Quality of water and air in artisanally refined crude oil-impacted communitiesin Ekeremor, Bayelsa state, Nigeria

Abstract

The practice of artisanal refining of crude oil remains rampant within the Niger Delta region of Nigeria with consequent pollution and destruction of the environment as well as exposure of the human population to various pollutants known to cause health problems. It was thus necessary to conduct this study to assess the quality of water and air in communities where artisanal refining of crude oil is carried out in Ekeremor, Bayelsa state, Nigeria. This was a comparative cross-sectional study that was conducted in Peretorugbene community in Ekeremor Local Government Area of Bayelsa state. Water samples from five points (L1-L5) in the study site (Peretorugbene) and one control site (LX were obtained and assessed. Also, air quality assessments were conducted and results were comparatively assessed for significant differences between test and control sites. Results revealed that the water samples from the third sampling site (L3) had the highest levels of chromium of 0.100±0.055, while the first sampling site (L1) had the highest levels of lead of 5.225±0.687. Heavy metals' concentrations from the water samples obtained from the artisanal refining sites significantly differed from the concentration of the samples from the non-artisanal refining site (p-value: 0.006 [for chromium], p-value: <0.001 [for lead]). Assessment of the concentration of noxious gases in the air at these two differing sites revealed that the carbon monoxide (3.110±0.160), nitrogen oxides (2.870±0.212), and sulfur oxides (2.557±0.105) from the first sampling site (L1) were the highest, and carbon monoxide and nitrous oxides concentration at the non-artisanal refining site was significantly lower from the concentrations at all the artisanal refining sites (p-value: <0.001). Also, the turbidity, temperature, and salinity of the water samples exceeded the allowable standard limits, alongside the lead, cadmium and mercury levels. In this study, it was thus concluded that the turbidity, temperature, and salinity of the water samples exceeded the allowable standard limits, while the conductivity, and total dissolved solids (TDS) in the water samples were below the acceptable standards. Also, the assessed air quality parameters were found to exceed the laid down allowable limits.

Keywords: Crude oil, artisanal refining, water quality, air quality, Bayelsa

Introduction

Nigeria is the continent's most prolific producer of crude oil and the energy superpower of Africa (Khan & Cheri, 2019). The huge economic dependence on crude oil exploration and exploitation implies that there are numerous oil and gas-related activities going on within Nigeria, especially at the Niger-Delta region of the country. These are related to certain problems including environmental health problems, vandalization of oil pipelines, crude oil theft and consequent artisanal refining in certain cases and so on (2,3).In the Niger Delta area of Nigeria, artisanal petroleum refining is a common practice that is characterized by crude extraction and refining of petroleum using primitive procedures (4).Hazardous substances found in the emissions from artisanal refineries include heavy metals, particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulphide (H_2S),

sulphur dioxide (SO_2), and volatile organic compounds (benzene, toluene, ethylbenzene, and xylene) which have harmful human and environmental effects (5).This illegal petroleum refining and its associated activities which have worsened over the years, do not only produce very poor-quality refined products, but also lead to severe environmental pollution and degradation of the Niger Delta ecosystem(2,3).

The majority of the emissions from artisanal refining sites are made up of carbon soot which is produced as a result of the incomplete burning of the raw crude oil in the open-air furnace or oven at the artisanal refinery's archaic boiling unit (6).Groundwater supplies and other surrounding bodies of water may become contaminated as a result of improper disposal or insufficient remediation of these impacts, and this pollution endangers local residents' access to clean drinking water in addition to endangering aquatic ecosystems (7).The body of research has also clearly shown how susceptible the human body organ-systems are, to the harmful consequences of air pollution (2,6).Long-term exposure to these contaminants may cause oxidative stress, lung impairment, chronic respiratory diseases, and an increased risk of respiratory infections (6,8).These compounds may raise the risk of cancer, neurological conditions, fertility and reproductive health problems and hormone abnormalities since they are recognized carcinogens, neurotoxicants, and endocrine disruptors (6,9).

It is obvious that the practice of artisanal refining of crude oil is still a problem within the Niger Delta region of Nigeria (6,10) with consequent pollution of the environment and occurrence of health risks to human populations (3,11,12). Considering that artisanal refining of crude oilis an ongoing problem within Bayelsa State (one of the states located within the Niger Delta region), and that there are currently scant or no published studies of its effects on water and air in Ekeremor, Bayelsa state, it will be necessary to conduct this study. In addition, this study wasuseful in providing evidence necessary for the conduct of action to protect the health and well-being of communities living near artisanal refineries. It will also contribute in encouraging the development of a multifaceted approach by concerned agencies of government in protecting the Niger Delta environment from the damaging effects of artisanal refining activities. This study was thus aimedat assessing the quality of water and air in communities where artisanal refining of crude oil is carried out in Ekeremor, Bayelsa state, Nigeria.

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Materials and methods

This study that adopted a comparative, cross-sectional design was conducted inPeretorugbenecommunity located within the Ekeremor Local Government Area (LGA)of Bayelsa state(Figure 1). This area is known as a habitation for the practice of artisanal refining of crude oil.

