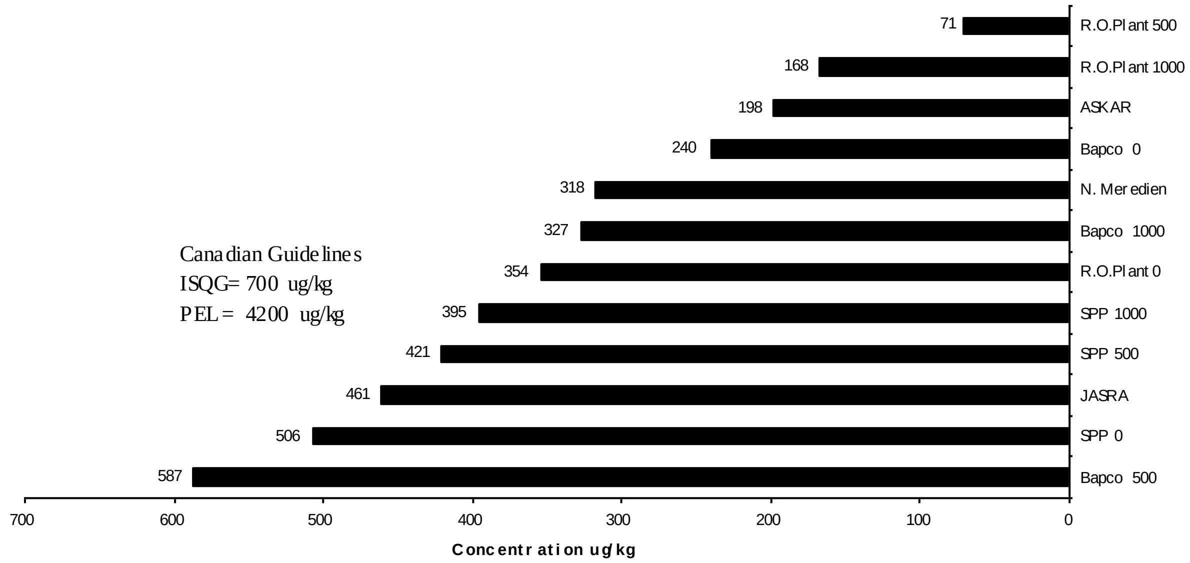


Figure 29: Cadmium in sediment 2002

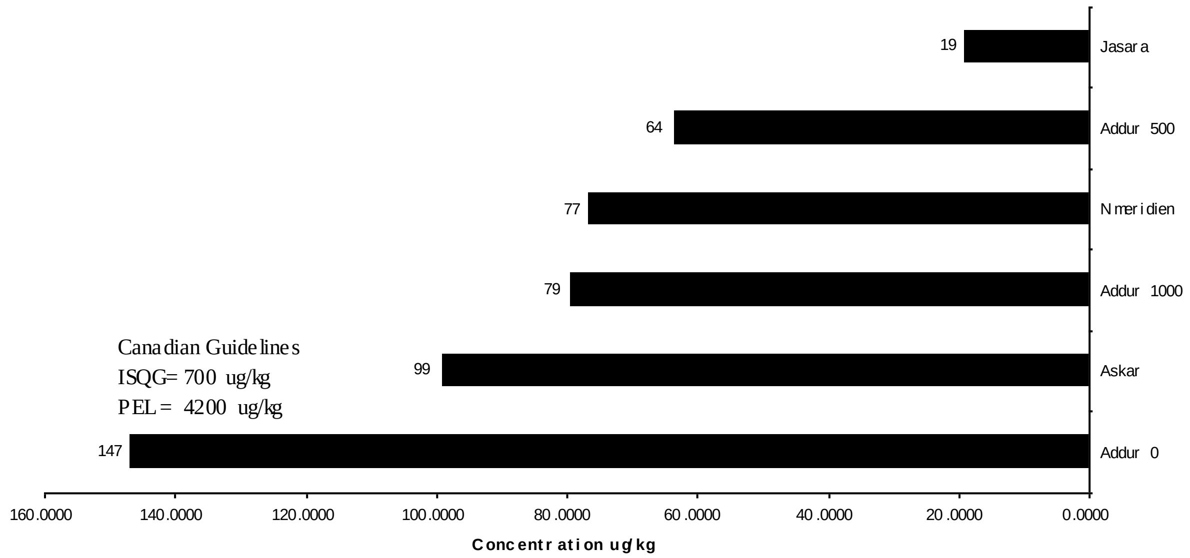


