Journal of Health and Environmental Research
2023; 9(1): 11-17
http://www.sciencepublishinggroup.com/j/jher
doi: 10.11648/j.jher.20230901.12
ISSN: 2472-3584 (Print); ISSN: 2472-3592 (Online)

Pollution Status of Sediment from a Remediated Crude Oil Produced Water Discharge Channel Using Various Indices

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To cite this article:

Gaja Caroline, Asibor Godwin, Edjere Oghenekohwiroro. Pollution Status of Sediment from a Remediated Crude Oil Produced Water Discharge Channel Using Various Indices. *Journal of Health and Environmental Research*. Vol. 9, No. 1, 2023, pp. 11-17.
doi: 10.11648/j.jher.20230901.12

Received: December 1, 2022; **Accepted**: December 26, 2022; **Published**: January 9, 2023

Abstract: The Forcados Terminal effluent discharged channel was remediated about twenty years ago with recommendation for periodic assessment of the organic and inorganic contaminants in the area. Forcados Terminal is in Delta State, Nigeria. This study was carried out to evaluate heavy metals pollution status of sediments in the remediated crude oil effluent discharge channel. A total of sixteen sediments samples were collected from ten sampling locations using grab sampling technique in October 2019 (wet season) and February 2020 (dry season). Heavy metals were determined in all the samples using atomic absorption spectrophotometry after digestion with aqua regia. The results showed that the concentrations of the sediment samples (mg/kg) ranged from <0.01-0.05, <0.01-0.91, <0.01-3.46, 13.2-45.3, 14.7-64.1, 5.56-105, 3.10-108, 0.14-5.86, 78.8-289, 28.2-254 and 3529-7773 for Hg, As, Cd, Pb, Cr, Ni, Cu, V, Mn, Zn and Fe. Hg and As were generally not detected in the sediments. On the average, the geoaccumulation index of Cd in the sediments falls into the moderately polluted category while the geoaccumulation index of all the other metals falls into the practically unpolluted category. On the average, the Contamination/Pollution index (CPI) value of Cd was > 1 which indicates that the sediments were polluted with Cd but the CPI values of other heavy metals were < 1 which indicates that these sediments were contaminated with the other heavy metals.

Keywords: Heavy Metals, Pollution, Contaminants, Produced Water Channel, Geoaccumulation

1. Introduction

Crude oil is a complex mixture of tens of thousands of hydrocarbons and constitute a significant number of non-hydrocarbons. Heavy metals form a very important part of the non-hydrocarbon component of crude oil. Heavy metal denotes any metallic element that has a high density and is poisonous at very low concentrations [1]. Heavy metals are a fundamental part of contemporary life. Some heavy metals (such as. Zn, Cu, Mn, Cr, Ni) are vital trace elements in nutrition of plants, animals, and humans while others like Pb, Cd, Hg are not known to have any positive nutritional effect. However, all heavy metals can have toxic effects if they occur in excess [2]. The presence of heavy metals in the aquatic environment is of particular concern due to their non-biodegradability, their ability to bioaccumulate in tissues of living organisms and their inherent toxicity [3]. Currently, heavy metals have become a global issue of concern [4]. Heavy metals are generally introduced into aquatic environments from natural and anthropogenic sources [5]. They are among the major environmental pollutants in the world [6]. The study of heavy metals contamination of aquatic ecosystem has involved the chemical analysis of sediment as they are valuable indicators of heavy metal pollution.

Sediments are significant reservoir for diverse pollutants. They also play large role in the remobilization of pollutants in aquatic ecosystems under positive circumstances and in relations amid water and sediment [7]. The health effects of metals pollution on humans include morphological abnormalities, neurophysical disturbances, gene mutation, etc.

The presence of metals affects enzymes and hormonal activities as well as growth and mortality rate [8, 9].

