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Evaluation of Heavy Metals in Water from a Post-Remediated Crude Oil Produced Water Discharge Channel in the Niger Delta

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ABSTRACT

This study was carried out to evaluate heavy metals in a post remediated crude oil produced water discharge channel. A total of twenty water samples were collected from ten sampling locations using grab sampling technique in October, 2022 (wet season) and February, 2023 (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 (mg/L) for heavy metals in the water for all locations and seasons ranged from <0.001-0.05 for Cd, 0.04-0.28 for Pb, 0.002-0.09 for Cr, 0.03-0.22 for Ni, 0.01-0.07 for Cu, <0.005-0.007 for V, 0.01-0.18 for Mn, 0.04-0.14 for Zn and 0.58-6.71 for Fe for all locations and seasons. The results showed that there was no significant ($p > 0.05$) spatial variation in the concentrations of all the heavy metals in the water but there was significant ($p < 0.05$) seasonal variation. Analysis of Variance (ANOVA) showed that there was no significant ($p > 0.05$) spatial variation in the concentrations of the heavy metals in the wet season (WS) and dry season (DS), however, t-test analysis showed that there was significant ($p < 0.05$) seasonal variation in the concentrations of the heavy metals. The heavy metals were significantly higher in the dry season than the wet season except for Cu, V and Fe which have higher in the dry season. On the average, the concentrations of the heavy metals in the water decrease in the order of Fe > Mn > Zn > Cu = Ni > Pb > V > Cr > Cd > As = Hg during the wet season and Fe > Pb > Ni > Mn > Zn > Cr > Cd = Cu > V > As = Hg during the dry season. The concentrations of the heavy metals except, Pb, Ni and Fe in the water samples were below or within their regulatory limits indicating recovery of the post remediated channel. This should be sustained to ensure full recovery of the remediated channel.

Keyword: Heavy Metals, Pollution, Contaminants, Produced Water Channel.

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 and may accumulate in the environment over a period of time (Alloway 2012) and and enter the aquatic environment through precipitation or deposition (Nriagu and Pacyna, 1988; Nagajyoti *et a*l., 2010). Heavy metal denotes any metallic element that has a high density and is poisonous at very low concentrations (Irwandi and Farida, 2009; Motswaiso *et al*., 2019). 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 (Ullah *et al*., 2022; Mat, 2023; Naoum, 2024) while others like Pb, Cd, Hg are not known to have any positive nutritional effect (Khan et al., 2022; Werner et al., 2024; WHO 2024; USEPA 2024). However, all heavy metals can have toxic effects if they occur in excess (Spiegel 2002; Abubakar *et al.,* 2024). 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 (Akan *et al*., 2009). Currently, heavy metals have become a global issue of concern (Censi *et al.,* 2006). Heavy metals are generally introduced into aquatic environments from natural and anthropogenic sources (Davutluoglu *et al*., 2010). They are among the major environmental pollutants in the world (Papafilippaki *et al*., 2008). 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.

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.

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 1). The community host one of the largest crude oil export terminals in the Niger Delta region of Nigeria.

Sample Collection and Treatment

Water samples were collected from ten sampling locations along the post remediated crude oil produced water discharge channel using grab sampling technique in October, 2022 (wet season) and February, 2023 (dry season) making a total of 20 water samples. In each location, samples were collected from three points and combined to form a homogenous sample. Water samples for heavy metals analysis were kept in plastic containers and acidified with two drops of concentrated nitric acid for preservation. All the collected water, sediment and biota samples were labeled appropriately, stored in a block of ice, and taken to the laboratory for analysis.