Figure 29: Cadmium in sediment 2002

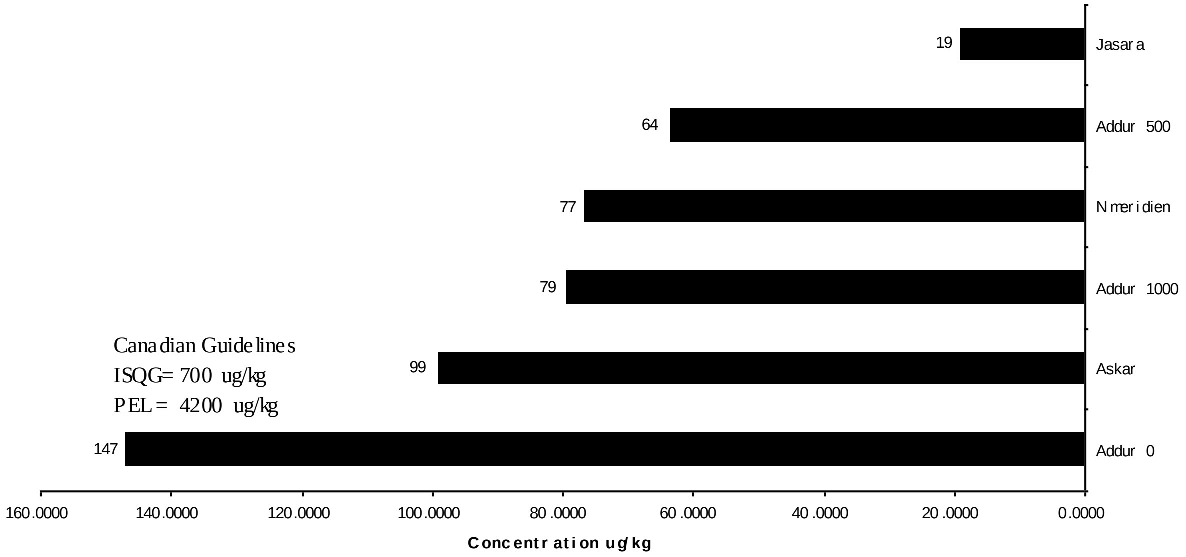


Figure 30: Lead in sediment2001

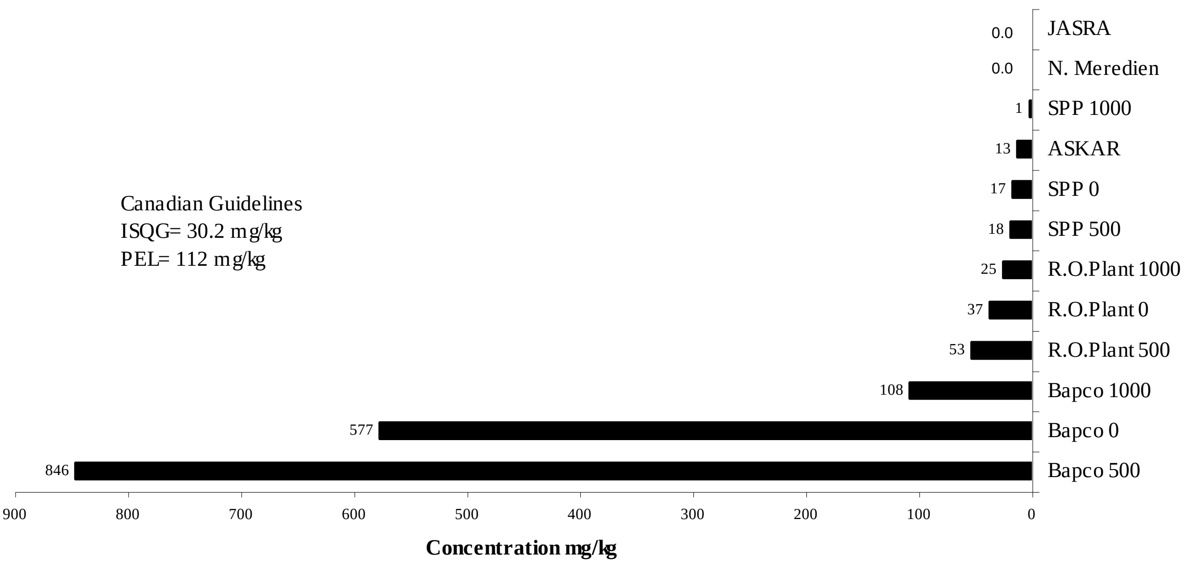


