International Journal of Community Medicine and Public Health
Luke A et al. Int J Community Med Public Health. 2023 Oct;10(10):3465-3472
http://www.ijcmph.com
pISSN 2394-6032 | eISSN 2394-6040

Original Research Article
DOI: https://dx.doi.org/10.18203/2394-6040.ijcmph20233072

Physiochemical analysis of drinking water in high and low crude oil-producing communities in the Niger Delta Region, Nigeria

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Received: 11 September 2023
Revised: 16 September 2023
Accepted: 20 September 2023

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ABSTRACT

Background: Access to potable water is a human right that plays a significant role in maintaining health and sanitation. Its limited supply in oil-producing areas has been variously linked to diverse pollutants in crude oil-producing communities, in Nigeria's Niger Delta region. This cross-sectional study analysed and compared the physico-chemistry of drinking water sources in high and low crude oil-producing communities in the Niger Delta region between January to February 2023.
Methods: Water samples were collected from a total of 28 samples from geo-referenced points in 10 communities. Analysis was done using the approved APHA and ASTM methods and assessed based on the recommended World Health Organization (WHO) permissible limits of detection for water quality. Data were analyzed using the statistical package for social science (SPSS) version-26. Test of significance and associations were set at $p<0.05$ and 95% confidence level.
Results: There were significant differences in the mean concentrations of water alkalinity, chromium (Cr), barium (Ba), total petroleum hydrocarbons (TPH), polyaromatic hydrocarbons (PAH), and TOG in water sources of the high and low oil-producing communities. Other mean concentrations of the analysed physicochemical parameters were found to be within normal limits for pH, salinity, turbidity, EC, total dissolved solids (TDS), total suspended solid (TSS), DO, and BOD, below the limit for alkalinity, chemical oxygen demand (COD), nitrate (NO_3), ammonia (NH_3), sulphate (SO_4), bicarbonates (HCO_3), chromium (Cr), copper (Cu), iron (Fe), TPH and above recommended limits for temperature, PAH and TOG.
Conclusions: The study showed that both high and low oil-producing communities had contaminated ground and surface water sources, although the high oil-producing areas were much more polluted. It is, therefore, necessary to enhance the national oil pollution regulatory mechanisms and remediation activities in heavily polluted sites to safeguard community water sources and protect human health.

Keywords: Physico-chemical, Analysis, Drinking water, Crude oil-producing, Niger delta

INTRODUCTION

Globally, the availability and accessibility of portable drinking water have become a vital problem for sustainable development due to climate change and anthropogenic activities leading to distortion in the hydrologic cycle.[1-3] Water, an essential natural resource for human consumption and utilization at small- and large-scale levels is required to maintain good hygiene and promote adequate environmental sanitation.[4,5] In 2016, the consumption of safe and wholesome water was declared a human right by the United Nations General Assembly, noting that water plays a significant role in maintaining human health and welfare. The absence of potable water supply has been attributed to diverse pollutants from poorly treated run-offs, and industrial effluents, especially in crude oil-producing host communities.[6-8]

The Niger Delta region known as the hub of oil and gas production in Nigeria experiences both conventional and artisanal refining of crude oil from oil wells, flow stations, gas plants, crude oil processing terminals, storage tanks, loading platforms, and vandalized pipelines. In this region, hydrocarbons, their metabolites, and heavy metals (barium, uranium, cadmium, chromium, strontium, lead etc. are the most implicated chemical pollutants. These contaminants are deposited into the environment through spills/leaks during legitimate or artisanal refining resulting from human error, poor maintenance of infrastructure, pipeline vandalism, processing, transportation, and distribution of crude oil and its products. These operations expose residents of oil and gas-producing host communities to toxic pollutants through ingestion, inhalation, and direct contact resulting in long-term adverse environmental and health consequences.[9-11]

