Original

Heavy Metal concentrations in Drinking water sources of oil and non-oil producing communities in Rivers State: a cross-sectional study

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Article history: Received 2 February 2024, Reviewed 8 March 2024, Accepted for publication 12 March 2024

How to cite this article:
Iwunze EC, Tobin-West CI; Heavy Metal concentrations in Drinking water sources of oil and non-oil producing communities in Rivers State: a cross-sectional study. The Nigerian Health Journal 2024; 24(1):1109 – 1117. Doi: https://www.doi.org/10.60787/tnhj-24-1-778

Abstract

Background: Chronic low-dose exposures to heavy metals are a huge public health problem in heavily polluted environments. This study aimed at comparing the heavy metal concentrations in drinking water sources of oil and non-oil-producing communities in Rivers State.

Method: This was a cross-sectional, comparative study conducted on water samples collected from 14 randomly selected water sources from crude oil and non-oil producing communities. Data analysis was done using Statistical Package for Social Sciences (SPSS) version 25. T-test was used to compare the mean differences between the heavy metal concentrations of the drinking water sources in the two communities.

Result: Mean lead concentrations of the drinking water sources of both communities exceeded the WHO permissible limits. Mean arsenic concentrations of the drinking water sources in the oil-producing community were higher than that of the non-oil-producing community ($P > 0.05$). Mean concentrations of mercury were significantly higher in the oil-producing than in the non-oil-producing communities. (P-value = 0.005).

Conclusion: Heavy metal contamination of drinking water sources in oil and gas-producing communities in Nigeria is a potential human health disaster. This calls for consistent environmental monitoring of the environmental parameters of oil-producing and adjourning communities for clean-up interventions by all concerned stakeholders.

Keywords: heavy metal, cross-sectional study, environmental exposure, drinking water, oil pollution.

Introduction

Chronic low dose exposure to heavy metals is a huge public health problem in environments with heavy metal contamination.[1,2] Heavy metals, a constituent of crude oil are among the priority substances to be monitored. Thus, specific permissible levels for their concentrations in water have been established by environmental quality standards (EQ).[3,4,5]

Historically, commercially viable crude oil was discovered in Nigeria's Niger Delta region in 1956.[5] Since then, oil exploration has steadily impacted the region's ecosystem.[5,6] The harmful effects of oil and gas exploration are primarily a fall-out of oil spills. According to earlier reports, oil tanker accidents and pipeline degradation account for over 50% of oil spills in the Niger Delta; other prevalent causes include human error, mechanical breakdown, vandalization, and insurgency.[6,7] Nigeria has the second-largest oil resource in Africa and is the continent's primary producer of crude.[8] Significant quantities of crude oil are spilled and pollute the area with heavy metals, leading to severe ecosystem damage and adverse human health effects.[9]

The soil is the core of the ecological system and therefore is frequently contaminated with crude oil-associated heavy metals.[10] Also, the persistence of heavy metals in the soil makes it a repository for heavy metals.[11] On entry into the soil, heavy metals have the potential to seep into the soil and contaminate groundwater.[12,13]

Although heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and mercury(Hg), occur naturally in small amounts, environmental contamination is caused primarily by anthropogenic activities.[14,15] There is evidence that these metals are systemic toxins that produce harmful health effects in man, such as cardiovascular disease (CVD), congenital anomalies, neurologic and behavioural abnormalities, hearing impairment, haematological and immune disorders, and various cancers.[15]

Ingestion of contaminated farm produce and using contaminated water for cooking or drinking water, inhalation, and dermal absorption are the common pathways of exposure pathways.[16] Majority of residents in these areas are not aware of the potential dangers or health risks that heavy metals from oil spills may pose. Even where risk awareness exists, it is almost impossible for them to avoid using polluted water for cooking or drinking due to poor access to portable water.[17,18]

Several studies have investigated heavy metal concentrations in drinking waters of oil-producing communities[19,20,21] but there is a dearth of literature on a comparative assessment of these pollutants between oil and non-oil producing communities in the Niger Delta to show a clear disparity in them and strengthen this evidence. This study therefore was aimed at providing a comparative analysis of heavy metal concentrations in drinking water sources of oil and non-oil-producing communities in Rivers State.