Figure31: Lead in sediment 2002

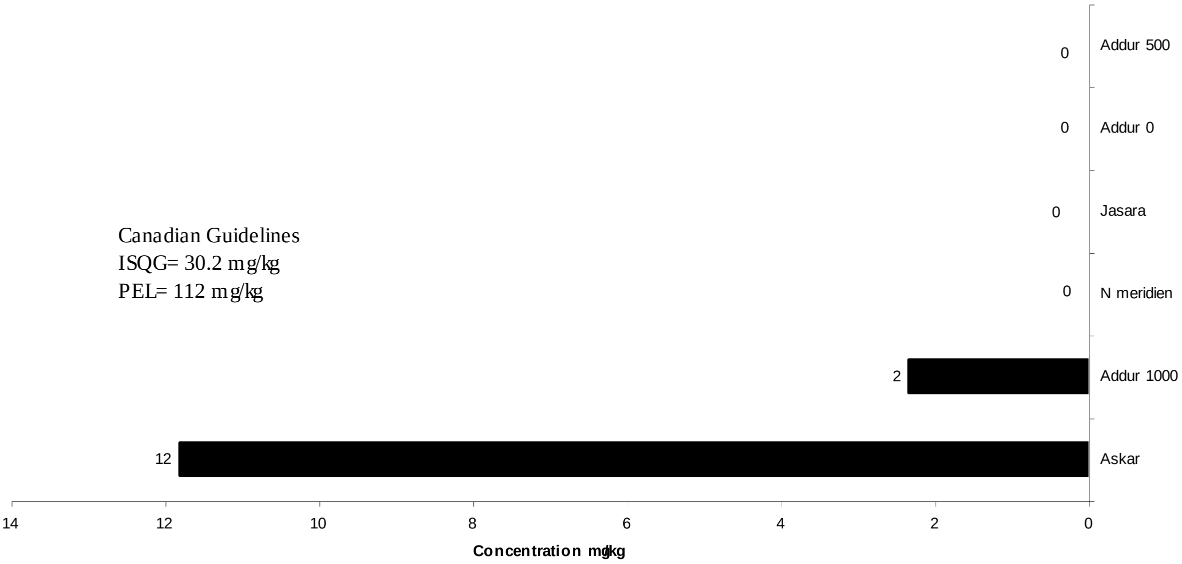


Figure 32: Copper in sediment 2001

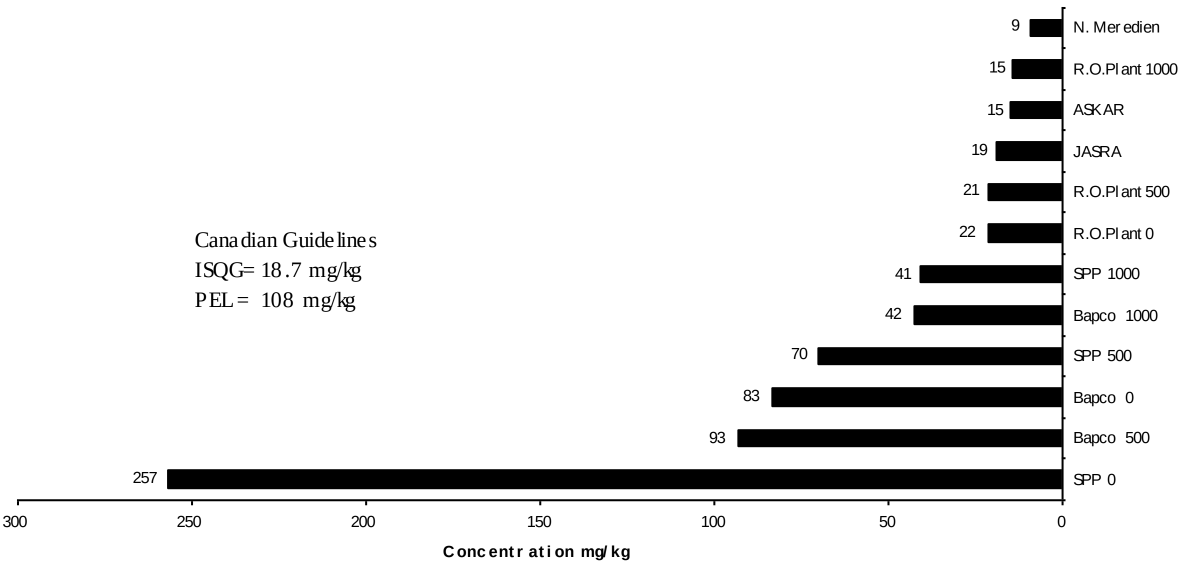