The Forcados Terminal produced water discharge channel was established in 1971 and was operated for about twenty-five years. Before decommissioning, remediation was carried out along the channel from 1996 and 1999. Aside the numerous risks connected with crude oil storage such as oil spills, air pollution and other forms of waste discharge. Managing the channel has remained a concern to the immediate community after the decommissioning and abandonment. Considering the non-biodegradability, persistence, environmental and health effects of heavy metals, deposited over the years, it is pertinent to have a review of current levels of these contaminants within the slot and also evaluate the pollution status of the slot. It is on this basis this study was carried out.

a b c

Figures 1. *a, b and c: View of the Forcados Effluent Slot discharge channel, fishing activity along the channel and a typical catch.*

2. Materials and Methods

2.1. Description of Study Area

The study area is the abandoned remediated Forcados Terminal crude oil produced water discharge channel. It is located in Ogulagha Community, Burutu Local Government Area of Delta State (Figure 2). The community host one of the largest crude oil export terminals in the Niger Delta region of Nigeria.

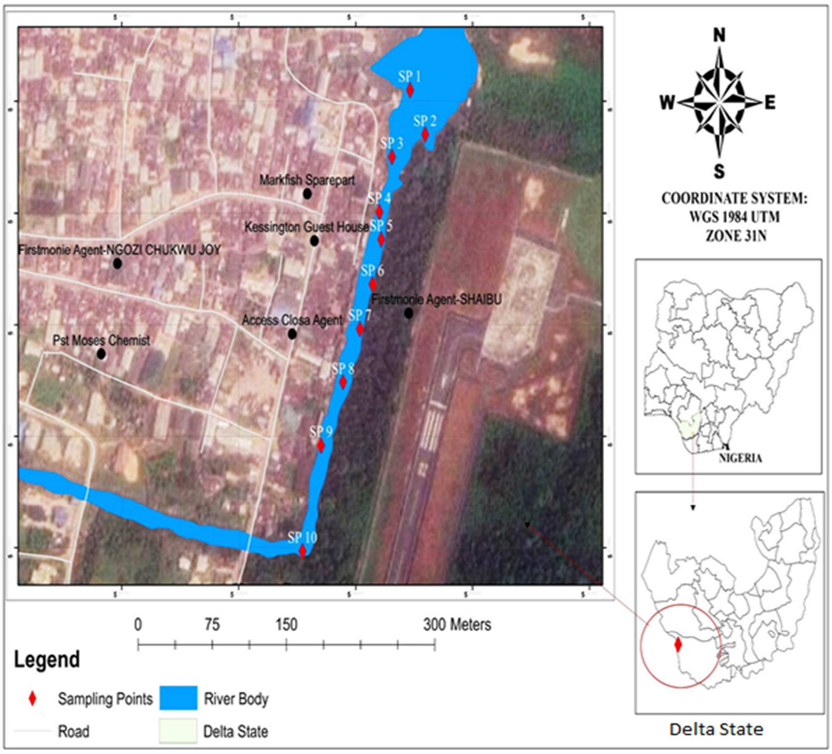

Figure 2. *Map of study area showing the sampling locations.*

2.2. Sample Collection and Treatment

Sediment samples were collected from ten sampling locations as shown in Figure 2. Sampling was done in two seasons (October 2019) for wet season and February 2020 (dry season). In each location, samples were collected from three points and combined to form a homogenous sample. However, only six sediment samples were collected during the wet season as sediments could not be collected from four sampling locations (SL3, SL7, SL8 and SL9) due to the tides and waves in those locations.

Collected samples were labeled appropriately, stored in a block of ice, and taken to the laboratory for analysis. Samples were air dried in the dark, ground, filtered to pass 2 mm sieved and stored in a refrigerator prior to analysis.

2.3. Determination of Heavy Metals Concentrations in Sediment Samples

Wet digestion method using aqua-regia was used. 15ml of aqua-regia (HNO_3: HCl, 1:3 ratio) was added to 1.0 g of the sediment in a beaker and was allowed to stand overnight, digested at 125 ^oC for 2h. The digests were cooled and filtered using Whatman No 1 filter. The digest was diluted to 25 mL with 0.25M HNO_3. Thereafter the solutions were made up to mark in a volumetric flask with deionized water. The solutions were kept in the refrigerator prior to heavy metals analysis using atomic absorption spectrophotometry (PG Instructions AA 500).