Method

The study was carried out in Nweekol-Kegba Dere, an oil-producing/impacted community in Gokana Local Government Area, and Omerelu, a non-oil-producing community in Ikwerre Local Government Areas, both in Rivers State, Nigeria. The areas of the communities were determined using geospatial maps.

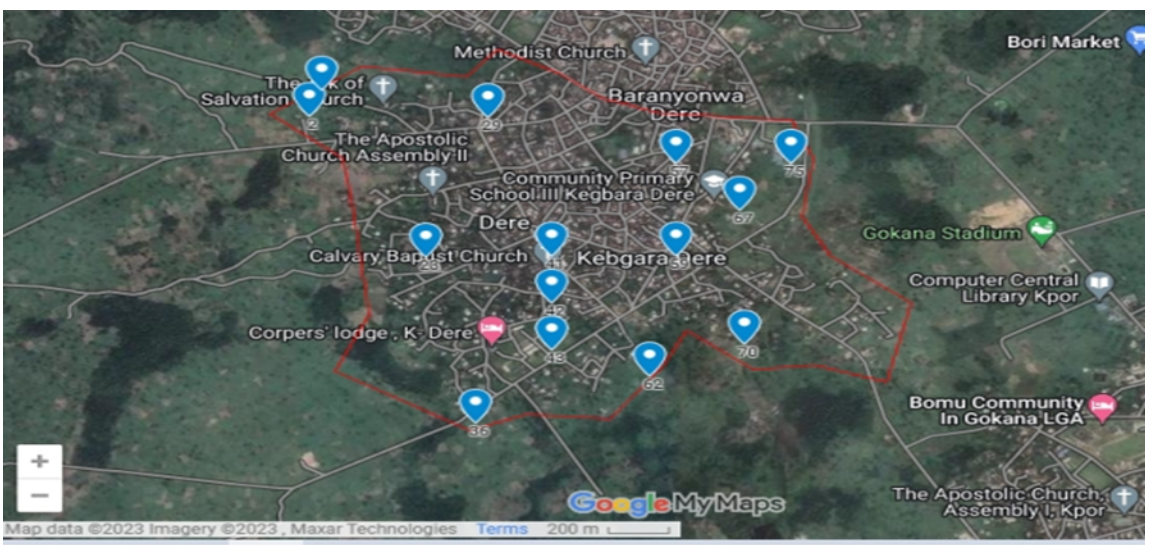

Figure 1: Map of the Study area showing the sampling points in Kegbara Dere Community

Print ISSN: 0189-9287 Online ISSN: 2992-345X

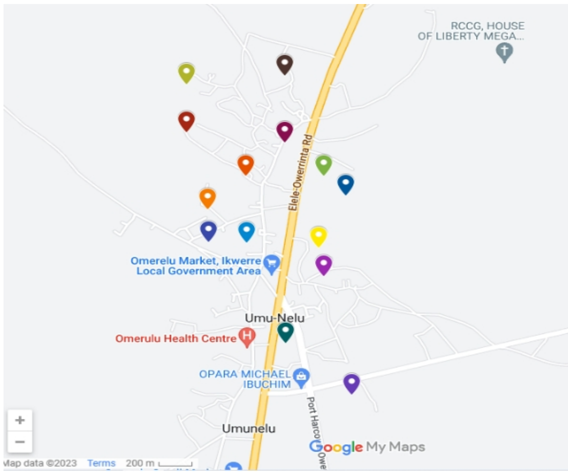

Figure 2: Map of the Study area showing the sampling points in Omerelu Community

Study Design
This was a descriptive cross-sectional study.

Sampling technique
The sampling points were randomly determined and geo-referenced for easy identification. At the sample site, the Google map and the location tracking icon of a hand-held device were turned on to give a precise location of the sampling site. The geographic coordinate systems displaying latitude and longitude were identified.

Study Tools
Data extraction sheets were developed following the objectives of the study and used to collect data on the type of water source sampled, the geo-coordinates of the sampling points, and the various heavy metals analyzed.