Figure 33: Copper in sediment 2002

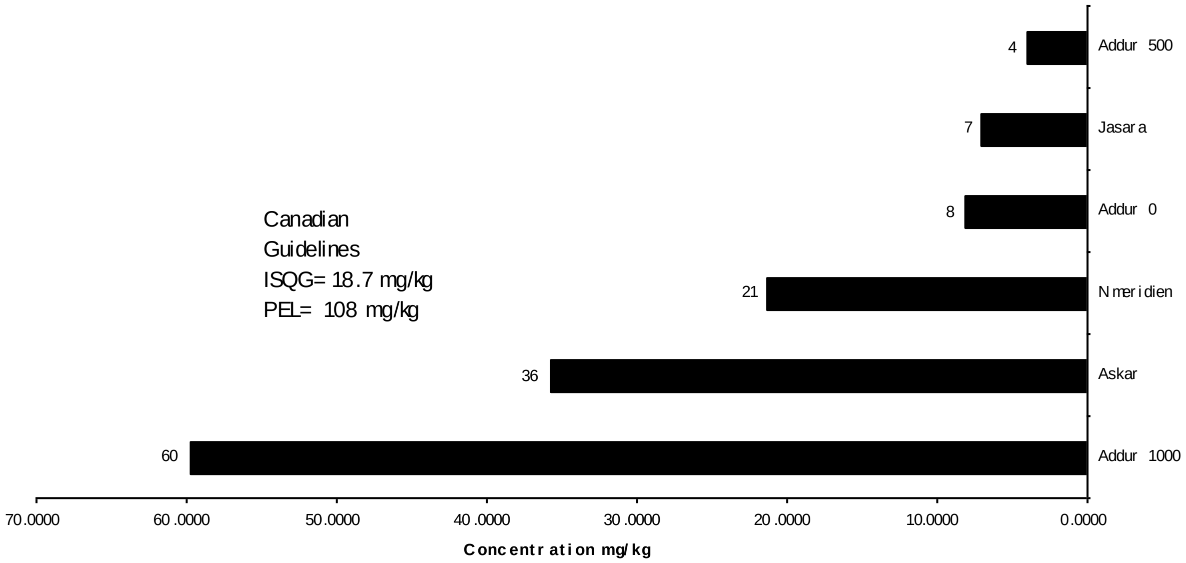


Figure34: Nickel in sediment 2001