2.4. Quality Assurance and Quality Control

All the bottles for heavy metal analysis were washed with metal free detergent and sterilized by soaking with 10 % HNO_3 analytical grade overnight and then rinsed several times with distilled water. Spike recovery studies was carried out on already analyzed samples with known concentration of the individual metals and re-analyzed. The percentage recovery was calculated for each sample analyzed. The percent recovery ranged from 94.3 to 98.5 %. Blanks were analyzed for heavy metals along with samples and the results for blanks were subtracted from those obtained for samples before data analysis and interpretations.

2.5. Data Treatment

2.5.1. Contamination/Pollution Index of Heavy Metals

The Contamination/Pollution index (CPI) of heavy metals in the sediments was obtained by using the CPI equation given by Lacatusu, R. [11].

$$\text{CPI} = \frac{Concentration\ of\ metal\ in\ sediments}{Reference\ value}$$

The reference value of heavy metals used in this study is the Department of Petroleum Resources (DPR) of Nigeria target value of heavy metals in soil [10]. The reference values were 0.8 for Cd, 85 for Pb, 100 for Cr, 35 for Ni, 36 for Cu and 140 for Zn. CPI value greater > 1 define a pollution range and < 1 define the contamination range. However, the significance of the CPI is shown in Table 1.

Table 1. *Significance of intervals of contamination/pollution index [11].*

CPI	Significance
<0.1	Very slight contamination
0.10-0.25	Slight contamination
0.26-0.50	Moderate contamination
0.51-0.75	Severe contamination
0.76-1.00	Very severe contamination
1.10-2.00	Slight pollution
2.10-4.00	Moderate pollution
4.10-8.00	Severe pollution
8.10-16.0	Very severe pollution
>16.0	Excessive pollution

2.5.2. Index of Geoaccumulation (Igeo) of Metals

The Igeo was originally used with bottom sediments by [12]. Igeo enables the assessment of contamination by comparing current and pre-industrial concentration. The Igeo equation used in this study is given as follows [12]:

$$\text{Igeo} = \log_2 \frac{Cn}{1.5\ Bn}$$

Where; Cn = the measured concentration of the heavy metals in the sediments

Bn = the geochemical background concentration.

The crustal abundance values (CAV) for the respective metals [13] were used as geochemical background concentrations.

The crustal abundance values of the metals used were 0.3 for Cd, 20 for Pb, 90 for Cr, 68 for Ni, 45 for Cu, 130 for V, 850 for Mn, 95 for Zn and 47000 for Fe. The value 1.5 in the equation allows for natural fluctuations in the concentration of a given metal in the sediments. The Igeo classification given by Muller, G. [12] is shown in Table 2.

Table 2. *Significance of intervals of Geoaccumulation index.*

Igeo Values	Significance	Class
<0	Practically unpolluted	Class 1
0-1	Unpolluted to moderately polluted Class 2	
1-2	Moderately polluted	Class 3
2-3	Moderately to strongly polluted	Class 4
3-4	Strongly polluted	Class 5
4-5	Strongly polluted to very polluted	Class 6
>5	Extremely polluted	Class 7

3. Results and Discussion

3.1. Heavy Metals Concentrations in Sediments

The concentrations of heavy metals in the sediments from the remediated channel in this study are shown in Table 3. On the average, the concentrations of the heavy metals in the sediment decrease in the order of Fe > Mn > Zn > Ni > Cu > Cr > Pb > V > Cd > As > Hg during the wet season and Fe > Mn > Zn > Cr > Pb > Cu > Ni > Cd > V > As > Hg during the dry season. The concentrations of Ni, Cu, V, Zn and Fe were significantly higher in the wet season than the dry season, The significant seasonal variations observed may be due to runoff and inflow of contaminants during the wet season. A comparison of heavy metals concentrations in sediment from the post remediated discharge channel with others reported in literature for rivers from the Niger Delta and Nigeria are shown in Table 4.