Sample Collection, Study Equipment, and Study Procedure
In November 2022, which was during the dry season, water sampling from the two communities was conducted. Water samples were collected from randomly selected water sources. Fourteen (14) water samples were taken from deep wells (boreholes), shallow wells, mono pumps, and the local stream. In Kegbara Dere, twelve samples were collected from the boreholes, one from a well, and one from the local stream. A total of seven (7) samples each were collected from the boreholes and mono-pumps in Omerelu. These sources of water were major drinking water sources for the community and also served other domestic purposes. A total of 28 water samples were collected from the drinking water sources of the two communities. Water was collected from each of the fourteen sites using a 1L polyethylene water sampler bottle. Prior to usage, detergents were used to wash all sampling bottles, and deionized water was used to rinse them. The bottles were used to collect the samples after being rinsed three times with water from the various sources during the sampling period. The obtained samples were transported to the lab for further analysis in ice-packed coolers.[22]

Sample preparation and pretreatment
Water samples were digested in the laboratory. First, a mark was made with a marker at the 20 mL mark of the beaker. In a beaker with a watch glass cover, 50 mL of thoroughly mixed water samples were digested by adding 1 mL of concentrated (69–72%) HNO_3 and 2.5 mL of concentrated (30%) HCl. The mixture was then heated on a hot plate at 90 degrees Celsius and boiled until the solution got to the 20ml mark. The beaker was then taken out and allowed to cool. Each sample of digested water was filtered using Whatman filter paper No. 42 into a 100 mL volumetric flask, which was then completely filled to the mark with deionized water and 2 mL of nitric acid to produce a clear solution.[22]

Determination of heavy metal content of the samples
To determine the unknown concentration of a heavy metal in a solution, a calibration curve was used. Several solutions with known concentrations were used to calibrate the instrument. By using more concentrated solutions, which absorb more radiation up to a given absorbance, a calibration curve was created that is continuously rescaled. The calibration curve depicted the concentration versus the absorbed radiation. Atomic absorption spectroscopy was used to analyze the water sample obtained from the study site. Using an Atomic Absorption Spectrometer (AAS), the concentration of the heavy metals was determined. [22]

Definition of terms
Heavy metals: Heavy metals are classified as elements belonging to a metallic group with relative densities that are nearly five times greater than those of water.[17, 23]

Oil-producing community: An oil-producing community has oilfields and a history of oil production.[5]

Non-oil-producing community: A non-oil-producing community has no oilfields and no prior history of any oil production or exploration in the past. It is also not located close to towns that have been exposed to oil exploration in the past. However, the community is in

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Print ISSN: 0189-9287 Online ISSN: 2992-345X

the same state as the oil-producing community and shares similar population characteristics such as size, structure, and socio-demographics. [24,25]

Data Analysis

Data entry and analysis were done using Microsoft Excel spreadsheet and IBM Statistical Package for Social Sciences (SPSS version 20).[26] T-test was used to compare the heavy metal concentrations of the drinking water sources between the two communities. For this study, the guideline values for heavy metal concentrations in drinking water for Pb and As were 0.01mg/l (10μg/l), Cd 0.003mg/l (3 μg/l), Pb 0.01mg/l (10μg/l), Hg (inorganic) was 0.006mg/l (6μg/l). [3] Any values for the heavy metal studied that were higher than the guideline values were considered elevated.[3,27]

Ethical considerations

Ethical approval was obtained from the Ethics Committee of the University of Port Harcourt before the study commenced. Community entry into the study communities was done and permission to conduct the study was obtained from the Chiefs and Heads of the communities.

Results

Table 1 shows the heavy metal concentration of drinking water sources in the oil-producing community. Four (4) out of the 14 sampled drinking water sources had Pb concentrations exceeding the recommended WHO limits. Cadmium levels were elevated in 2 of the sampled drinking water sources. Mercury concentration was within normal limits. Only one drinking water source had Arsenic levels above WHO maximum permissible limits.