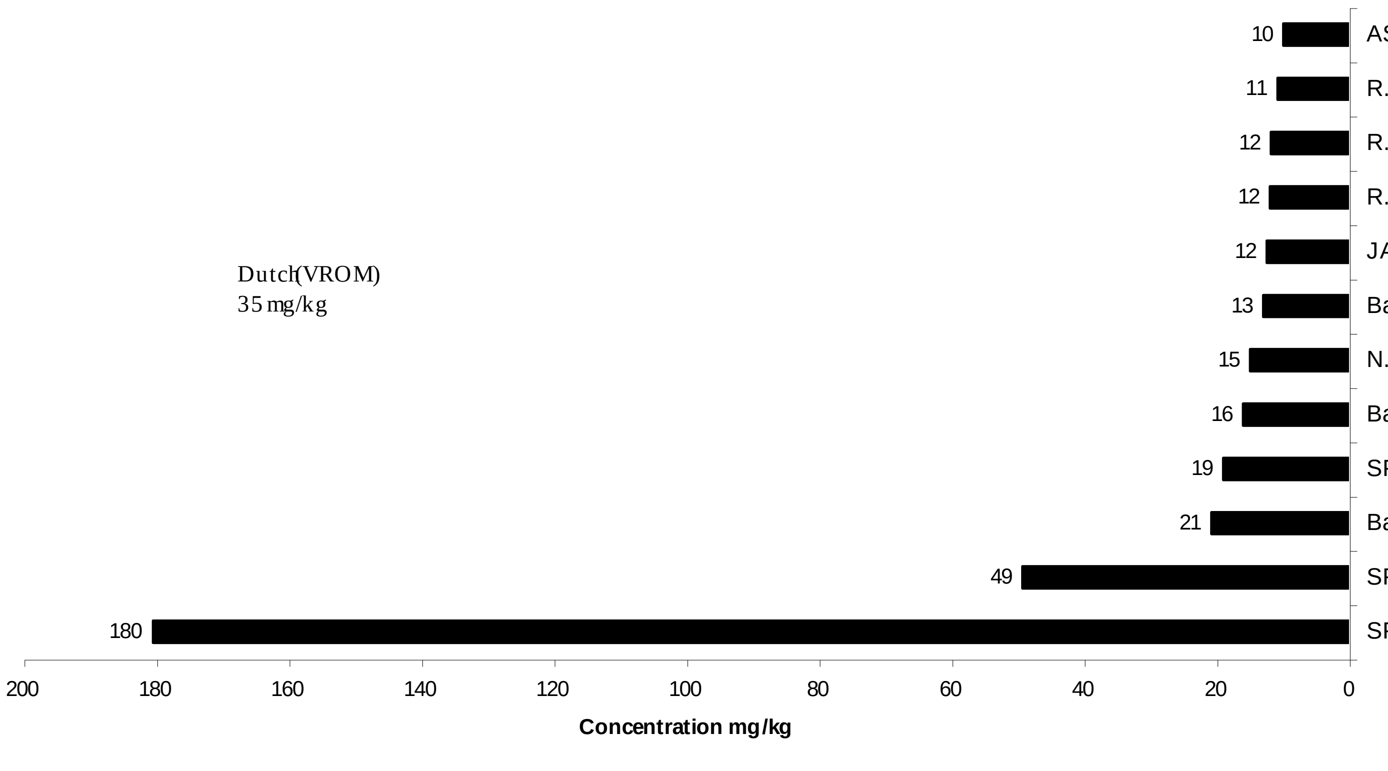


Figure 35: Nickel in sediment 2002

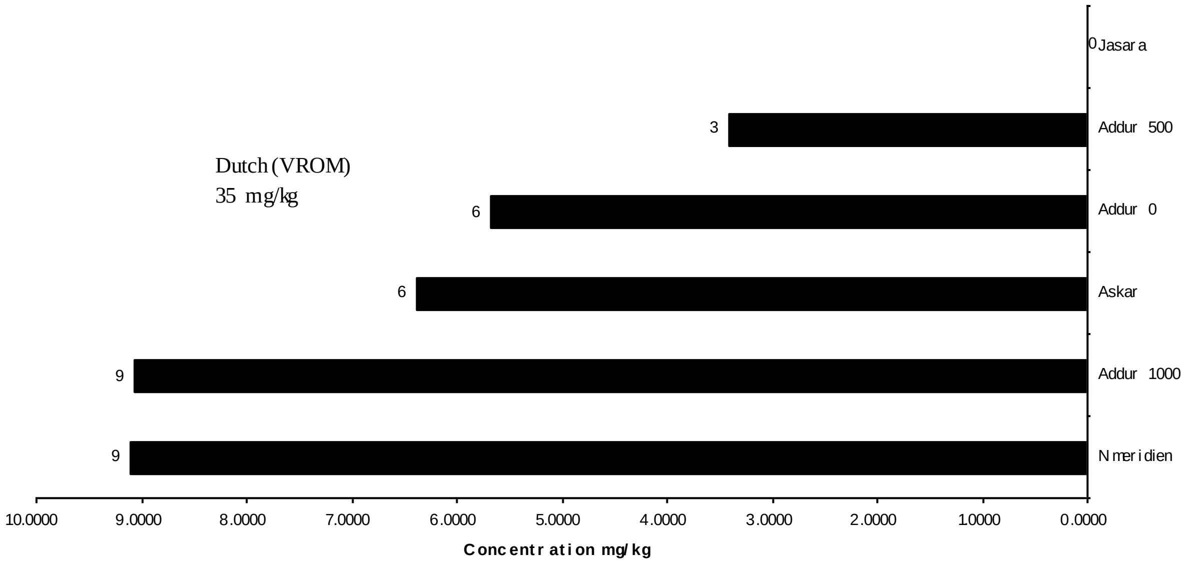


Figure 36: Chromium in sediment 2001