Table 3. *Heavy metal concentrations (mg/kg) in sediments of post remediated crude oil produced water discharge channel.*

Seasons	Locations	Hg	As	Cd	Pb	Cr	Ni	Cu	V	Mn	Zn	Fe
Wet	SL1	<0.01	<0.01	<0.01	<0.01	14.7	37.1	8.77	2.06	78.8	39.5	4969
	SL2	<0.01	<0.01	<0.01	<0.01	23.6	57.0	35.1	3.17	121	77.6	5871
	SL4	<0.01	0.60	<0.01	30.2	40.3	105	20.5	5.86	224	144	6899
	SL5	<0.01	0.30	<0.01	15.1	32.8	77.0	46.8	4.28	164	186	6424
	SL6	<0.01	0.30	<0.01	15.1	27.6	77.0	108	4.28	164	133	6130
	SL10	0.05	0.905	1.77	45.3	64.1	60.8	35.1	3.38	129	254	7773
Dry	SL1	<0.01	<0.01	<0.01	13.2	14.9	5.56	3.10	0.14	84.6	28.2	3529
	SL2	<0.01	<0.01	1.73	13.2	30.9	11.1	8.60	0.28	178	69.6	4016
	SL3	<0.01	0.03	3.46	13.2	49.2	16.7	19.8	0.42	289	128	4305
	SL4	<0.01	<0.01	1.73	13.2	52.7	16.7	30.9	0.38	235	119	4202
	SL5	<0.01	<0.01	1.73	27.9	27.6	11.1	8.6	0.24	111	70.6	3891
	SL6	<0.01	<0.01	1.73	13.2	35.9	11.1	11.4	0.23	133	76.8	4062
	SL7	<0.01	<0.01	1.73	<0.01	20.8	5.56	5.80	0.14	90.0	49.9	3704
	SL8	<0.01	0.02	3.46	13.2	37.4	11.1	14.2	0.26	142	86.1	4065
	SL9	<0.01	<0.01	<0.01	13.2	23.6	11.1	8.60	0.22	82.8	57.1	3818
	SL10	<0.01	0.02	3.46	13.2	35.7	11.1	14.2	0.27	144	99.6	4081
WET	MEAN	0.01	0.53	1.77	26.4	33.9	69.0	42.4	3.84	147	139	6345
	SD	0	0.29	0	14.4	17.1	23.2	34.8	1.29	49.3	76.4	950
	MIN	<0.01	0.30	1.77	15.1	14.7	37.1	8.77	2.06	78.8	39.5	4969
	MAX	0.05	0.91	1.77	45.3	64.1	105	108	5.86	224	254	7773
	CV	0	54.7	0	54.7	50.6	33.6	82.2	33.6	33.6	54.9	15.0
DRY	MEAN	0	0.02	2.38	14.8	32.87	11.1	12.52	0.26	149	78.5	3967
	SD	0	0.01	0.90	4.90	12.0	3.70	8.01	0.09	67.9	30.8	234
	MIN	0	0.02	1.73	13.2	14.9	5.56	3.10	0.14	82.8	28.2	3529
	MAX	0	0.03	3.46	27.9	52.7	16.7	30.9	0.42	289	128	4305
	CV	0	24.7	37.6	33.0	36.4	33.3	64.0	34.8	45.6	39.2	5.89
	DPRTV	-		0.8	85	100	35	36	-	-	140	-
	CAV	-	13	0.3	20	90	68	45	130	850	95	47000

Table 4. *A comparison of heavy metal concentrations (mg/kg) in the post remediated crude oil discharge channel with sediments from some Rivers in the Niger Delta and other parts of the world.*