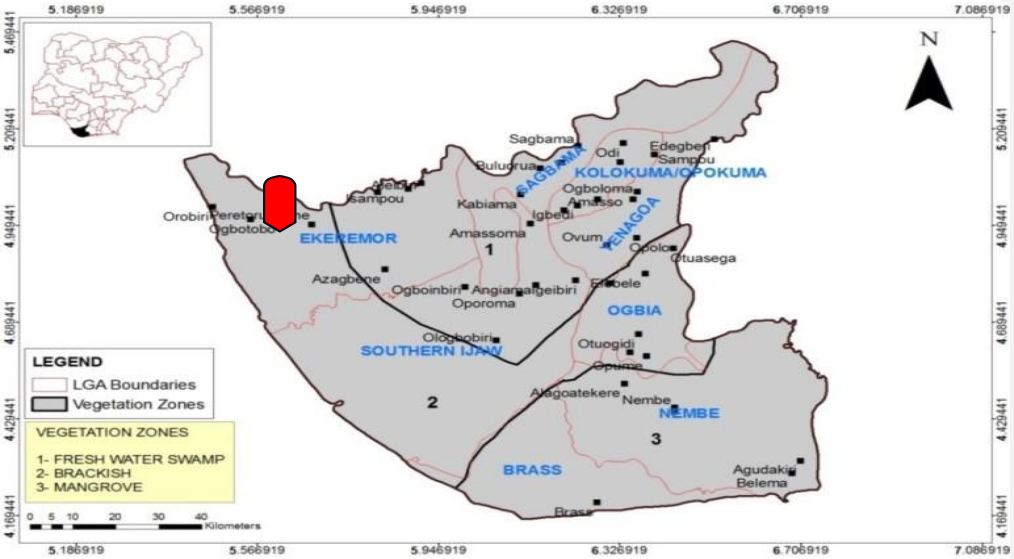

Figure 1: Map of Bayelsa state showing Peretorugbene community within Ekeremor LGA

The formula for sample size for comparing two means was used in calculating the sample size for environmental samples used for this study (13). The mean and standard deviation of the attribute of interest (sulfur oxide concentration in water) in an artisanal refining area: 196.3±76 mg/kg and in a non-artisanal refining area: 148.75 ±23.75 mg/kg were obtained from the study conducted by authors in Andoni LGA in Rivers state, Nigeria (14). For the collection of air samples, sampling was done from an abandoned site located at kalaperetorugbene creek (by the trans-Erema line in Tubu-ama) purposively selected as a result of being an area where artisanal refining activities have been carried out in the past. This was a similar scenario for sampling of water samples which were also purposively obtained from this abandoned site.

In-situ measurements of water physicochemical properties

An on-site assessment of four water samples obtained from five points (L1-L5) in the study site (Peretorugbene) and one control site (LX), was conducted. The geographic locations for these points from top to bottom (areas on the map with orange-coloured pins) (5^0N05^l 42^{II} 5^0E 73^l 11^{II},5^0N 05^1 23^{II} 5^0E 72^1 95^{II},5^0N 05^1 11^{II} 5^0E 72^1 85^{II}, 5^0N 04^1 92^{II} 5^0E 72^1 76^{II}, 5^0N 04^1 56^{II} 5^0E 72^1 61^{II}) are shown in Figure 2**.** The water's physical and chemical properties were conducted which included assessing the temperature,dissolved oxygen (DO), pH, conductivity, and turbidity of the water samples.

Temperature

In each sampling station, the temperature of the water was measured using mercury in glass thermometer and results were recorded accordingly.

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pH (Hydrogen Ion Concentration)

This was done using a pH meter. Small quantity of the water sample was put in a beaker and shaken thoroughly, after which a pH electrode was immersed into the sample and the result was recorded immediately.

Assessment of other physicochemical properties

To achieve this, a portable EXTECH Multi-probe (DO-700) meter was used. The meter's probe was carefully placed into the water at the sampling location, allowing it to settle for 1-2 minutes before taking the readings. Additionally, to measure the turbidity, a HANNA Turbidimeter (HI93414). Before conducting any analysis, it was ensured that all the meters were properly calibrated using appropriate standards to ensure the highest level of accuracy. To obtain a reading, the meter was powered on, and the sensor was inserted 2cm above the water sample level, and waited for the measurement to stabilize. For dissolved oxygen analysis, a well labelled 70ml Do bottle was rinsed with the water from the sampling area and then filled to overflow to remove trapped air bubbles. Then, 0.5ml magnesium sulfate (Winker-1) solution and 0.5ml alkali-iodine reagent (Winker-2) were added and mixed properly. The mixture was allowed to stand for few minutes, packed in an ice box and then transported to the laboratory for further analysis.

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Heavy metal analysis of water samples

Three water samples each were collected from five points (L1-L5) in the study site (Peretorugbene) and one control site (LX), using previously cleaned well labelled 75cl plastic containers. Water samples were retrieved along the flow direction of the river from upstream to downstream by dipping the container 10 centimetres below the water surface. The geographic locations for these points from top to bottom (areas on the map with orange-coloured pins) (5^{0}N05^{l} 42^{II} 5^{0}E 73^{l} 11^{II},5^{0}N 05^{1} 23^{II} 5^{0}E 72^{1} 95^{II},5^{0}N 05^{1} 11^{II} 5^{0}E 72^{1} 85^{II}, 5^{0}N 04^{1} 92^{II} 5^{0}E 72^{1} 76^{II}, 5^{0}N 04^{1} 56^{II} 5^{0}E 72^{1} 61^{II}) are shown in Figure 2**.** These water samples were then acidified with 1% nitric acid (HNO_3) for preservation, labeled accordingly and transported to the laboratory for analysis of heavy metals including arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) (15). The analysis of the heavy metals was done using the Atomic Absorption Spectrophotometer analytical instrument which is based on the principle of atomic absorption spectroscopy and is an excellent way to detect metal ion concentrations in drinking water samples(16,17).

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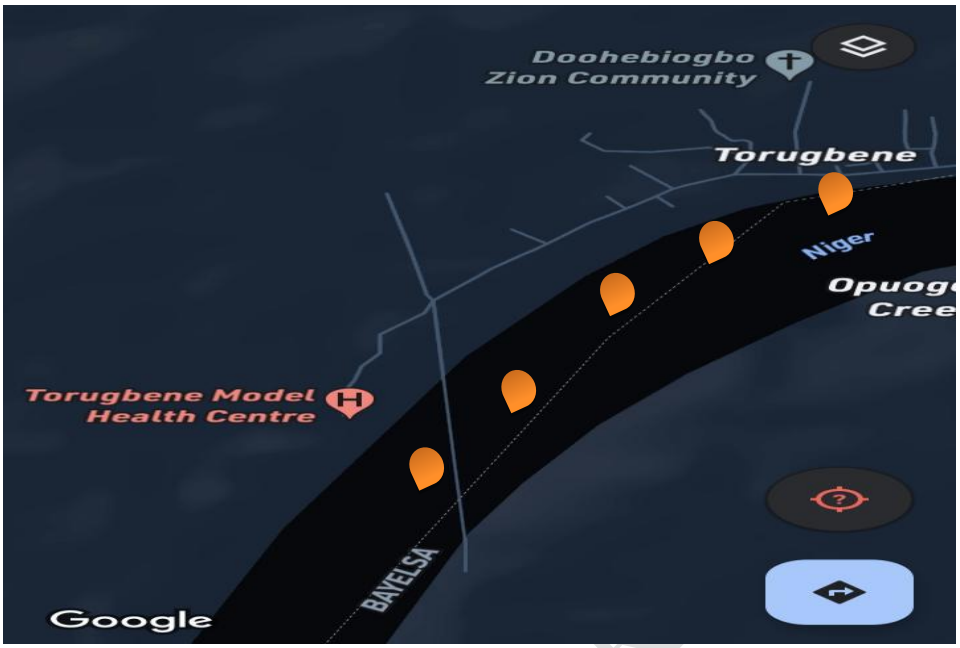