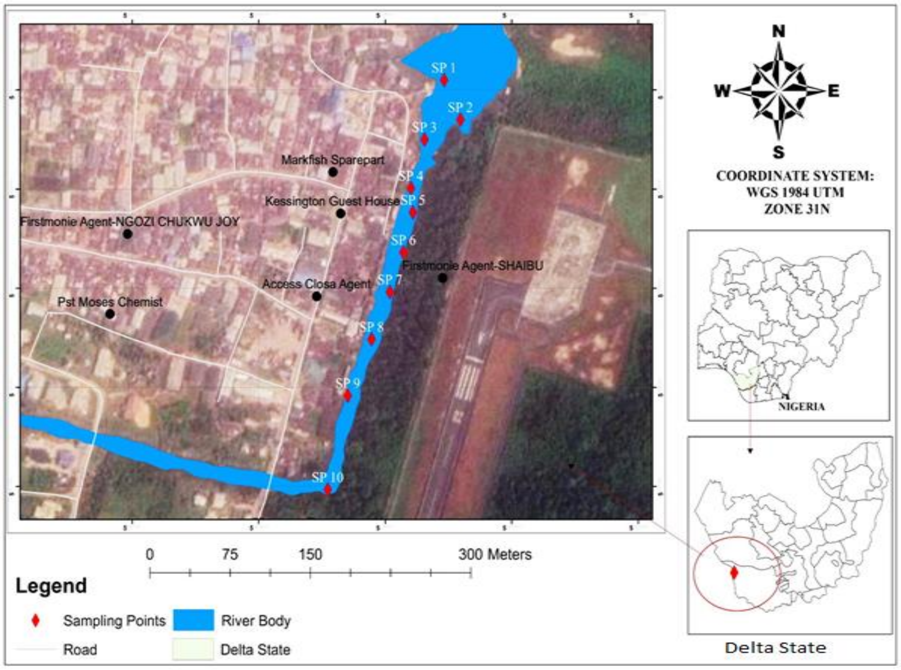

Figure 1: Map of study area showing the sampling locations

Determination of Heavy Metals Concentrations in Water Samples

The method of Radojevic and Bashkin (1999) was used. About 100 ml of well mixed water samples was measured and transferred into a beaker. Then, 2 mL of nitric acid and 6 mL of hydrochloric acid was added. The sample was stoppered with a watch glass and heated on a hotplate at 90 ^oC until the sample solution was reduced to about 20 mL. The beaker was removed and allowed to cool. Thereafter, the beaker wall and watch glass were washed down with distilled water. Thereafter, the sample was filtered into a 25 mL standard volumetric flask and then made to mark with 0.25 M HNO_3. The sample solutions were subsequently analysed for heavy metals using atomic absorption spectrophotometry (Perkin Elmer Analyst 200).

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 analysed samples with known concentration of the individual metals and re-analysed. The percentage recovery was calculated for each sample analysed. The percent recovery ranged from 94.3 to 98.5 %. Blanks were analysed for heavy metals along with samples and the results for blanks were subtracted from those obtained for samples before data analysis and interpretations.

Statistical Analysis

Analysis of Variance (ANOVA) was used to determine if there is significant spatial variation in the concentrations of heavy metals. T-test was used to determine if there is significant seasonal variation in the concentrations of heavy metals. The level of the significance that was adopted for the analysis was p = 0.05. P-value < 0.05 indicated significant variation while p-value > 0.05 indicated no significant variation. Relationship between individual contaminants was established by means of Pearson correlation coefficient. Principal component analysis (PCA) was used to establish the sources of the contaminants in the water. The statistical calculations were performed with SPSS version 20.0.

RESULTS AND DISCUSSION

Heavy Metals Concentrations in Water Samples

The concentrations of heavy metals in surface water of the post remediated crude oil produced water discharge channel are shown in Table 1. On the average, the concentrations of the heavy metals in the water decrease in the order of Fe > Mn > Zn > Cu = Ni > Pb > V > Cr > Cd > As = Hg during the wet season and Fe > Pb > Ni > Mn > Zn > Cr > Cd = Cu > V > As = Hg during the dry season.

Mercury (Hg) and Arsenic (As)

The concentrations of As and Hg in the water samples of post remediated crude oil produced water discharge channel were below the detection limit (< 0.001) during the wet and dry seasons.