Sediment system	Cd	Pb	Cr	Ni	Cu	Mn	Zn	Fe	Reference
Discharge Channel	<0.01-3.46	13.2-45.3	14.7-64.1	5.56-105	3.10-108	78.8-289	28.2-254	3529-7773	This Study
Forcados River, Nigeria	0.78 - 2.16	11.5-72.0	21.9-49.6	4.75-11.7	4.48-13.7	153-545	11.7-35.1	935-1840	Iwegbue *et al.* (2018)
River Orle, Nigeria	<0.1	2.2-162.3	5.3-109.3	1.2-28.5	3.1-24.3		5.0-57.0	688-6787	[13]
Warri River, Niger Delta	0.08-0.72	6.8-55.3	1.0-8.43	1.0-6.93	2.10-22.5		37.25-110	369-3600	[15]
Bodo creek, Niger Delta	Nd-1.0	0.09-2.3	1.9-13.6	0.4-2.3	4.2-23.0	4.0-32.0	2.7-380		[16]
Cross River, Niger Delta	1.20-2.60	27.4-86.4	0.1-1.7				88.3-117.85		[17]
Qua Iboe River, Niger Delta	1.00-3.20	38.2-68.35	0.5-1.2				74.2-108.3		[17]
Imo River, Niger Delta	1.0-1.8	9.0-29.0	10.0-67.0				31.0-306		[17]
Calabar River, Niger Delta		0.6-30.0	0.60-3.3				0.8-27.0	353-1045	Akpa *et al.* (2002)
Orogodo River, Niger Delta	<0.001	0.01-32.98	0.15-1.53	0.98-4.78	1.92-17.4	14.81-60.55	69.95-100.16	19.51-250	[14]
Ase Rive, Niger Delta	0.06-6.91	1.15-24.79	0.27-6.44	0.53-19.86	1.19-7.14	7.70-43.5	2.15-19.84		[13
Kolo creek, Niger Delta		0.94-2.31	10.95-22.53	5.52-14.33					[18]
Yellow River, China	0.10-0.47	10.08-37.39	40.28-75.67	-	11.5-45.7	-	50.69.119.83	-	[19]
Manoa River, Hawaii, USA	0.50-0.14	17-1078	-	289-360	172-367	-	208-510	-	[20]
Beiyunhe River, China	0.08-1.93	-	41.9-156	14.7-55.9	17.2-316	380-654	66.50-741.91	-	[21]
MoulayBousselham Lagoon, Morocco	0.02-0.84	6.9-31.67	18.98-113	10.5-96.0	21.35-322.36	157-700	167-758.89	2090-5710	[22]
Haraz River, Southern Caspian Sea basin	2.0-7.0	22-32	12-32	36-51	27-35	-	55-148	1460-1570	[23]
Kor River, Southwest Iran	-	3.1-11.1	40-128	40-152.5	6.5-34.7	-	14.1-59.7	-	[24]
Gediz River, Turkey	0.05-0.18	4.58-40.89	18.5-1192	3.47-35.45	4.33-19.8	-	-	-	[25]
Danube River, Serbia and	2.12-4.03	2.85-43.6	30.6-112.5	23.7-116.4	17.8-57.6	-	49.4-389.5	-	[26]

Sediment system	Cd	Pb	Cr	Ni	Cu	Mn	Zn	Fe	Reference
Montenegro									
Narew River, Poland	0.04-1.07	0.71-7.13	1.70-40.5	1.26-7.81	0.39-4.51	68-932	7.0-166	260-1600	[27]
Yangtze River, China	2.28-2.48	371-455	85.75-95.58	46.9-56.38	56.9-83.8	-	131.78-189	-	[28]
Utrata River, Poland	1.25-4.39	23.6-112	-	-	8.21-281	26.9-1536	71.13-338.36	94-3600	[29]
Han River, Korea	0.05-1.02	14.2-96.6	25.2-125	9.16-57.1	7.69-139	322-1492	34.3-551	1410-5120	[30]
Swartkops River estuary, South Africa	-	24.7-32.9	11.9-20.3	-	6.8-9.5	114.4-119.4	35.9-45.9	-	[31]
Jihlava River, Czech Republic	0.62-0.64	9.53-19.5	8.71-15.4	6.39-8.28	4.49-14.3	-	46.48-102.88	-	[32]
Huangshui River, China	4.4-6.2	29.1-121.9	44.2-201.7	-	-	-	0.9-89.4	-	[33]
Silver River, Nigeria	1.69-3.84	4.69-7.89	4.03-8.32	5.127.78	6.15-11.91	16.0-127.2	10.7-19.1	189.2-243.4	[34]

3.2. Contamination/Pollution Index (CPI) of Heavy Metals in Sediment

The computed contaminated/pollution index values of heavy metals in sediments of the post remediated crude oil produced water discharge channel are shown in Table 5.