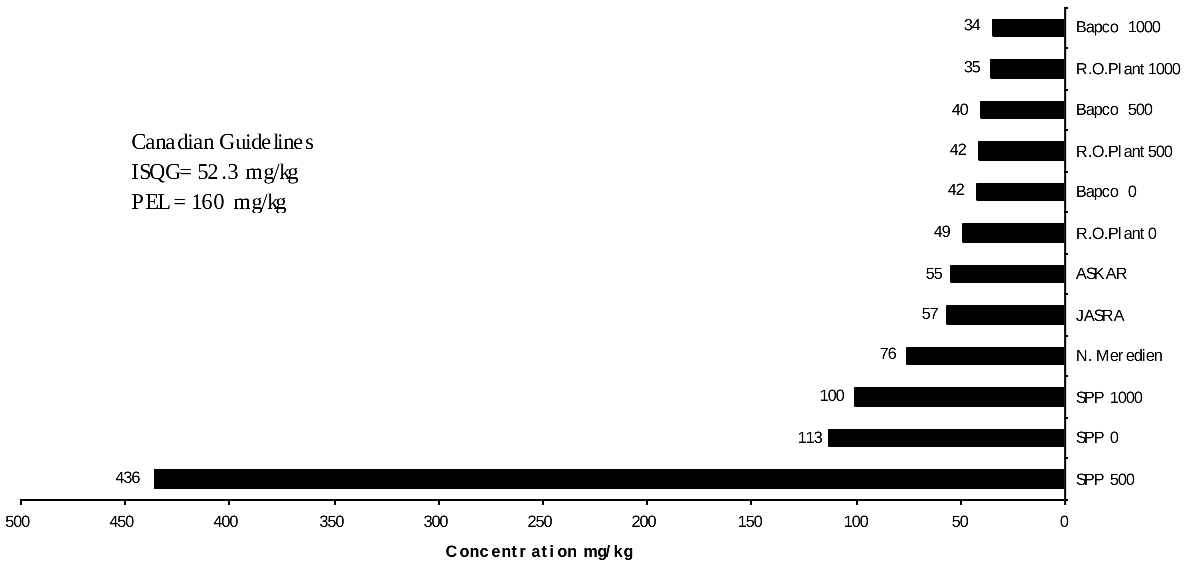


Figure 37 : Chromium in sediment 2002

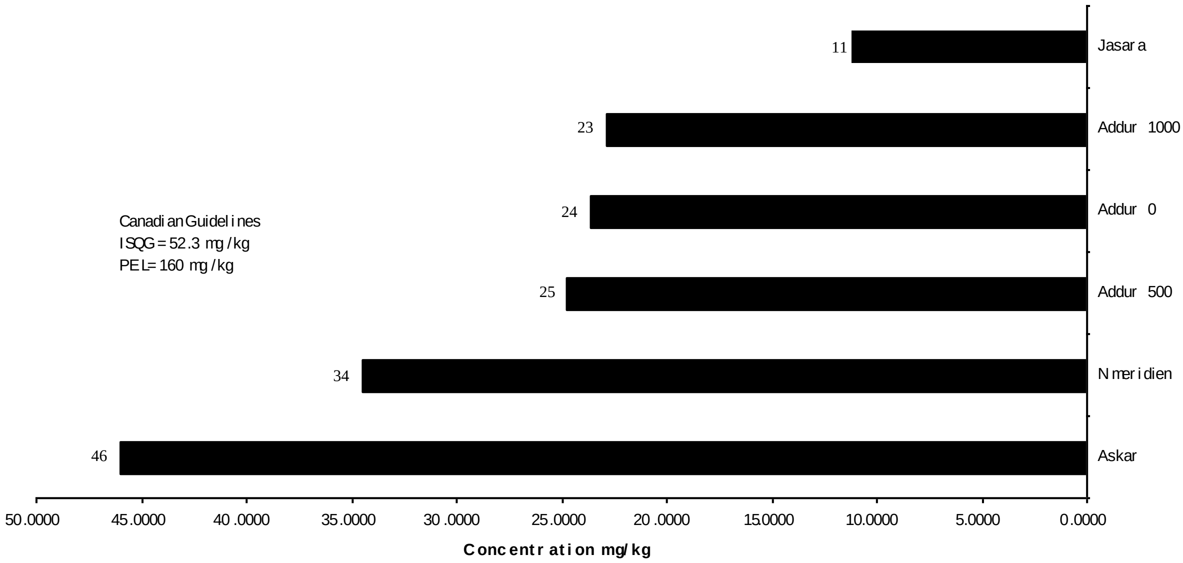