Cadmium (Cd)

The concentration of Cd in the water samples during the wet season was below the detection limit (< 0.001), while concentration during the dry season ranged from <0.001 - 0.05 mg/L. The concentrations of Cd during the dry season is similar to others reported for surface waters of rivers in the Niger Delta (Ayenimo *et al*., 2005; Wogu and Okaka 2011; Okoye and Iteyere, 2014; Aghoghovwia *et al*., 2014; Tesi *et al.*, 2019).

Lead (Pb)

The concentrations of Pb in the water samples ranged from 0.035 - 0.081 mg/L (wet season) and 0.13 - 0.28 mg/L (dry season). T-test analysis showed significant ($p < 0.05$) seasonal variation in the concentrations of Pb in the water samples. The concentrations of Pb obtained in this study were above the permissible values set by USEPA (1999), CCME (1999), SON (2007) and WHO (2011). The high concentrations of Pb may be attributed to industrial discharges, emissions from speed boats, and urban surface run-off**.**

Chromium (Cr)

Chromium concentrations in the water samples ranged from 0.002 to 0.008 mg/L for the wet season and 0.002 to 0.089 mg/L for dry season. The concentrations of Cr in the water samples varied significantly ($p < 0.05$) with respect to season. The concentrations of Cr observed in the water samples were within the WHO (2011), SON (2007), Canadian water quality criteria (CCME, 1999) and USEPA (1999) water quality guideline. The Cr concentrations were lower than the range of 0.33 - 0.57 mg/L and 0.12 - 0.25 mg/L reported by Owamah (2013) and Tesi *et al*. (2019) for the Warri River, 0.1 - 2.9 mg/L reported for Bonny/Calabar River (Onojake *et al*., 2015) and 0.11 - 0.17 mg/L reported for Ikpoba River (Owamah, 2013) bu similar to the range reported for Ase, Agbarho, Ekakpamre and Afiesere Rivers as reported by Kaizer and Osakwe (2010).

Nickel (Ni)

The concentrations of Ni ranged from 0.028 - 0.104 mg/L for the wet season and 0.056 - 0.222 mg/L for dry season. The concentrations of Ni in the water samples varied significantly (p <

0.05) with respect to season. The concentrations of Ni for the two seasons were higher than the WHO (2007) and SON (2007) permissible values and similar to previous work carried out in the Niger Delta (Agbaire and Obi, 2009; Kaizer and Osakwe, 2010; Owamah, 2013).

Table 1: Metal concentrations (mg/L) in water of the post remediated crude oil produced water discharge channel