Figure 2: Geolocations of water sample collection points

Air sampling

The KASTREL NV-1500 Meter was utilized to gather meteorological data, including temperature, wind speed, and relative humidity. Meanwhile, the measurements for carbon monoxide (CO), nitrogen oxides (NOx), and sulfur oxides (SOx) in the air quality samples were obtained through the portable hand-held Aeroqual meter (AEROQUAL Series 300 - New Zealand) with infrared sensor. The Met-One SPM Meter was used to measure the levels of suspended particulate matter (SPM) for both PM2.5 and PM10. It was powered and probed for possible emissions at an average height of 2 metres in the prevailing wind direction, with a flow rate of 2.83 L/min (18). The collection of data was done in triplicate to ensure its accuracy. This implied that the air quality measurements were done at three locations within the study area in the morning and evening periods. Measurements were done by holding the equipment to a breathing height of about 1.5 metres in the direction of the prevailing wind, and readings were only recorded when the monitor had warmed up for about 3 minutes to burn off contaminants on the sensor and air sucked into the sensor. Metrological parameters (wind speed, temperature and relative humidity) were measured by holding the instrument at a height of 2 metres above ground level, after which the displayed concentrations on the visual display unit of the instrument were recorded.

Instrument validity

Before conducting any analysis, it was ensured that all the meters were properly calibrated using appropriate standards to ensure the highest level of accuracy. Also, to obtain a reading, after powering the meter and inserting the sensor into the tested sample, the researcher ensured that the measurement was stabilized before a reading was made. Concerning the

laboratory analysis of heavy metals in water samples, it was ensured that standards, blanks and duplicate samples were run for quality control purposes.

Determination of heavy metal concentration in water samples

Digestion of water sample

2.5 cm3 of 1mol.dm-3 HNO3 was added to 50 cm3 of water sample and digested by heating on a plate until colourless solution was obtained.Digestion may be performed in open or closed vessels using classical heating blocks or microwaveradiation. The digest was allowed to cool and then filtered into a 50 cm^3 volumetric flask. The volume of the digested water sample was made to 50 cm3 with distilled water(17,19).

Extraction of metals of interest

Liquid- liquid extraction

Solvent extraction separation is based on the differences in the solubility of elements and the associated compounds in two immiscible liquid phases. Usually, the initial phase is an aqueous solution and thesecond phase is an organic solvent immiscible with water. Stripping (re-extraction, back-extraction or scrubbing) involvesbringing the element from the organic extract back to the aqueous phase.After extraction the concentration of the metallic complex in the organic phase can then be directlydetermined by flame atomic absorption spectrophotometric methods. Concentration values for each metal was expressed in units of mg/kg (17).

Ethical considerations

Ethics approval for the research was obtained from the Research Ethics Committee of the University of Port Harcourt (Approval number: UPH/CEREMAD/RECMM/90/108) [Appendix 1]. Permission to conduct the research was also obtained from the Bayelsa State Ministry of Health and from necessary authorities of Peretorugbene community. In the course of collection of samples from the environment, it was ensured that the appropriate techniques were applied and that no harm came to the environment.

Data Analysis

The data was entered into a spreadsheet of the Microsoft Excel 2019 (Microsoft Corp., Washington, USA), where the data was cleaned and prepared for analysis. The Statistical Package for Social Sciences (SPSS) version 23 (IBM, Armonk, New York, USA) was then used to perform both descriptive and inferential analyses. The concentrations of the physicochemical parameters and heavy metals in water samples as well as carbon monoxide (CO), nitrogen oxides (NOx), and sulfur oxides (SOx) in the different assessed air samples were expressed as means and standard deviation. They were also presented in tables. The One-way Analysis of Variance (ANOVA) test was used to compare the concentrations of heavy metals in water samples as well as the physicochemical values of the samples for both the artisanal refining and non-artisanal refining sites. This statistical test was also used to compare the concentrations of carbon monoxide (CO), nitrogen oxides (NOx), and sulfur

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oxides (SOx) in the different assessed air samples from both sites. The Bonferonni post-hoc test was then used to identify sample concentrations that significantly differed from others. All analyses were performed at the 0.05 level of significance, where all p-values equal to or below 0.05 were regarded as being statistically significant.

Results

Concentration of physicochemical parameters in water sources

Table 1: Physicochemical parameters in water sources from artisanal refining and non-artisanal refining sites