The quality of water sources for human consumption and domestic purposes irrespective of the source or location is determined by its physiochemical and bacteriological parameters that when maintained within the ideal concentrations promote the survival of plants and animals in their various habitats.[9,12] These physiochemical parameters include the power of hydrogen (pH), known as the concentration of hydrogen ions ($H^{+/-}$) assessed by the acidic, alkaline or neutral character of water. It is determined by the acid-base titration processes, which is a mixture of acids and bases, with seasonal variation, though higher in the wet than the dry season. Temperature, measured in Celsius (˚C), monitors and controls the terrestrial and aquatic ecosystems. Biochemical oxygen demand is the amount of oxygen essential for microbial metabolism of organic compounds in the water sources, but when insufficient may cause the death of aquatic life. Electrical conductivity, measured in micro-Siemens per centimetre (µs/cm), assesses the electric current in water sources through inorganic compounds and dissolved salts (alkalis, chlorides, sulfides, and carbonate compounds). Turbidity measured in nephelometric turbidity unit (NTU), is the concentration of clouding of water sources due to the increased concentration of sediment (silt, sand, mud, microorganisms, chemical and other precipitates) entering the aquatic ecosystem caused by the growth of phytoplankton and other human activities. Salinity, measured in part per thousand (ppt), is the amount of total dissolved salt found in water sources. Dissolved oxygen affects the solubility and availability of nutrients present in water sources and released from sediments at low dissolved oxygen concentrations. Other parameters include total suspended solid (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), sulphide (SO_3), sulphate (SO_4), bicarbonates (HCO_3), nitrate (NO_3), nitrite (NO_4), heavy metals, barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), vanadium (V). Total petroleum hydrocarbons (TPH), polyaromatic hydrocarbons (PAH), total oil and grease concentrations.[13-15] This study analysed and compared the physicochemical of drinking water sources in high and low-crude oil-producing communities in the Niger Delta region of Nigeria to observe if water sources for drinking and domestic activities are contaminated only on heavily polluted sites alone or otherwise.

METHODS

Study area

The Niger Delta of Nigeria is one of the world's largest wetlands and mangrove forests in Africa. Its ecosystem maintains rich vegetation (flora and fauna) with a variety of crops, lumber/agricultural trees, and different species of freshwater fish compared to other terrain in West Africa. The region is categorized into four ecological zones: coastal barrier islands, mangrove swamp forests, freshwater swamps, and lowland rainforests. The area covers over 20,000 km^2 within wetlands, while 70,000 km^2 is formed primarily by sediment deposition, thus constituting almost 7.5% of the country's land mass. Over 31 million people are living in the Niger Delta with 185 local government areas (LGAs), more than 40 ethnic groups, and almost 250 different dialects. This rich oil-producing region consists of nine states: Abia, Imo, Ondo, Edo, Delta, Akwa-Ibom, Cross River, Bayelsa, and Rivers. However, Rivers, Bayelsa, and Delta are high oil-producing States, while Ondo, Cross River, Imo, and Abia are low oil-producing States.[16,17]

Study design

This research is a cross-sectional, comparative study that assessed and compared the physiochemistry of water sources in high and low crude oil-producing communities in the Niger Delta region of Nigeria.

Definition of terms

The high crude oil-producing rural communities

These communities are defined as places where exploitation and exploration activities occurred unabated over the last ten years and beyond (≥10), and located within at least 500 meters (approximately 0.3 miles) of gas flaring sites, flow stations and where people live.[16,18]

Low oil-producing rural communities

Communities classified as low oil-producing are those with little or no history of exposure to exploitation and exploration activities that occurred over the last ten years (≤10) and situated located beyond a distance of 500 meters (>0.3 miles) gas flaring sites, flow stations and where people live.[16,18]

Sampling technique

The multi-stage sampling technique was used to select high and low crude oil-producing communities where exploration/exploitation activities occurred in the last 10 years and the study was conducted in selected communities between January to February 2023.

Rivers State was first stratified into the three existing Senatorial governance structures (districts), each made up of 7-8 Local Government Areas: Rivers East Senatorial District; Emohua, Etche, Ikwerre, Obio/Akpor, Ogu/Bolo, Okrika, Omuma, Port Harcourt; Rivers South-East Senatorial District; Andoni, Eleme, Gokana, Khana, Opobo/Nkoro, Oyigbo, Tai; Rivers West Senatorial District; Abua/Odual, Ahoada-east, Ahoada-west, Akuku-Toru, Asari-Toru, Bonny, Degema, Ogba/Egbema/Ndoni.

Stage 1

Two out of the three existing Senatorial districts were selected by balloting. Those selected were Rivers East Senatorial District (Emohua, Etche, Ikwerre, Ogu/Bolo, Okrika, Omuma LGAs); Rivers West Senatorial District (Abua/Odual, Ahoada-East, Ahoada-west, Akuku-Toru, Asari-Toru, Bonny, Degema, Ogba/Egbema/Ndoni LGAs). The LGAs of the two selected senatorial districts were stratified into 2 (high & and low) crude oil-producing LGAs. High oil-producing LGAs; Akuku-Toru, Asari-Toru, Bonny, Degema, Obio/Akpor, Ogba/Egbema/Ndoni, Port Harcourt; Low oil-producing LGAs; Abua/Odual, Ahoada-east, Ahoada-west, Emohua, Etche, Ikwerre, Ogu/Bolo, Okrika, Omuma.