Table 1: Heavy metal concentration of drinking water sources in Kegbara Dere Community (an oil-producing community)

Samples			Heavy metal Concentration (mg/l or ppm)			
	Longitude	Latitude	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	Arsenic (As)
Station 1	7.28	4.67	0.0471	0.0046	<0.001	<0.003
Station 2	7.26	4.67	0.1141	0.0022	<0.001	<0.001
Station 3	7.26	4.67	0.0034	0.0023	<0.001	<0.001
Station 4	7.27	4.67	0.1314	<0.001	<0.001	0.0012
Station 5	7.27	4.66	0.0112	<0.001	<0.001	0.0010
Station 6	7.27	4.66	0.0114	0.0014	<0.001	0.0201
Station 7	7.27	4.66	<0.001	<0.001	<0.001	<0.001
Station 8	7.27	4.66	0.0073	<0.001	<0.001	0.0031
Station 9	7.27	4.66	<0.001	0.0013	<0.001	<0.001
Station 10	7.27	4.66	0.0123	0.001	<0.001	0.0024
Station 11	7.27	4.67	0.0316	<0.001	<0.001	<0.001
Station 12	7.27	4.67	<0.001	0.0024	<0.001	<0.001
Station 13	7.28	4.67	0.0134	<0.001	<0.001	0.0031
Station 14	7.27	4.66	<0.001	0.0032	<0.001	<0.001
WHO max permissible limit (2017 edition)			0.01	0.003	0.006	0.01

<0.001: below detecting limit

Table 2 shows the heavy metal concentration of drinking water sources in the non-oil-producing community. Nine (9) out of the 14 drinking water sources sampled in the study had elevated Pb concentrations compared to the approved WHO maximum limits. Cd, Hg, and Pb concentrations of the sampled drinking water sources were all within the permissible WHO limits.

Print ISSN: 0189-9287 Online ISSN: 2992-345X

Table 2: Heavy metal concentration of drinking water sources in Omerelu Community (a non-oil producing community in Ikwerre LGA Rivers State)

Samples			Heavy metal Concentration (mg/l or ppm)			
	Longitude	Latitude	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	Arsenic (As)
Station 1	6.87	5.20	0.0214	<0.001	<0.001	<0.003
Station 2	6.87	5.20	0.0143	0.0021	<0.001	<0.001
Station 3	6.87	5.21	0.3470	0.016	<0.001	<0.001
Station 4	6.87	5.21	0.0104	<0.001	<0.001	<0.001
Station 5	6.87	5.22	<0.001	<0.001	<0.001	<0.001
Station 6	6.87	5.22	0.0271	0.0023	<0.001	<0.001
Station 7	6.87	5.22	0.1924	<0.004	<0.001	0.0031
Station 8	6.87	5.21	0.3162	<0.001	<0.001	<0.001
Station 9	6.87	5.21	<0.001	<0.001	<0.001	<0.001
Station 10	6.87	5.21	0.1163	0.0014	<0.001	<0.001
Station 11	6.86	5.20	0.0413	0.0020	<0.001	<0.001
Station 12	6.86	5.20	<0.001	<0.001	<0.001	<0.001
Station 13	6.86	5.18	0.0172	<0.001	<0.001	<0.001
Station 14	6.86	5.19	0.3326	<0.001	<0.001	<0.001
WHO max permissible limit (2015 edition)			0.01	0.003	0.006	0.01

<0.001 : below detecting limit

Table 3 shows the comparison of the mean heavy metal concentration in the drinking water sources of the oil and non-oil-producing communities. The mean Pb concentrations of the drinking water sources of both communities (0.027 ± 0.042, 0.102 ± 0.135) exceeded the WHO permissible limits. The difference in the mean concentrations of Pb was not significant (t=1.985; p-value = 0.06) The mean cadmium concentrations of the drinking water sources of the oil and non-oil communities were (0.001 ± 0.001, 0.001 ± 0.004; p-value = 0.54) The mean concentrations of mercury in the oil and non-oil producing communities were 0.001 ± 0.001, 0.000 ± 0.000; p-value = 0.005) The mean arsenic concentrations of drinking water sources of the oil and non-oil producing communities respectively (0.002 ± 0.005, 0.000 ± 0.001; p=0.24).