		Mean	Std. Deviation	Minimum	Maximum
pH	L1	6.475	0.275	6.20	6.80
	L2	6.350	0.311	6.00	6.70
	L3	6.375	0.350	6.00	6.80
	L4	6.528	0.147	6.40	6.70
	L5	6.625	0.171	6.40	6.80
	LX	6.177	0.133	6.10	6.33
Temp	L1	29.725	1.081	28.70	31.20
	L2	29.525	1.957	27.70	31.80
	L3	31.400	1.523	30.00	33.00
	L4	32.050	1.949	29.70	34.10
	L5	31.745	1.095	30.80	32.80
	LX	32.267	0.666	31.70	33.00
Turbid	L1	6.253	3.070	3.00	10.40
	L2	8.675	2.092	5.80	10.50
	L3	7.880	4.430	3.10	12.40
	L4	6.393	2.904	4.00	10.60
	L5	6.948	2.289	5.83	47.00
	LX	5.493	1.435	3.93	6.75
Conductivity	L1	17.975	5.058	12.00	24.30
	L2	15.300	3.536	10.10	18.00
	L3	17.500	2.070	15.40	19.90
	L4	17.325	0.330	16.90	17.70
	L5	16.068	0.501	15.70	16.80
	LX	14.790	0.774	13.90	15.30
Salinity	L1	14.450	8.174	9.30	26.60
	L2	11.350	5.278	7.00	18.70
	L3	9.725	2.366	7.80	13.00
	L4	8.525	0.222	8.30	8.80
	L5	7.933	0.438	7.43	8.50
	LX	7.277	0.333	6.90	7.53

"L1 to L5 are the artisanal refining sampling sites and LX is the non-artisanal refining site

Assessment of the physicochemical parameters of the water sources in this study revealed that water samples from the fifth sampling site (L5) had the highest pH values of 6.625±0.171 ranging from 6.40 to 6.80. Water temperature assessment revealed that water

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samples from the fourth sampling site (L4) had the highest temperature values of 32.050±1.949 ranging from 29.70 to 34.10. Regarding the water turbidity, the second sampling site (L2) was the most turbid of all the water samples with a turbidity level of 8.675±2.092 ranging from 5.80 to 10.50. Water sample one (L1) was also found to have the highest conductivity and salinity of 17.975±5.058 and 14.450±8.174 ranging from 12.00 to 24.30 and 9.30 to 26.60 respectively. These are shown in Table 1.

Table 2: Physicochemical parameters in water sources from artisanal refining and non-artisanal refining sites (contd.)

		Mean	Std. Deviation	Minimum	Maximum
Dissolved Oxygen	L1	4.520	0.125	4.39	4.67
	L2	4.445	0.294	4.12	4.77
	L3	4.528	0.251	4.29	4.80
	L4	4.378	0.472	3.93	4.81
	L5	4.460	0.371	4.02	4.84
	LX	4.450	0.036	4.42	4.49
Total Dissolved Solids	L1	14.600	11.457	3.00	30.40
	L2	13.375	2.809	11.50	17.50
	L3	12.275	1.318	10.90	13.50
	L4	12.075	0.299	11.70	12.40
	L5	10.143	0.892	9.00	10.90
	LX	10.133	0.306	9.80	10.40

L1 to L5 are the sampling Locations and LX is Control

Assessment of the dissolved oxygen of the water samples revealed that water samples from the third sampling site (L3) had the highest levels of dissolved oxygen of 4.528±0.251 ranging from 4.29 to 4.80. Regarding the total dissolved solids (TDS), the first sampling site (L1) had the highest level of all the water samples with a TDS level of 14.600±11.457 ranging from 3.00 to 30.40. These are shown in Table 2.Assessment of the difference in the pH, temperature and turbidity of the water samples obtained from the different artisanal refining sites and the non- artisanal refining site in this study revealed that there was no statistically significant difference in these physicochemical parameters (p-value: 0.289, 0.077 and 0.714 respectively). These are shown in Table 3.

Assessment of the difference in the conductivity and salinity of the water samples obtained from the different artisanal refining sites and the non- artisanal refining site also revealed that there was no statistically significant difference in these physicochemical parameters (p-value: 0.562, 0.236 respectively). Assessment of the difference in the dissolved oxides and total dissolved solids of the water samples obtained from the different artisanal refining sites and the non- artisanal refining site, also revealed that there was no statistically significant difference in these physicochemical parameters (p-value: 0.983, 0.796 respectively). These are all shown in Figure3.

Table 3: Difference in physicochemical properties of water from the artisanal refining and non-artisanal refining sites

Locations	pH	Temperature	Turbidity
L1	6.475±0.275	29.725±1.081	6.253±3.069
L2	6.350±0.311	29.525±1.957	8.675±2.092
L3	6.375±0.350	31.400±1.523	7.880±4.430
L4	6.528±0.147	32.050±1.949	6.393±2.904
L5	6.625±0.171	31.745±1.095	6.948±2.289
LX	6.178±0.133	32.267±0.666	5.493±1.435
F-statistic (ANOVA)	1.358	2.443	0.581
p-value	0.289	0.077	0.714