		Hg	As	Cd	Pb	Cr	Ni	Cu	V	Mn	Zn	Fe
WET	SL1	<0.001	<0.001	<0.001	0.081	0.006	0.072	0.074	0.005	0.18	0.041	6.71
	SL2	<0.001	<0.001	<0.001	0.035	0.003	0.04	0.038	0.003	0.05	0.058	3.45
	SL3	<0.001	<0.001	<0.001	0.055	0.008	0.104	0.055	0.007	0.13	0.055	4.97
	SL4	<0.001	<0.001	<0.001	0.040	0.006	0.072	0.048	0.005	0.09	0.059	3.96
	SL5	<0.001	<0.001	<0.001	0.037	0.003	0.04	0.040	0.003	0.05	0.050	3.36
	SL6	<0.001	<0.001	<0.001	0.039	0.003	0.035	0.043	0.002	0.05	0.053	3.55
	SL7	<0.001	<0.001	<0.001	0.038	0.003	0.035	0.048	0.002	0.05	0.051	3.41
	SL8	<0.001	<0.001	<0.001	0.037	0.002	0.03	0.043	0.002	0.05	0.046	3.09
	SL9	<0.001	<0.001	<0.001	0.037	0.002	0.028	0.046	0.002	0.04	0.050	3.32
	SL10	<0.001	<0.001	<0.001	0.043	0.003	0.035	0.054	0.002	0.05	0.058	3.87
DRY	SL1	<0.001	<0.001	0.05	0.28	0.033	0.222	0.03	0.005	0.06	0.060	0.62
	SL2	<0.001	<0.001	0.03	0.13	0.017	0.111	0.03	<0.005	0.08	0.090	0.58
	SL3	<0.001	<0.001	0.02	0.13	0.025	0.111	0.03	<0.005	0.01	0.09	0.77
	SL4	<0.001	<0.001	<0.001	0.13	0.002	0.056	0.01	<0.005	0.11	0.10	0.62
	SL5	<0.001	<0.001	0.02	0.28	0.054	0.111	0.01	<0.005	0.15	0.11	1.03
	SL6	<0.001	<0.001	0.02	0.28	0.006	0.167	0.03	<0.005	0.15	0.11	1.49
	SL7	<0.001	<0.001	0.02	0.28	0.031	0.111	0.03	<0.005	0.17	0.13	0.88
	SL8	<0.001	<0.001	0.02	0.28	0.017	0.167	0.03	<0.005	0.15	0.13	0.88
	SL9	<0.001	<0.001	0.02	0.28	0.089	0.167	0.03	<0.005	0.13	0.13	0.69
	SL10	<0.001	<0.001	0.03	0.13	0.023	0.167	0.03	<0.005	0.15	0.14	0.92
WET	MEAN	0.0	0.0	0.0	0.044	0.004	0.049	0.049	0.003	0.074	0.052	3.969
	SD	0.0	0.0	0.0	0.014	0.002	0.025	0.010	0.002	0.046	0.006	1.098
	MIN	0.0	0.0	<0.001	0.035	0.002	0.028	0.038	0.002	0.040	0.041	3.090
	MAX	0.0	0.0	<0.001	0.081	0.008	0.104	0.074	0.007	0.180	0.059	6.710
	CV	0.0	0.0	0.0	32.0	51.9	51.0	21.2	53.5	62.5	11.0	27.7
DRY	MEAN	0.0	0.0	0.026	0.220	0.030	0.139	0.026	0.005	0.116	0.109	0.848
	SD	0.0	0.0	0.010	0.077	0.025	0.047	0.008	0.000	0.051	0.025	0.271
	MIN	0.0	0.0	<0.001	0.130	0.002	0.056	0.010	<0.005	0.010	0.060	0.580
	MAX	0.0	0.0	0.050	0.280	0.089	0.222	0.030	0.005	0.170	0.140	1.490
	CV	0.0	0.0	39.7	35.2	85.8	34.0	32.4	0.0	44.0	22.7	31.9

Copper (Cu)

The concentrations of Cu in the water samples ranged from 0.038 - 0.074 mg/L for the wet season and 0.01 - 0.03 mg/L for the dry season. T-test analysis showed significant ($p < 0.05$) seasonal variation in the concentrations of Cu in the water samples. The wet season has significant higher concentrations of Cu than the dry season which might be as a result of run-off during the wet season. The concentrations of Cu in this study were below the WHO (2011) and SON (2007) permissible value of 0.05mg/L and 1.0 mg/L. The observed concentrations of Cu in this study were similar to others as reported for Warri and Ikpoba Rivers (Okoye and Iteyere, 2014; Aghoghovwia *et al*., 2014; Owamah, 2013), lower than those reported for Crayford creek Bonny/Calabar Rivers (Nwajei *et al*., 2014 &Onojake *et al*., 2015) and higher than those reported for Ase, Agbarho, Ekakpamre and Afiesere Rivers (Kaizer and Osakwe, 2010).

Vanadium (V)

The concentrations of V ranged from 0.002 - 0.007 mg/L for the wet season and <0.005 - 0.005 mg/L for the dry season. Vanadium was only detected at SL1 during the dry season.