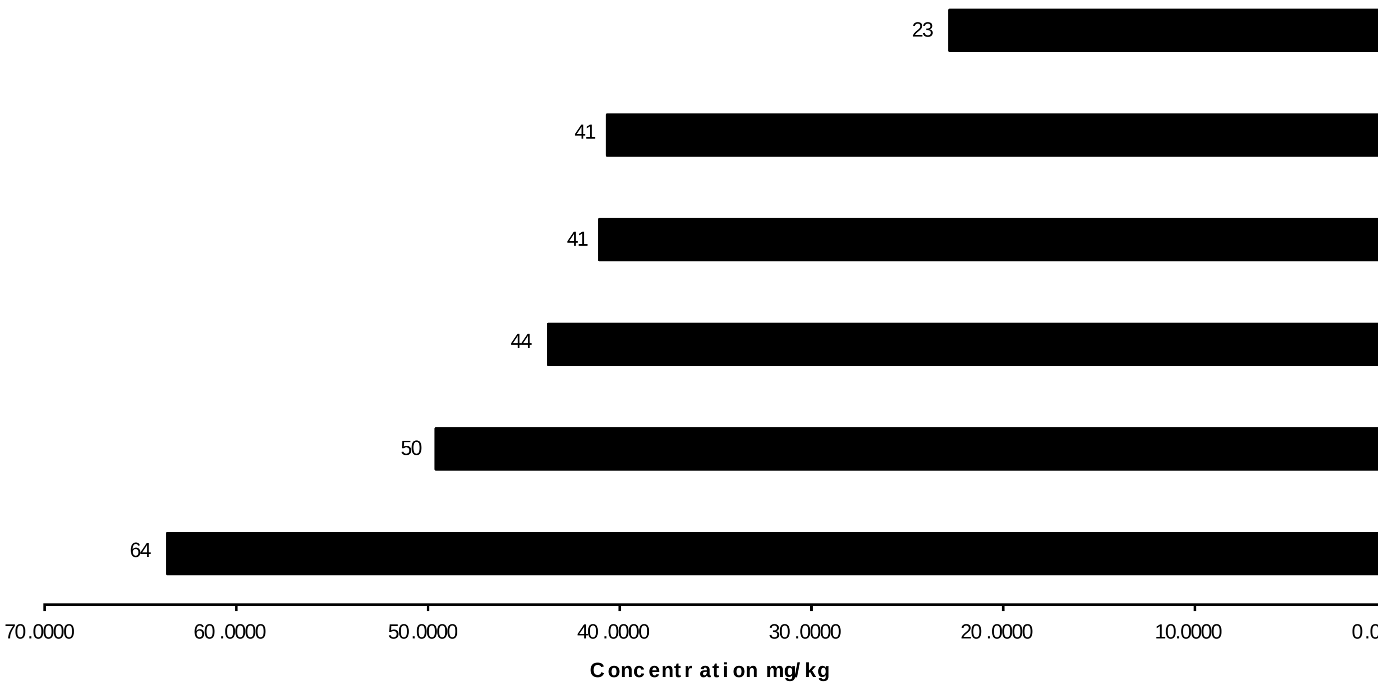


Figure 38 : Manganese in sediment 2002



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