L1 to L5 are the sampling Locations and LX is Control

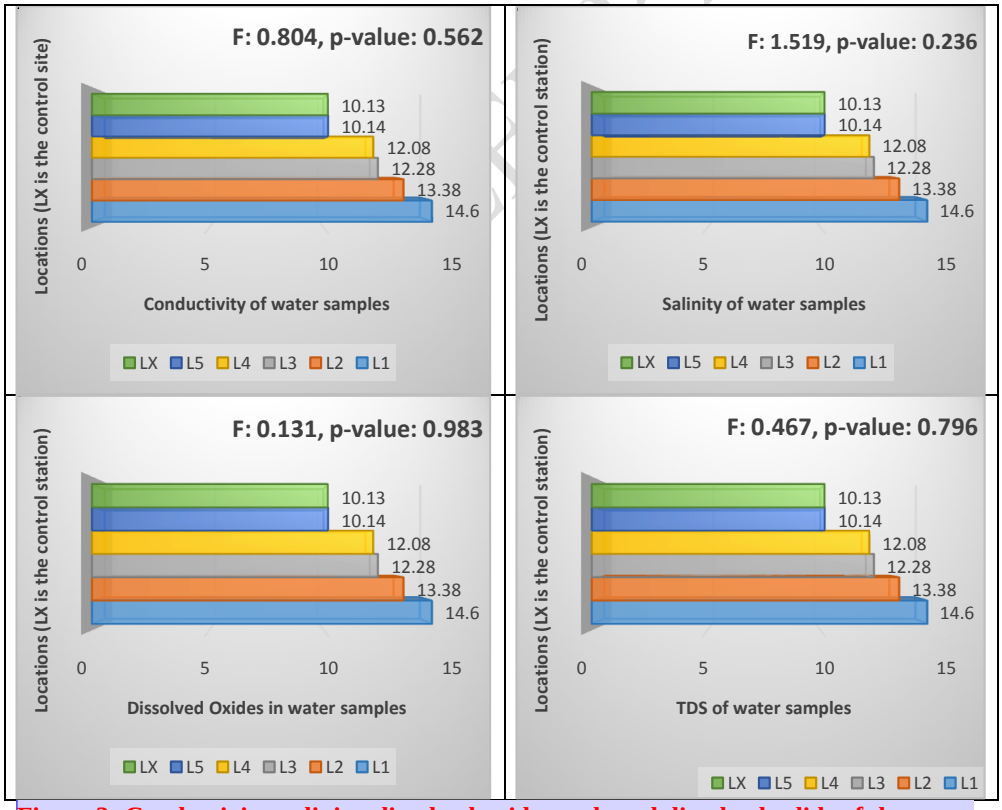

Figure 3: Conductivity, salinity, dissolved oxides and total dissolved solids of the water samples

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Table 4a: Heavy metal concentrations in water at artisanal refining and non-artisanal refining sites

		Mean	Std. Deviation	Minimum	Maximum
As	**L1**	0.010	0.000	0.01	0.01
	L2	0.010	0.000	0.01	0.01
	L3	0.010	0.000	0.01	0.01
	L4	0.010	0.000	0.01	0.01
	L5	0.010	0.000	0.01	0.01
	LX	0.010	0.000	0.01	0.01
Cd	**L1**	0.010	0.000	0.01	0.01
	L2	0.010	0.000	0.01	0.01
	L3	0.010	0.000	0.01	0.01
	L4	0.010	0.000	0.01	0.01
	L5	0.010	0.000	0.01	0.01
	LX	0.010	0.000	0.01	0.01
Cr	**L1**	0.065	0.014	0.05	0.09
	L2	0.045	0.018	0.01	0.06
	L3	0.100	0.055	0.05	0.15
	L4	0.070	0.017	0.05	0.09
	L5	0.050	0.000	0.05	0.05
	LX	0.048	0.004	0.04	0.05

L1 to L5 are the sampling locations and LX is control

Table 4b: Heavy metal concentrations in water at artisanal refining and non-artisanal refining sites

		Mean	Std. Deviation	Minimum	Maximum
Pb	**L1**	5.225	0.687	4.46	6.06
	L2	4.277	0.427	3.71	4.81
	L3	3.910	0.155	3.71	4.01
	L4	4.290	0.275	4.01	4.60
	L5	3.930	0.268	3.55	4.31
	LX	3.845	0.308	3.51	4.21
Hg	**L1**	0.010	0.000	.01	.01
	L2	0.010	0.000	.01	.01
	L3	0.010	0.000	.01	.01
	L4	0.010	0.000	.01	.01
	L5	0.010	0.000	.01	.01
	LX	0.010	0.000	.01	.01

L1 to L5 are the sampling locations and LX is control

Assessment of the heavy metal concentrations of the water samples revealed that water samples from the third sampling site (L3) had the highest levels of chromium of 0.100±0.055 ranging from 0.05 to 0.15, while the first sampling site (L1) had the highest levels of lead of 5.225±0.687 ranging from 4.46 to 6.06. Other assessed heavy metals (arsenic, cadmium and

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mercury) were at levels of 0.01 in all assessed sampling sites. These are shown in Tables 4a and 4b.

Table 5: Comparison of level of heavy metals in the artisanal refining and non-artisanal refining sites

Locations	Arsenic	Cadmium	Chromium	Lead	Mercury
L1	0.010±0.00	0.010±0.00	0.065±0.014	5.225±0.687	0.010±0.00
L2	0.010±0.00	0.010±0.00	0.045±0.018	4.277±0.427	0.010±0.00
L3	0.010±0.00	0.010±0.00	0.100±0.055	3.910±0.155	0.010±0.00
L4	0.010±0.00	0.010±0.00	0.070±0.017	4.290±0.275	0.010±0.00
L5	0.010±0.00	0.010±0.00	0.050±0.000	3.930±0.268	0.010±0.00
LX	0.010±0.00	0.010±0.00	0.048±0.004	3.845±0.307	0.010±0.00
F-statistic (ANOVA)	-	-	4.040	10.439	-
p-value	-	-	0.006*	<0.001*	-

L1 to L5 are the sampling locations and LX is control ****: significant results***

Assessment of the difference in the concentrations of the heavy metals present in water samples tested in this study revealed that the metals' concentrations from the water samples obtained from the artisanal refining sites significantly differed from the concentration of the samples from the non-artisanal refining site (F: 4.040, p-value: 0.006 [for chromium]; F: 10.439, p-value: <0.001 [for lead]). These are shown in Table 5.

Table 6: Meteorology of air at artisanal refining and non-artisanal refining sites

		Mean	Std. Deviation	Minimum	Maximum
Temperature	**L1**	30.447	0.627	30.05	31.17
	L2	29.933	0.699	29.33	30.70
	L3	29.377	0.068	29.30	29.43
	L4	29.493	0.046	29.44	29.52
	L5	30.170	0.010	30.16	30.18
	LX	29.303	0.370	29.07	29.73
Humidity	**L1**	62.350	0.090	62.26	62.44
	L2	61.470	0.070	61.40	61.54
	L3	60.227	0.100	60.13	60.33
	L4	60.433	0.030	60.40	60.46
	L5	59.830	0.030	59.80	59.86
	LX	62.267	0.058	62.20	62.30
Wind	**L1**	2.450	0.050	2.40	2.50
	L2	2.720	0.050	2.67	2.77
	L3	2.853	0.038	2.81	2.88
	L4	1.507	0.040	1.47	1.55
	L5	3.260	0.060	3.20	3.32
	LX	2.790	0.000	2.79	2.79

Comment [O16]: What is the unit of the concentration

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Comment [O17]: Unit of the parameters determined

L1 to L5 are the sampling locations and LX is control

Assessment of the meteorology of the air at the artisanal refining and non-artisanal refining sites revealed that the temperature (30.447±0.627 ^{o}c) and humidity (62.350±0.090) from the first sampling site (L1) were the highest ranging from 30.05 to 31.17 and 62.26 to 62.44 respectively. Also, the windspeed from the fifth sampling site (L5) was found to be the highest with a windspeed of (3.260±0.060) ranging from 3.20 to 3.32. These are shown in Table6. Comparison of the meteorological parameters of the different sampling sites revealed a statistically significant difference in the temperature (F:3.828, p-value: 0.026); humidity (F:750.699, p-value: <0.001) and windspeed (F: 545.582, p-value: <0.001) values between the artisanal refining sites and the non-artisanal refining sites. This was confirmed by the post-hoc tests for humidity and windspeed which showed significant difference between both sites (p-value: <0.001). The temperature at the control site did not however significantly differ between both sites (p-value: 0.081). These can be seen in Table 7.