Stage 2

At least one LGA was selected from a list of the eight high and low crude oil-producing by balloting to reflect the conventional and artisanal refining operations; high oil-producing: Ogba/Egbema/Ndoni (conventional flow stations/Artisanal), Emohua; low oil-producing (Artisanal); Ikwerre.

Stage 3

Five communities were selected each from a list of the high and low crude oil-producing LGAs by balloting and the listed communities were selected in the process; high oil-producing; Ebocha, Ibaa, Obrikom, Ohali/Usumini/Idu, Okwuzi; Low oil-producing; Ipo, Omuanwa, Omerelu, Ozuoha, Ubima.

Selection of sampling points

The water sampling points were geo-referenced using a geographic information system (GPS). The criteria for selecting sampling points were based on the population density, areas of industrial, and the river catchment areas. Water samples were collected from three major water sources (boreholes/deep wells, rivers, commercial water hawkers) in five locations from each of the communities.

The water samples from the borehole pumps (deep wells) were collected midstream, whereas the samples for the surface water (rivers/streams) were collected from points where members of the communities commonly fetched their water for use.

Sample collection, storage, and transportation

The drinking water sources of each of the study communities were collected. A total of 28 water samples; 20 boreholes, 2 rivers; and recycled water (2 bottles and 4 sachets) were collected from the 10 communities (5 high sites; 5 low sites). A 2-litre sterile non-reactive plastic bottle was rinsed before collecting water samples from each source, leaving a margin of 2.5cm to allow the mixing of particles by shaking. Each water sample was labelled appropriately, stored in an iced-lined cooler (geo-style boxes), and transported to the laboratory within 24 hours for analysis, using the American Public Health Authority (APHA) recommended guidelines.[19]

Analytical instruments

Physiochemical characterization of water sources

In every selected crude-oil-producing rural community approximately four litres of each water source were collected, stored at 4°C and sent to a reference laboratory for analysis within 24 hours. At the laboratory, each water sample underwent two stages of assessment.

Pretreatment analysis

Two litres of each water sample (in triplicate) collected from each study site was filtered using a glass fibre filter (0.45 μm, Millipore, USA), enriched with SPE (Supelco, USA), a C18 cartridge preconditioned with 10 ml of dichloromethane, 10 ml of methanol, and then 10 ml of ultrapure water. Following enrichment, the C18 cartridge was eluted with 10 ml of dichloromethane and eluents were collected in a K-D concentrator to approximately 0.5 ml under a gentle nitrogen stream. Then, 20 μl of injection standards (10 μg/ml HMB) was added to prepare the final volume of 1 ml in dichloromethane for instrumental analysis.[20]

Instrumental analysis

Samples were analyzed using a GC2010 gas chromatograph coupled with a QP2010 mass spectrometer (GC-MS, Shimadzu, Japan). Aliquots of sample extracts (1 µL) were added by the splitless injection at 280°C. Rtx-5MS capillary column (length 30.0 m, i.d. 0.25 mm, film 0.25 µm, Shimadzu, Japan) and employed to complete Chromatographic separation of PAHs over 57 min using a triple ramp oven programme (initial temperature 60°C; 20°C/min to 160°C; 3°C/min to 280°C, held for 6 min; 20°C/min to 300°C, held for 5 min). Also, to ensure sustained flow (1 ml/min) of ultrapure helium carrier gas (99.999%), mass spectra were collected between 50-500 m/z at a transfer line and ion source temperatures of 220^{0}C and 250^{0}C at electron ionization of 70 eV. Then, a full scan of the mixture standard comprising each hydrocarbon (1 µg/ml) was identified at its peaks based on its retention times and mass spectra.

However, retention time locking with an internal standard was applied to guarantee the reproducibility of retention time hydrocarbon, followed by data acquisition, requiring identification and distinct fragment ions for each hydrocarbon within an allotted time window.[20]

Physico-chemical parameters

A comprehensive physical and chemical analysis was conducted for samples collected from the water sources. The physico-chemical parameters assessed were pH, temperature, electrical conductivity (EC), turbidity, salinity, alkalinity, total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD_5), nitrate (NO_3), ammonium (NH_3), sulphate (SO_4), bicarbonate (HCO_3); total petroleum hydrocarbon (TPH), polyaromatic hydrocarbons (PAH), total oil and grease (TOG); heavy metals like barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), vanadium (V). The findings of each parameter were compared with the World Health Organization (WHO) standard for quality water.