Table 5. *Contamination/Pollution index of metals in sediments of the post remediated crude oil produced water discharge channel.*

		Cd	Pb	Cr	Ni	Cu	Zn
Wet	SL1	0.00	0.00	0.15	1.06	0.24	0.28
	SL2	0.00	0.00	0.24	1.63	0.97	0.55
	SL4	0.00	0.35	0.40	3.01	0.57	1.03
	SL5	0.00	0.18	0.33	2.20	1.30	1.33
	SL6	0.00	0.18	0.28	2.20	3.01	0.95
	SL10	2.21	0.53	0.64	1.74	0.97	1.81
Dry	SL1	0.00	0.16	0.15	0.16	0.09	0.20
	SL2	2.16	0.16	0.31	0.32	0.24	0.50
	SL3	4.33	0.16	0.49	0.48	0.55	0.91
	SL4	2.16	0.16	0.53	0.48	0.86	0.85
	SL5	2.16	0.33	0.28	0.32	0.24	0.50
	SL6	2.16	0.16	0.36	0.32	0.32	0.55
	SL7	2.16	0.00	0.21	0.16	0.16	0.36
	SL8	4.33	0.16	0.37	0.32	0.39	0.62
	SL9	0.00	0.16	0.24	0.32	0.24	0.41
	SL10	4.33	0.16	0.36	0.32	0.39	0.71
WET	MEAN	0.37	0.21	0.34	1.97	1.18	1.01
	SD	0.90	0.21	0.17	0.66	0.97	0.55
	MIN	0.00	0.00	0.15	1.06	0.24	0.28
	MAX	2.21	0.53	0.64	3.01	3.01	1.81
DRY	MEAN	2.38	0.16	0.33	0.32	0.35	0.56
	SD	1.60	0.08	0.12	0.11	0.22	0.22
	MIN	0.00	0.00	0.15	0.16	0.09	0.20
	MAX	4.33	0.33	0.53	0.48	0.86	0.91

During the wet season, the CPI value of Cd at SL10 was > 1 which indicates that the sediment at SL10 was polluted with Cd. The CPI values of Pb and Cr for all the locations during the wet season were < 1 suggesting that these sediments were contaminated with Pb and Cr. The CPI values of Cu at SL5 and SL6 were > 1 which indicates that the sediment at these two locations were polluted with Cu whereas the CPI of Cu at SL1, Sl2, SL3 and SL10 were < 1 which indicates that the sediment at these locations were contaminated with Cu. The CPI values of Zn at SL4, SL5 and SL10 were > 1 which indicates that the sediment at these three locations were polluted with Zn whereas the CPI of Zn at SL1, Sl2, and SL6 were < 1 which indicates that the sediment in these three locations were contaminated with Zn.

During the dry season, the CPI values of Cd were > 1 for all the locations except at SL1 and SL9 which indicates that these sediments were polluted with Cd. However, the CPI values of Pb, Cr, Ni, Cu and Zn were < 1 which indicates that the sediment in the study area was contaminated with Pb, Cr, Ni, Cu and Zn during the dry season.

3.3. Geo-accumulation Index of Metals in Sediment

The computed geoaccumulation index values of metals in sediments of the Post remediated crude oil produced water discharge channel are shown in Table 6. The geoaccumulation index of the metals ranged from -9.93 to -4.43 for As, 1.94 to 2.94 for Cd, -3.43 to -1.66 for Pb, -3.20 to -1.08 for Cr, -4.20 to 0.05 for Ni, -4.44 to 0.68 for Cu, -10.5 to -5.06 for V, -4.02 to -2.14 for Mn, -2.34 to 0.83 for Zn and -4.32 to -3.18 for Fe. On the average, the geoaccumulation index of Cd in the sediments falls into the moderately polluted category (Class 3) while the geoaccumulation index of all the other metals falls into the practically unpolluted category (Class 1) according to the [12] geoaccumulation index categorization (Table 2). This implies that industrial activities in the study area have led to the pollution of the Post remediated crude oil produced water discharge channel sediment with Cd.