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Comparison of meteorology of air at artisanal refining and non-artisanal refining sites

Table 7: Meteorology of the artisanal refining and non-artisanal refining sites

Locations	Temperature(^{o}C)	Relative humidity	Wind speed
L1	31.156±0.253	62.353±0.855	2.453±0.367
L2	30.703±0.040	61.467±0.112	2.720±0.066
L3	29.437±0.430	60.130±0.191	2.883±0.047
L4	29.527±0.068	60.460±0.034	2.547±0.055
L5	30.187±0.104	59.860±0.626	3.260±0.397
LX	29.738±0.208	62.257±3.083	2.793±0.012
F-statistic (ANOVA)	3.828	750.699	545.582
p-value	0.026*	<0.001*	<0.001*

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Assessment of the concentration of noxious gases in the air at the artisanal refining and non-artisanal refining sites revealed that the carbon monoxide (3.110±0.160), nitrogen oxides (2.870±0.212), and sulfur oxides (2.557±0.105) from the first sampling site (L1) were the highest ranging from 2.95 to 3.27, 2.71 to 3.11 and 2.45 to 2.66 respectively. These are shown in Table 8.

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Assessment of the difference in the carbon monoxide (CO), nitrogen oxides (NO) and sulfur oxides (SO) of the air samples obtained from the different artisanal refining sites and the non-artisanal refining site, also revealed that the carbon monoxide and nitrous oxides concentration at the non-artisanal refining site was significantly lower from the concentrations at all the artisanal refining sites (p-value: <0.001). These are shown in Figure 4.

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Table 8: Concentration of noxious gases at artisanal refining and non-artisanal refining sites

		Mean	Std. Deviation	Minimum	Maximum
CO	**L1**	3.110	0.160	2.95	3.27
	L2	2.650	0.452	2.15	3.03
	L3	2.097	0.202	1.97	2.33
	L4	1.603	0.061	1.55	1.67
	L5	2.080	0.070	2.01	2.15
	LX	0.420	0.026	0.40	0.45
NO	**L1**	2.870	0.212	2.71	3.11
	L2	2.570	0.020	2.55	2.59
	L3	2.000	0.100	1.90	2.10
	L4	2.047	0.072	2.00	2.13
	L5	1.597	0.064	1.55	1.67
	LX	0.323	0.040	0.30	0.37
SO	**L1**	2.557	0.105	2.45	2.66
	L2	2.390	0.060	2.33	2.45
	L3	1.770	0.090	1.68	1.86
	L4	1.537	0.023	1.51	1.55
	L5	1.423	0.021	1.40	1.44
	LX	0.330	0.036	0.30	0.37

Permissible limits: CO: 0.04-0.1mg/m^3, NO: 0.2mg/m^3, SO: 0.125 mg/m^3(20,21)

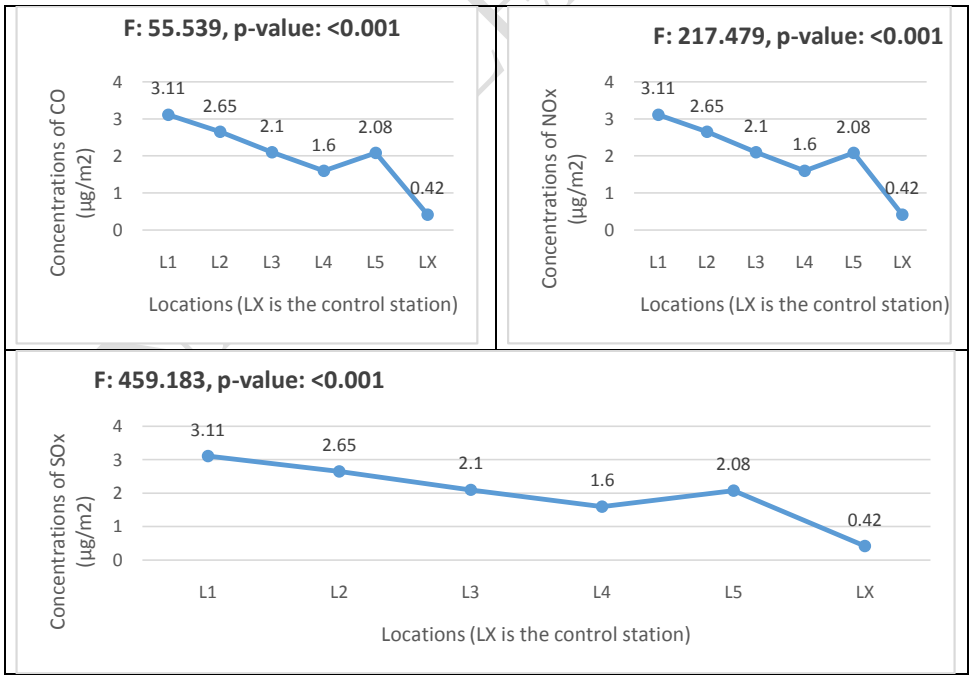

Figure 4: Difference in the CO, NO and SO levels in air samples from the sampled sites

Table 9: Presence of suspended particulate matter at artisanal refining and non-artisanal refining sites