Statistical analysis

The independent descriptive variables such as concentration of physical (pH, temperature, EC, turbidity, alkalinity, salinity, DO, TDS, TSS, COD, BOD_5) and chemical (NO_3, NH_3, SO_4, HCO_3), heavy metals (Ba, Cd, Cr, Cu, Fe, Pb, V), and hydrocarbons (TPH, PAH, TOG) were the parameters identified in the sampled water sources were summarized as mean and standard deviation. The independent t-test and analysis of variance (ANOVA) were used to test for the significance of associations. The significant variables from the bivariate analysis were set at probability value ($p<0.05$) and 95% confidence level and compared with the recommended WHO standards for drinking water quality.

RESULTS

Table 1 shows that the mean levels of power of hydrogen (pH), electrical conductivity (EC), total dissolved solid (TDS), salinity, turbidity, total suspended solids (TSS), and dissolved oxygen (DO) were within the recommended WHO limit of detection in both the high and low oil-producing sites. On the other hand, the temperature level, and the concentration of COD in both study sites were found above the standard WHO allowable limits of detection for water quality.

Table 2 shows that the mean concentration of NO_3, NH_3, SO_4, HCO_3, and alkalinity in all the sampled water sources was below the recommended WHO allowable limits in both the high and low oil-producing communities. The mean alkaline concentration of the water samples in both sites was significantly different (p=0.012).

Table 1: Comparison of physical properties in water sources of high and low oil-producing communities based on WHO recommended limits.

Variable	High oil-producing site		Low oil-producing sites		t	P value	WHO limit
	Mean	Std	Mean	Std			
pH	6.31	0.61	6.01	0.72	1.123	0.273	6.5-8.5
Temperature (°C)	27.83	0.34	28.09	0.6	-1.371	0.183	25
EC (µS/cm)	53.45	27.46	50.05	27.75	0.314	0.756	750
TDS (mg/l)	26.85	13.53	25.07	13.79	0.331	0.743	500
Salinity (mg/l)	9.45	5.02	8.89	5.00	0.283	0.780	100
Turbidity (NTU)	2.85	1.72	3.15	2.12	-0.406	0.688	5
TSS (mg/l)	1.35	0.69	1.54	0.88	-0.622	0.540	75
DO (mg/l)	5.01	0.59	4.98	0.45	0.112	0.912	4.0-6.0
BOD_5 (mg/l)	4.54	0.73	4.58	0.65	-0.171	0.866	1-5
COD (mg/l)	10.34	6.72	10.29	5.700	0.019	0.985	≤10

*Statistical significance. BOD: clean (1-2 ppm), moderately clean (3-5 ppm), polluted (6-9 ppm).

Table 2: Comparison of chemical parameters in water sources of high and low oil-producing communities based on WHO recommended limits.

Variable	High oil-producing site		Low oil-producing sites		t	P value	WHO limit
	Mean	Std	Mean	Std			
Nitrate (NO_3)	0.30	0.31	0.49	0.33	-1.525	0.140	45
Ammonia (NH_3)	0.15	0.20	0.30	0.24	-1.791	0.086	0.50
Sulphate (SO_4)	1.72	1.02	1.64	0.97	0.200	0.843	250
Alkalinity ($CaCO_3$)	3.07	1.84	5.11	1.98	-2.729	0.012*	100
Bicarbonate (HCO_3)	6.88	2.03	6.81	1.39	0.099	0.922	125-350

*Statistical significance.

Table 3 shows that the cadmium, lead, and vanadium levels in all the analyzed water sources were found below the detectable limit (BDL). The mean concentration of the other heavy metals like copper, iron, chromium, and barium was below the recommended WHO allowable limit for drinking water quality in the high and low oil-producing sites. However, there was an observed significant difference in the concentrations of chromium (p=0.034) and barium (p=0.004) between both oil-producing sites.

Table 4 shows that the mean concentration of polycyclic aromatic hydrocarbons (PAH) and total oil and grease (TOG) were above the WHO permissible limit. While the total petroleum hydrocarbon (TPH) was found within the allowable limit of detection. However, there was an observed significant difference in all the parameters; TPH (p=0.001), PAH (<0.001), and TOG (p=0.001) analyzed in the water sources of the high and low-oil-producing communities.

Table 3: Comparison of heavy metals in water sources of high and low oil-producing communities based on WHO recommended limits.