Manganese

In this study, the concentrations of Mn in the water samples ranged from 0.04 - 0.18 mg/L and 0.01 - 0.17 mg/L for wet and dry seasons respectively. T-test analysis showed significant ($p < 0.05$) seasonal variation in the concentrations of Mn in the water samples. The dry season has significant higher concentrations of Mn compared to wet season in all the sampling points except SL1 and SL3. The concentrations of Mn were within the permissible values set regulatory authorities.

Zinc (Zn)

The concentrations of Zn in the water ranged from 0.041 - 0.0.059 mg/L and 0.06 - 0.14 mg/L for wet and dry seasons respectively. T-test analysis showed significant ($p < 0.05$) seasonal variation in the concentrations of Zn in the water samples. The dry season has significant higher concentrations of Zn than the wet season in all the sampling points. Zinc concentrations in the samples were within the standard permissible values and were comparable to those reported by Nwajei *et al*. (2014) andAghoghovwia *et al*. (2014) but lower than lower than those reported by other researchers (Kaizer and Osakwe, 2010; Okoye and Iteyere, 2014; Freeman and Omoregie, 2016; Tesi *et al*., 2019).

Iron (Fe)

The concentrations of Fe in the water samples ranged from 3.09 - 6.71 mg/L for the wet season and 0.58 - 1.49 mg/L for the dry season. T-test analysis showed significant ($p < 0.05$) seasonal variation in the concentrations of Fe in the water samples. The wet season has significant higher concentrations of Fe than the dry season. The concentrations of Fe were higher than the permissible value. The observed concentrations of Fe in this study were similar to others reported for Warri River and Crayford creek (Ayenimo *et al*., 2005; Owamah, 2013; Nwajei *et al*., 2014) but higher than those reported for Ase, Agbarho, Ekakpamre and Afiesere Rivers (Kaizer and Osakwe, 2010).

Analysis of Variance (ANOVA) showed that there was no significant ($p > 0.05$) spatial variation in the concentrations of the heavy metals in the post remediated channel between the stations in the wet season (WS) and dry season (DS) (Tables 2 and 3). However, t-test analysis showed that there was significant ($p < 0.05$) seasonal variation in the concentrations of the heavy metals in water of the post remediated channel as shown in Table 4.

Table 2: ANOVA result of heavy metals concentrations (mg/L) in water from the discharge channel during the WS

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.57851	9	0.17539	0.08499	0.999779	2.016601
Within Groups	144.4562	70	2.06366			
Total	146.0347	79				

Table 3: ANOVA result of heavy metals concentrations (mg/L) in water from the discharge channel during the DS

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.136262	9	0.01514	0.194136	0.994213	1.999115
Within Groups	6.239009	80	0.077988			
Total	6.375271	89				

Table 4: Summary of t-test results of heavy metals in water from the discharge channel between WS and DS

	Mean concentrations (mg/L)					
Metals	**Wet season**	**Dry season**	**t-cal**	**t-crit**	**p-value**	**Decision**
Cd	0.00	0.02	5.8109	1.8331	0.0001	Significant
Pb	0.04	0.22	7.1338	1.8331	2.75×10^{-5}	Significant
Cr	0.004	0.030	3.1181	1.8331	0.0006	Significant
Ni	0.05	0.14	4.8612	1.8331	0.0004	Significant
Cu	0.05	0.03	6.2226	1.8331	7.73×10^{-5}	Significant
V	0.0033	0.0005	4.5826	1.8331	0.0007	Significant
Mn	0.07	0.12	1.9553	1.8331	0.0398	Significant
Zn	0.05	0.11	7.4966	1.8331	1.85×10^{-5}	Significant
Fe	3.97	0.85	8.1248	1.8331	9.81×10^{-6}	Significant

The concentrations of all heavy metals were significantly higher in the dry season than the wet season except for Cu, V and Fe which have higher concentrations in the wet season than the dry season. The significant seasonal variations observed may be due to evaporation during the dry season or runoff and inflow of contaminants during the wet season. A comparison of some heavy metals concentrations in water of the post remediated crude oil produced water discharge channel with others reported in literature for rivers from the Niger Delta and Nigeria are shown in Table 5 while Table 6 gives a comparison of heavy metals in the water from the discharge channel with some water quality standards.