Table 3: Mean for heavy metals concentration in drinking water sources for oil and non-oil producing community

Heavy metals	Oil producing community Mean ± SD	Non-oil producing community Mean ± SD	Mean difference (95% CI)	T	p-value	WHO (2011)
Lead	0.027 ± 0.042	0.102 ± 0.135	-0.075 (-0.153,0.002)	-1.985	0.06	0.01
Cadmium	0.001 ± 0.001	0.001 ± 0.004	-0.000 (-0.003, 0.001)	-0.619	0.54	0.003
Mercury	0.001 ± 0.001	0.000 ± 0.000	0.001 (0.000, 0.002)	3.097	0.005*	0.006
Arsenic	0.002 ± 0.005	0.000 ± 0.001	0.001 (-0.001, 0.004)	1.202	0.24	0.01

SD – standard deviation CI – confidence interval *Statistically significant

Discussion

The findings show that there were higher mean concentrations of Hg and As in the drinking water sources of the oil-producing community compared to the non-oil-producing community. Also, increased levels of Cd and As above WHO limits were detected in the two and one major drinking water sources respectively in the oil-producing community, while the Cd and As levels in all the drinking water sources of the non-oil-

Print ISSN: 0189-9287 Online ISSN: 2992-345X

producing community were within normal limits. This suggests that the elevated heavy metals in the water sources were probably from the environmental pollution from crude oil in the oil-producing community.

It is important to note that Ogoniland in the Niger Delta region has experienced vast oil pollution in both coastal and upland environments, which has led to the catastrophic devastation of delicate ecosystems including mangroves and wetlands.[5,28] Groundwater contamination by heavy metals occurs via leaching and the ability of the metal to remain within the depths of the soil layers. This contamination can lead to heavy metal poisoning in humans and aquatic life in the K-dere community. Also, heavy metals have a property of persistence in the environment, they may be taken up and bioaccumulated by plants through the nodules in their roots. This affects man through the food chain when such bioaccumulated plants are consumed over time.[29,30]

The Niger Delta is referred to as a tropical rainforest, and its ecosystems are home to a wide variety of aquatic and terrestrial species of flora and wildlife. This region can be divided into four ecological zones: the coastal inland zone, the freshwater zone, the lowland rainforest zone, and the mangrove swamp zone.[6,8].

According to the environmental reports, the Niger Delta region is one of the ten most significant wetlands and marine ecosystems in the world.[31,5] Wetlands naturally can degrade and absorb contaminants.[8] Compared to surface water, groundwater is much more likely to have significant arsenic concentrations as seen in the index study. This is in consonance with a study carried out by Ejike *et al* on heavy metal concentration in underground water sources from different sample points in an oil-polluted area of the Niger Delta, who reported that the concentration of the sampled heavy metals (Cd, Pb, and Arsenic) were higher than the WHO recommended levels.[32] They observed that the heavy metal concentration sampled at an estimated distance of 300m from an area where the effluent was discharged (effluent discharge area EFA) was higher than those from the same distance from the wellhead area and flare area, and the point that served as the control located about 10km from the oil-polluted areas. This further supports the epidemiological hypothesis of the link between elevated heavy metal concentration in drinking water sources, which is an indirect measure of exposure, and crude oil pollution.

Additionally, a similar study in Bayelsa[33] observed that heavy metals present in the community river which serves as a source of drinking water exceeded WHO limits. Ogbole *et al* reported that the Sagbama River, like many rivers in Niger Delta, is subjected to crude oil pollution. This further elucidates the importance of safe drinking water for residents in these heavily oil-polluted communities. Conversely, a study done by Ezekwem *et al* in three communities of Gokana, Rivers State reported Pb concentrations below permissible limits.[20]

Gokana is a region that has been beset by a number of problems including periodic inadvertent crude oil spills from industries and ongoing illicit crude oil exploitation (also known as Kpofire) by residents, which frequently results in both minor and significant oil spills. These frequently cause contamination of the soil, the groundwater, and the surface water.[20] This contrary finding observed by the authors could be attributed to the fact that only nine samples were analyzed for Pb content from these three communities. The sample size for the drinking water sources seems insufficient and therefore may not be representative of the overall drinking water sources in the three communities studied. This calls for more comprehensive studies that will help to precisely highlight the heavy metal concentration of drinking water sources in communities in Gokana local government area.