Variable	High oil-producing site		Low oil-producing sites		t	P-value	WHO limit
	Mean	Std	Mean	Std			
Lead	BDL	BDL	BDL	BDL	-	-	-
Copper	0.05	0.04	0.05	0.04	0.731	0.348	2
Iron	0.004	0.003	0.003	0.003	0.697	0.397	0.1
Chromium	0.01	0.01	0.01	0.01	0.973	0.034*	0.05
Cadmium	BDL	BDL	BDL	BDL	-	-	-
Barium	0.58	0.37	0.58	0.40	0.997	0.004*	0.7
Vanadium	BDL	BDL	BDL	BDL	-	-	-

*Statistical significance.

Table 4: Comparison of hydrocarbons in water sources of high and low oil-producing communities based on WHO recommended limits.

Variable	High oil-producing site		Low oil-producing sites		t	P-value	WHO limit
	Mean	Std	Mean	Std			
TPH (mg/l)	0.35	0.28	0.03	0.05	3.985	0.001*	0.001-0.437
PAH (mg/l)	0.05	0.03	0.00	0.01	5.376	<0.001*	0.007
TOG (mg/l)	0.78	0.49	0.19	0.30	3.728	0.001*	0.2

*Statistical significance.

DISCUSSION

Findings from the study revealed that many of the analysed physiochemical parameters (pH, turbidity, salinity, EC, TDS, TSS, DO) were within the recommended WHO permissible limits. However, there was a significant difference in alkalinity in both study communities/areas which were at low limits of permissible values. Similar observations were made in previous studies conducted in Rivers State, in Bayelsa State, and Delta States.[13,21-26] Some studies have reported that at low alkaline levels, water pipes and fixtures corrode, thus leading to the release of potentially harmful metals like copper and lead from the plumbing system into the drinking water. This action alters the aesthetics and taste of water (bitter or metallic taste) and may erode the enamel of the teeth of members of the community who consume it.[27,28] In the process the water quality is severely compromised and renders it unsafe for drinking.[29,30]

Concerning the mean concentration of heavy metals, Ba and Cr were observed to be significantly below the WHO acceptable limits. These observations were consistent with the outcome of studies carried out in Rivers, Delta State, and Kolo-creek by other workers in the Niger Delta region in which the concentrations of these parameters were also found below the allowable WHO limits.[23,31,32]

However, at low concentrations, Cr an essential trace element required for normal physiological functions in the human body are not potentially harmful. Likewise, barium does not pose any substantial health risk to the general population.[29,33]

PAH and TOG were found to be significantly higher above the WHO tolerable limits in the high oil-producing communities when compared to the low oil-producing communities. This finding was in line with that of a previous study carried out also in the Niger Delta which showed elevated levels of TOG and TPH.[34] Also, a similar study conducted in Bayelsa State corroborated the high level of TPH found in our study.[35]

The observed pollution of water sources may not be attributed entirely to the conventional government-controlled oil and gas production activities, but may also result from the unregulated, illegal artisanal crude oil refining activities from stolen crude carried out in the oil-producing and adjourning communities. The high levels of PAH and TOG are a pointer to a potential increased risk of cancers over a prolonged period of exposure and calls for regular watchfulness and vigilance on the part of regulatory authorities in the oil and gas sector on the Nigerian environment as well as other concerned citizens and stakeholders, including the international community.

Limitations

The problem of insecurity is due to the incessant cases of kidnapping that occur in the Niger Delta oil-producing rural communities. However, this was circumvented with the use of a reputable community representative who served as a tour guard during the period of data collection.

CONCLUSION

It is obvious from the study that ground and surface water sources were contaminated in both the high main and low areas without clear-cut distinction. However, the more polluted water sources were found in the high oil-producing communities, perhaps a situation worsened by rampant artisanal refining activities in the affected communities.

Recommendations

It is pertinent to ensure that residents of oil-producing communities (both high and low) have access to portable water supply. Therefore, regulatory measures should be reinforced to control oil spills from conventional and artisanal refining processes. This should be in addition to remediation of already polluted sites. Furthermore, environmental monitoring with regular water testing and appropriate treatment are recommended.

ACKNOWLEDGEMENTS

Authors would like to thank all the esteemed gatekeepers/representatives who went the extra mile as tour guards/guides and made frantic efforts to interface with members of the selected communities to understand the importance of the data collection processes and ensure the safety of the researchers.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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Cite this article as: Luke A, Tobin-West CI, Ofuru VO, Owhonda G, Igwele PN. Physiochemical analysis of drinking water in high and low crude oil-producing communities in the Niger Delta Region, Nigeria. Int J Community Med Public Health 2023;10:3465-72.