Table 5: Metal concentrations (mg/L) in water in comparison with others in literatures

River system	FE	ZN	CU	MN	CR	PB	References
Post remediated discharge channel	0.58-6.71	0.04-0.14	0.01-0.07	0.01-0.18	0.002-0.089	0.04-0.28	This study
Warri river	0.11-4.68	-	0.01-1.80	-	0.01-0.14	ND-1.70	Ayenimo *et al.* (2005)
Warri river	-	-	ND-0.26	0.02-0.68	ND-0.06	ND-0.001	Wogu and Okaka (2011)
Warri river	1.28-1.56	-	0.28-0.55	-	0.33-0.57	0.72-0.99	Owamah (2013)
Warri river	21.1-36.6	0.85-1.04	0.02-0.02	-	0.01-0.09	0.06-0.10	Okoye and Iteyere (2014)
Warri river	0.30-0.70	0.002-0.05	0.001-0.02	-	0.07-0.24	0.03-0.08	Aghoghovwia *et al.* (2014)
Crayford creek, warri	4.44-5.07	0.05-0.06	1.48-4.30	0.30-0.40	0.01-0.01	0.01-0.01	Nwajei *et al.* (2014)
Ekpan creek, warri	0.43-0.65	0.13-0.32	0.001-0.004	0.01-0.05	0.001-0.004	0.001-0.004	Freeman and Omoregie (2016)
River benue	-	-	0.01-1.28	-	0.06-5.24	-	Akaahan *et al.* (2015)
Bonny/new calabar river	-	0.1-2.5	0.3-1.2	-	0.1-2.9	0.2-0.3	Onojake*et al.* (2015)
River niger, agenebode	-	0.15-0.35	0.08-0.30	-	-	0.00-0.017	Wangboje and Ikhuabe (2015)
Ikpoba river	0.11-0.27	-	0.01-0.11	-	0.11-0.17	0.10-0.20	Owamah (2013)
River benue (yola)	0.0021-1.058	0.0002-1.66	0.0003-1.53	0.0004-2.04	0.0002-0.36	0.0002-0.12	Hong *et al.* (2014
River ethiope	<0.001-0.036	-	-	-	-	<0.001-0.27	Agbaire and Obi (2009)

Ase river	0.006-0.011	1.78-2.15	0.002-0.003	0.02-0.03	0.001-0.003	0.002-0.005	Kaizer and Osakwe (2010)
Agbarho river	0.002-0.007	2.35-3.05	0.001-0.002	0.02-0.04	0.001-0.002	0.002-0.003	Kaizer and Osakwe (2010)
Ekakpamre river	0.005-0.008	0.98-1.80	0.001-0.003	0.03-0.04	0.002-0.006	0.007-0.009	Kaizer and Osakwe (2010)
Afiesere river	0.005-0.007	2.91-3.05	0.003-0.006	0.02-0.03	0.001-0.002	0.002-0.003	Kaizer and Osakwe (2010)

Table 6: Comparison of heavy metal concentrations (mg/L) in water samples of the study area with some water quality standards