Elevated Cd and As levels were observed some of the drinking water sources of the oil producing community. There is documented evidence to show that following oral exposure, that the kidneys and the bone are primary and susceptible targets of Cd poisoning.[34] In addition, Cd is proven to be a cancer-causing substance in humans. Other toxic effects of Cd include reproductive toxicity, hepatic, haematological, and immunological effects in both animals and human.[17,34]

It was observed from the index study that the mean Pb concentration of the drinking water sources of both communities was higher than the WHO limits. However, the mean difference observed was not statistically significant. Although, Omerelu has no history of oil production and so was the basis for using it as a control site at the conceptualization of the study.

Reports from the locales and the state government revealed that illegal oil bunkering activities had been ongoing for months around the community. This may have been responsible for the high Pb concentration observed in the study site, and this further buttress the

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fact that crude oil pollution is one of the major sources of heavy metal contamination. This is of particular concern because heavy metals are persistent and bioaccumulate in the aquatic ecosystems and may enter into the human food chain posing a risk to human health.[16,35] These have potential health implications for both adults and children residing in these communities.

For instance, the kidneys and liver absorb most of the Cd that enters the human body, and this metal can persist within these organs for several years. Only a small amount of Cd is excreted slowly through the urine and faeces. Also, more Cd is absorbed from food by the body when there is insufficient iron and other nutrients in the diet.[34] Iron deficiency is still a major public health concern for most populations including children, adolescents, pregnant women, and the elderly. Additionally, with Pb exposure, children are also more susceptible because they engage in behaviours that contribute to the ingestion of Pb surface dust (such as hand-to-mouth activities) and because they absorb more Pb through their gastrointestinal tract than adults do, possibly as a result of a combination of physiological differences and dietary and nutritional variations.[36]

Chindah and Ordinioha in southern Nigeria reported elevated Pb concentrations in drinking water sources in an urban community.[37] This high concentration of Pb was attributed to environmental sources such as leaded petrol. Also, the authors observed that one of the water sources close to a vehicle repair shop had the highest Pb concentration. This finding is in keeping with that of the index study and further emphasizes the need for studies aimed at biological monitoring of these toxic metals to directly estimate exposure and subsequently proffer viable solutions to this public health problem. Studies by Ojikutu *et al*, and Dogara *et al* in some non-oil-producing states respectively reported that heavy metal concentration values in the drinking water sources from various locations of the study community were within the recommended drinking water limits.[38,39,40] The above findings as reported in these non-oil producing states corroborate with the evidence on the link between oil spillage and heavy metal exposure of residents in these oil-polluted environments. It is also important to sustain the efforts to ensure water quality and safety in our communities.

Corroborating with the present study, Studies in South China and North Africa reported high levels of heavy metal concentration from sampled drinking water sources. The authors linked this to a nearby point source of pollution.[41,42,43] This presents an ecological risk and highlights the need for continuous surveillance and remediation of the environment. This calls for action for environmental preservation from possible pollution arising from man's activities and the importance of ensuring that communities have access to safe drinking water.

Implications of the findings of the review

The local health authority should conduct regular assessments of environmental waters to determine their heavy metal concentrations and prompt interventions instituted when recommended limits are exceeded in order to reduce the health risks associated with exposure to heavy metals.

Limitation

Heavy metal assessment was not done during the rainy season due to paucity of funds. However, its assessment during the dry season has better implications for public health because of the accompanied reduced water availability.

Conclusion

There were higher mean concentrations of Hg and As in the drinking water sources of the oil-producing community compared to the non-oil-producing community while the mean Pb concentration of the drinking water sources of the oil-producing community was lower than that of the non-oil-producing community. However, only the difference observed in the mean Hg concentration was statistically significant.

Declarations

Ethical consideration: The Ethics Committee of a tertiary institution in the state, approved the study. Relevant stakeholders gave permission, while respondents gave informed consent and assent as appropriate before the study.

Authors' contribution:

ECI conceived the study, collected, interpreted the data and drafted the manuscript, CIT supervised the work and reviewed the manuscript.

Conflict of interest: The authors declare no conflict of interest

Funding: None

Acknowledgement: None

Print ISSN: 0189-9287 Online ISSN: 2992-345X

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Print ISSN: 0189-9287 Online ISSN: 2992-345X