		Mean	Std. Deviation	Minimum	Maximum
PM2.5	**L1**	23.710	1.150	22.56	24.86
	L2	22.170	0.180	21.99	22.35
	L3	19.150	0.160	18.99	19.31
	L4	21.330	1.110	20.22	22.44
	L5	17.980	1.210	16.77	19.19
	LX	7.927	0.118	7.79	8.00
PM10	**L1**	77.090	1.180	75.91	78.27
	L2	80.220	0.350	79.87	80.57
	L3	109.050	1.150	107.90	110.20
	L4	91.660	0.890	90.77	92.55
	L5	111.080	0.170	110.91	111.25
	LX	37.090	1.180	35.91	38.27

PM 10 levels exceeded recommended safe levels (90 µg/m^3) given by the World Health Organisation(18)**.**

Assessment of the concentration of suspended particulate matter in the air at the artisanal refining and non-artisanal refining sites revealed that the particulate matter 2.5 [PM 2.5], (23.710±1.150) from the first sampling site (L1) and particulate matter 10 [P.M 10], (111.080±0.170), from the fifth sampling site (L5) were the highest ranging from 22.56 to 24.86, and 110.91 to 111.25 respectively. These are shown in Table 9.

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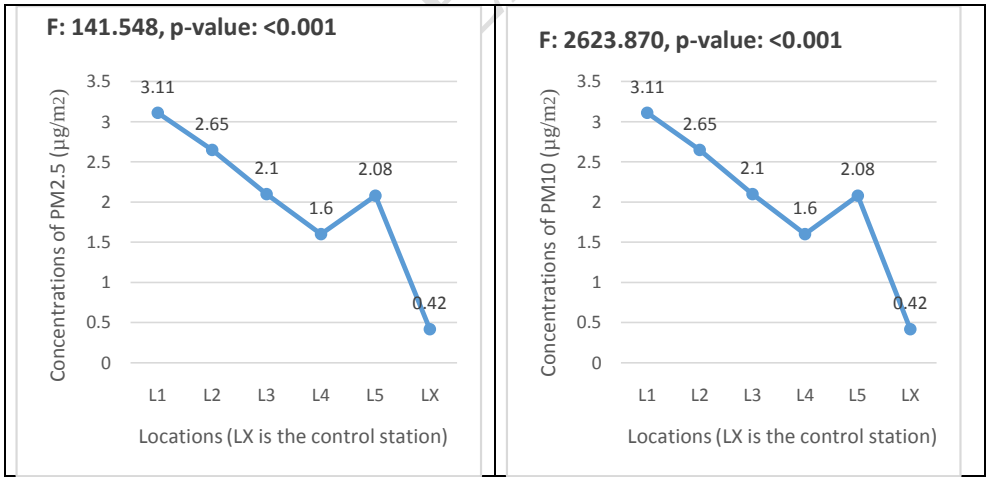

Figure 5: Levels SPM for PM 2.5 and PM 10

Assessment of the difference in the PM 2.5 and PM 10 levels in the air samples obtained from the different artisanal refining sites and the non-artisanal refining site, revealed that the concentrations of both suspended particulate matter sizes at the non-artisanal refining site was significantly lower from the concentrations at all the artisanal refining sites (p-value: <0.001). These are shown in Figure 5.

Discussion

This study was conducted to assess the water and air quality in communities in Ekeremor Local Government Area where artisanal refining of crude oil is known to take place in Bayelsa State, Nigeria. The study identified that concerning the water quality, assessment of the physicochemical properties of the water revealed that the potential of hydrogen (pH) and the dissolved oxygen (DO) content were within normal limits. However, the turbidity, temperature, and salinity of the water samples exceeded the allowable standard limits, while the conductivity, and total dissolved solids (TDS) in the water samples were below the acceptable standards of the World Health Organization as well as the United States Environmental Protection Agency (22,23). Lead, cadmium and mercury levels were also found to be higher than the acceptable limits in the sampled areas (16). Concerning the air quality of the assessed areas, it was also identified that all assessed air quality parameters including carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter (PM 10), exceeded the laid down allowable limits (18,20,24). These results are further discussed below.

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Comment [O20]: What do you mean by the potential of hydrogen? pH is different from hydrogen

Assessment of the physicochemical parameters of the water sources in this study revealed that the turbidity, temperature, and salinity of the water samples exceeded the allowable standard limits, while the conductivity, and total dissolved solids (TDS) in the water samples were below the acceptable standards provided by the World Health Organization as well as the United States Environmental Protection Agency (22,23). These parameters were however identified to insignificantly differ from the values recorded at the control site assessed in this study. Similar findings have also been reported in literature where reports of deranged physicochemical parameters have been reported to occur in relation to harmful oil and gas-related activities (23,25,26). The implication of turbidity, temperature, and salinity of water exceeding allowable standard limits is that this can have significant and interconnected consequences on aquatic ecosystems, considering that these parameters play crucial roles in maintaining the health and balance of aquatic environments (27). Excessive turbidity reduces the penetration of light into the water, disrupting photosynthesis in aquatic plants. This, in turn, affects the entire food chain, as many organisms depend on these plants for sustenance. High turbidity can also interfere with the feeding mechanisms of filter-feeding organisms, impacting their ability to obtain food (28,29).

Deviations from optimal specific temperature ranges within which various aquatic animals' species thrive, can lead to reduced oxygen solubility, altered metabolic rates, and increased susceptibility to diseases. Rapid temperature changes can also disrupt the reproductive cycles of aquatic organisms, affecting their ability to spawn and reproduce (29,30). Exceeding these tolerances can lead to osmotic stress, affecting their ability to maintain proper internal balance. Changes in salinity can also impact the distribution and abundance of different species, potentially leading to shifts in the composition of aquatic communities (29,31,32). In situations where aquatic life is adversely affected, this would have an impact on food availability considering that fish serve as a major food source in these communities (30). Salinity can affect the quality of water used for irrigation. High salinity levels in water can lead to soil salinization, reducing agricultural productivity. This can have economic implications for surrounding communities that rely on agriculture as a livelihood (27,29,33).