Table 6. *Geoaccumulation Index of metals in sediment of the Post remediated crude oil produced water discharge channel.*

		As	Cd	Pb	Cr	Ni	Cu	V	Mn	Zn	Fe
Wet	SL1	0.00	0.00	0.00	-3.20	-1.46	-2.94	-6.57	-4.02	-1.85	-3.83
	SL2	0.00	0.00	0.00	-2.52	-0.84	-0.94	-5.94	-3.39	-0.88	-3.59
	SL4	-5.02	0.00	-2.24	-1.74	0.05	-1.72	-5.06	-2.51	0.01	-3.35
	SL5	-6.02	0.00	-3.24	-2.04	-0.41	-0.53	-5.51	-2.96	0.39	-3.46
	SL6	-6.02	0.00	-3.24	-2.29	-0.41	0.68	-5.51	-2.96	-0.10	-3.52
	SL10	-4.43	1.98	-1.66	-1.08	-0.75	-0.94	-5.85	-3.30	0.83	-3.18
Dry	SL1	0.00	0.00	-3.43	-3.18	-4.20	-4.44	-10.46	-3.91	-2.34	-4.32
	SL2	0.00	1.94	-3.43	-2.13	-3.20	-2.97	-9.44	-2.84	-1.03	-4.13
	SL3	-9.35	2.94	-3.43	-1.46	-2.61	-1.77	-8.86	-2.14	-0.16	-4.03
	SL4	0.00	1.94	-3.43	-1.36	-2.61	-1.13	-9.00	-2.44	-0.26	-4.07
	SL5	0.00	1.94	-2.35	-2.29	-3.20	-2.97	-9.67	-3.52	-1.01	-4.18
	SL6	0.00	1.94	-3.43	-1.91	-3.20	-2.57	-9.73	-3.26	-0.89	-4.12
	SL7	0.00	1.94	0.00	-2.70	-4.20	-3.54	-10.44	-3.82	-1.51	-4.25
	SL8	-9.93	2.94	-3.43	-1.85	-3.20	-2.25	-9.55	-3.17	-0.73	-4.12
	SL9	0.00	0.00	-3.43	-2.52	-3.20	-2.97	-9.79	-3.95	-1.32	-4.21
	SL10	-9.93	2.94	-3.43	-1.92	-3.20	-2.25	-9.50	-3.15	-0.52	-4.11
WET	MEAN	-3.58	0.33	-1.73	-2.15	-0.64	-1.07	-5.74	-3.19	-0.27	-3.49
	SD	2.84	0.81	1.47	0.72	0.51	1.21	0.51	0.51	0.96	0.22
	MIN	-6.02	0.00	-3.24	-3.20	-1.46	-2.94	-6.57	-4.02	-1.85	-3.83
	MAX	0.00	1.98	0.00	-1.08	0.05	0.68	-5.06	-2.51	0.83	-3.18
DRY	MEAN	-2.92	1.85	-2.98	-2.13	-3.28	-2.69	-9.64	-3.22	-0.98	-4.15
	SD	4.71	1.08	1.10	0.56	0.54	0.93	0.52	0.61	0.64	0.09
	MIN	-9.93	0.00	-3.43	-3.18	-4.20	-4.44	-10.46	-3.95	-2.34	-4.32
	MAX	0.00	2.94	0.00	-1.36	-2.61	-1.13	-8.86	-2.14	-0.16	-4.03

4. Conclusion

This study was carried out to evaluate the pollution status of the sediments from a remediated crude oil produced water channel. The study shows presence of heavy metals in the sediment and also established the following:

1) The concentrations of heavy metals except Cd obtained in sediments of the post remediated crude oil produced water discharge channel were lower than their respective regulatory limits.
2) On the average, the CPI value of Cd was > 1 which indicates that the sediments were polluted with Cd but the CPI values of other heavy metals were < 1 which indicates that these sediments were contaminated with the other heavy metals.
3) On the average, the Geoaccumulation index of Cd in the sediments falls into the moderately polluted category while the Geoaccumulation index of all the other metals falls into the practically unpolluted category.

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