	WET SEASON		**DRY SEASON**		**WHO (2011)**	**CCME (1999)**	**USEPA (1999)**	**SON (2007)**
HEAVY METALS	**MEAN±SD**	**RANGE**	**MEAN±SD**	**RANGE**				
HG	<0.001	<0.001	<0.001	<0.001	0.006	-	-	0.001
AS	<0.001	<0.001	<0.001	<0.001	0.01	-	-	0.01
CD	<0.001	<0.001	0.03±0.01	<0.001-0.05	0.003	-	-	0.003
PB	0.04±0.01	0.04-0.08	0.22±0.08	0.13-0.28	0.01	0.017	0.003	0.01
CR	0.004±0.002	0.002-0.008	0.03±0.03	0.002-0.09	0.05	0.05	0.10	0.05
NI	0.05±0.03	0.03-0.10	0.14±0.05	0.06-0.22	0.02	-		0.02
CU	0.05±0.01	0.04-0.07	0.03±0.01	0.01-0.03	0.05	0.024	0.009	1.0
V	0.003±0.002	0.002-0.007	0.005±0.00	<0.005-0.005	-	-	-	-
MN	0.07±0.05	0.04-0.18	0.12±0.05	0.01-0.17	0.05	0.15	0.05	0.2
ZN	0.05±0.01	0.04-0.18	0.11±0.03	0.06-0.14	5.0	0.03	0.12	3.0
FE	3.97±1.09	3.09-6.71	0.85±0.27	0.58-1.49	0.03	0.3	0.30	0.3

Correlation Analysis of Heavy Metals in the Water Samples

In this study, the relationship between heavy metals in water of the study area was established using the Pearson's correlation (Table 7). Significant positive correlation ($r^2 \geq 0.4$) was observed among heavy metals at 0.01 and 0.05 level of significance. Cadmium correlates with Ni, Cu and V during the wet season. Pb correlates with all the other metals in both seasons except Zn during the wet season and Cu, V and Zn during the dry season. Like Pb, Cr correlates with all the other metals except Zn during the wet season. Ni correlates with Cu and V in both seasons and Mn and Fe during the wet season. Cu correlates with V, Mn and Fe during the dry season, V correlates with Mn and Fe during the wet season while Mn correlates with Fe in both seasons and Zn during the dry season.

Table 7: Pearson's correlation coefficient of heavy metals in water of the post remediated crude oil produced water discharge channel

	Cd	**Pb**	**Cr**	**Ni**	**Cu**	**V**	**Mn**	**Zn**	**Fe**
Wet Season									
Cd	1.00								
Pb	0.00	1.00							
Cr	0.00	0.65*	1.00						
Ni	0.00	0.61*	0.99**	1.00					
Cu	0.00	0.95**	0.59*	0.54*	1.00				
V	0.00	0.60*	0.97**	0.99**	0.50*	1.00			
Mn	0.00	0.94**	0.84**	0.82**	0.87**	0.81**	1.00		
Zn	0.00	-0.54	0.10	0.08	-0.46	0.06	-0.38	1.00	
Fe	0.00	0.99**	0.74**	0.70**	0.93**	0.70**	0.97**	-0.41	1.00
Dry Season									
Cd	1.00								

Pb	0.21	1.00							
Cr	0.16	0.44*	1.00						
Ni	0.78**	0.51*	0.26	1.00					
Cu	0.55*	0.10	0.04	0.62*	1.00				
V	0.76**	0.27	0.05	0.62*	0.17	1.00			
Mn	-0.27	0.48*	0.10	0.03	-0.14	-0.39	1.00		
Zn	-0.42	0.14	0.21	-0.08	0.09	-0.70	0.77**	1.00	
Fe	-0.14	0.40*	-0.19	0.18	0.04	-0.30	0.51*	0.35	1.00

**Pearson correlation is significant at 0.01 level of significance (1 tailed)
*Pearson correlation is significant at 0.05 level of significance (1 tailed)

CONCLUSION

This study evaluated heavy metals concentrations in a post remediated crude oil produced water discharge channel. The study has also shown that there was significant seasonal variation in the concentrations of heavy metals in the water. Mercury and arsenic were not detected in the water samples for both seasons, while Cd and V were not detected in the wet and dry seasons respectively. There was significant ($p < 0.05$) seasonal variation in the concentrations of all the heavy metals in the water samples from the post remediated crude oil water discharge channel. The concentrations of the heavy metals except, Pb, Ni and Fe in the water samples were below or within their regulatory limits.

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