This study also identified high levels of lead, mercury and cadmium levels in the assessed water samples. These concentrations exceeded safe limits that have been provided by regulatory bodies in environmental health (16,22,23). The concentrations of the heavy metals present in the artisanal refining and artisanal refining sites' water samples were also identified to significantly differ from one another, signifying that the artisanal refining activity going on

in the test environment could likely have heavy metal pollutant effects within that area. This finding is also corroborated by the findings of other studies that reported heavy metal pollution in affected areas (34,35). High lead, mercury and cadmium concentrations in water can have severe environmental and health implications, posing risks to both ecosystems and human populations. Lead is toxic to aquatic organisms, including fish and invertebrates. Elevated lead levels in water bodies can lead to physiological stress, impaired reproduction, and even mortality among aquatic species (36,37). These heavy metals also possess the potential to bioaccumulate in aquatic organisms upon which predatory species feed on and accumulate higher lead concentrations, leading to biomagnification along the food chain (37).

High heavy metal concentrations can disrupt aquatic ecosystems by affecting the abundance and diversity of species (38). The most significant health concern associated with elevated lead exposure is lead poisoning. Ingesting or inhaling lead-contaminated water can lead to neurological effects, particularly in young children. This can result in developmental delays, learning disabilities, and behavioral problems (38,39). Adults exposed to high lead and cadmium levels can experience cardiovascular and renal effects. These exposures have been linked to increased blood pressure, kidney damage, and other cardiovascular issues (38,39). Pregnant women exposed to lead and mercury may experience complications, and the exposure during fetal development can lead to low birth weight, premature birth, and developmental delays in infants. Prenatal mercury exposure can also lead to cognitive impairment and learning disabilities (36).

All assessed air quality parameters including carbon monoxide, nitrogen oxides, sulfur oxides and PM 10, exceeded the laid down allowable limits (18,20,21,24). Assessment of the difference in the concentrations of these gases between the artisanal refining and the non-artisanal refining sites, revealed significantly higher concentrations at all the artisanal refining sites. This was also a similar finding with the temperature, humidity and windspeed results compared between both study sites. This finding is in line with the findings of other authors who reported higher than usual concentrations of noxious gases present in areas where crude oil artisanal refining activities are conducted (40,41). This finding is mainly due to refiners continuous refueling of the refining oven with leftover crude oil and dry wood, which is associated with the lack of oxygen in the pit compartment beneath the oven, and the fire's forced intensification over time (40). The presence of these gases also has adverse implications for environmental and human health. Nitrogen and sulfur oxides can react with other atmospheric pollutants to form acids, contributing to acid rain. Acid rain can lead to the acidification of soil and water bodies, negatively impacting aquatic ecosystems, forests, and soil quality (24). Sulfur dioxide can cause damage to plant tissues by entering the stomata and reacting with water to form sulfuric acid. This can result in reduced crop yields, forest decline, damage to vegetation in the affected area, alongside reduced availability of food and food products and consequent problems of starvation and malnutrition (21,33,42). Inhalation of nitrogen dioxide and other nitrogen oxides can cause respiratory problems, particularly in individuals with pre-existing respiratory conditions. It can lead to coughing, wheezing, and shortness of breath. Long-term exposure to nitrogen oxides has been associated with cardiovascular issues, including an increased risk of heart attacks and other cardiovascular diseases (43). Sulfur oxides can also contribute to the formation of sulfate particles, which can become part of fine particulate matter ($PM_{2.5}$). Fine particulate matter is associated with respiratory and cardiovascular health issues and can have long-range transport, affecting air quality in distant areas.

Conclusion

In this study, concerning the water quality, assessment of the physicochemical properties of the water revealed that the potential of hydrogen (pH) and the dissolved oxygen (DO) contents were within normal limits. However, the turbidity, temperature, and salinity of the water samples exceeded the allowable standard limits, while the conductivity, and total dissolved solids (TDS) in the water samples were below the acceptable standards. Lead, cadmium and mercury levels were also found to be higher than the acceptable limits in the sampled areas. Concerning the air quality of the assessed areas, it was also identified that the carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter (PM 10) levels exceeded the laid down allowable limits.

Recommendations

Recommendations for practice

- Stakeholders at the Federal level of government should strengthen and enforce regulations specifically targeting artisanal refining activities to control and monitor their environmental impact, as well as impose strict penalties for illegal refining practices and non-compliance with environmental regulations.
- Concerned stakeholders at the Federal and State levels of government should implement regular and comprehensive water quality monitoring programs to regularly assess the levels of turbidity, salinity, temperature, and heavy metals of water bodies in the country. This could be done using advanced monitoring technologies and equipment for accurate and real-time data collection and environmental monitoring.
- The government should also engage in developing alternative livelihood programs for communities engaged in artisanal refining to reduce dependence on environmentally damaging activities.
- Environmental health stakeholders in the country should also conduct awareness campaigns within communities engaged in artisanal refining to educate them about the environmental consequences of their activities as well as emphasize the importance of sustainable practices and the long-term benefits of preserving air and water quality.
- Water treatment facilities could also be established by the government in areas affected by artisanal refining to reduce salinity and remove heavy metals. Remediation strategies for areas with existing contamination could also be developed with consideration of technologies like phytoextraction for heavy metal removal.
- The possibility of legalizing and formalizing certain aspects of artisanal refining under strict regulatory frameworks should also be explored by concerned oil and gas regulatory authorities.

Recommendations for policy

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- Environmental regulatory agencies of government alongside policymakers should review and strengthen existing regulations to specifically address the environmental impacts of artisanal crude oil refining, focusing on water quality standards, pollutant limits, and discharge permits. They should also ensure that these regulations are enforceable and include strict penalties for non-compliance. The enforcement of restrictions on artisanal refining activities in ecologically sensitive areas, such as near water bodies, wetlands, and critical ecosystems should also be considered.
- The government can also establish community-based monitoring systems, empowering local communities to actively participate in monitoring and reporting on artisanal refining activities and associated pollution. Mechanisms for communities to provide input into the regulatory decision-making process should also be set up.
- The implementation of continuous air quality monitoring systems to track and regulate pollutant emissions should be strengthened by necessary policy action.

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