


# Deleterious impacts of tank farms on Delta neighbourhoods: mitigation and environmental matrices

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## Abstract

The magnitude of the identified impacts of the ongoing activities of tank farms on climate, air, water, soils, vegetation, waste management, socio-economic and health were rated and the results indicated that the facilities have minimal negative impacts on the recipient environment. Results display that SPM levels in the study range from 69.8–85.4  $\mu\text{g}/\text{m}^3$  for  $\text{PM}_{10}$ , while CO and  $\text{H}_2\text{S}$  were both 100% not within regulatory limits, consequently leading to asthma, coughing and breathing difficulties. Besides,  $\text{H}_2\text{S}$  is corrosive gas, which is rapidly oxidized to sulphur dioxide ( $\text{SO}_2$ ) in the atmosphere, whereas sulphur oxides have been observed to cause a wide variety of health and environmental impacts as they react with other substances in the atmosphere to form acid rain, then affect cardio respiratory system, causing respiratory irritation, bronchoconstriction and several cardiovascular abnormalities. Based on age, the greatest impact (53%) was seen in ages varying from 0 to 16 while that of the age set 16 to 60 was 47%. Curb of oil and gas particulate pollutants and requesting a buffer region between the tank farms and neighborhood complemented with regulatory enforcement and persistent monitoring, should be top precedence for the regulatory authority.

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## Introduction

Air contamination isn't just an al fresco matter<sup>[1]</sup>, but its enclosed spaces, for instance workplaces, habitats or schools can also be contaminated via contagions emitted through outdoor and indoor sources<sup>[2–4]</sup>. Furthermore, some categories of air contagion may be worse for indoors than outdoors, for instance chemicals discharged from synthetic textiles, cigarettes, and fittings and home-use products<sup>[3,5]</sup>. Contamination of the environment by particulates, effluents, metals and other pollutants is of major concern due to their toxicity and risk to environment and human life<sup>[6,7]</sup>. Particulate and emissions toxicity seems to be dependent on exposure route, duration, dose and exposure frequency. For instance, when oil is explored in water sparse zones the water resources become strained. Off-shore oil exploration creates threats to oceanic<sup>[8–10]</sup> life whereas oil circulation and haulage will create extreme hazards for the ecosystem in case of seepage or accidents<sup>[2,11–13]</sup>. When oil spills-out or when there is waste matter expulsion, it percolates into the soil and blends with the underground water system. It has been ascertained that contaminated underground water takes many years before it can be cured<sup>[4,14–17]</sup>. Nonetheless this underground water moves into brooks, streams, rivulets and boreholes or wells which are the key sources of local water supply in the neighborhood which consequences are an upsurge of water-borne sicknesses<sup>[18–20]</sup>. This has disturbed the traditional rapport of the inhabitant within the oil-bearing enclaves<sup>[21–23]</sup>. There is a discernible trepidation that instead of being the life-giver, these water scenarios have become sources of death, misery, and sicknesses<sup>[24–27]</sup>.

## Materials and techniques

### Region of study

Delta state is one of the nine states created in 1991, excised from the old Bendel State (Figs 1 & 2). At its inception it has 19 Local Government Areas (LGAs). Delta state as revealed in the 2006 census, has a population of 4,112,445; comprising 2,069,309 males and 2,043,136 females; distributed over about 890,312 households. It also encompasses a landmass or area of over 17,239,24  $\text{km}^2$ , with average density of 238.6 persons per  $\text{km}^2$  (NPC 2006). According to the 2006 census, Delta state like the nation Nigeria has witnessed an increase in population, ranks the 12<sup>th</sup> most populous state in the country and the 2<sup>nd</sup> most inhabited among the nine oil producing states that comprises the Niger Delta Region. The population is being estimated to be growing at an annual growth rate of 3.2% just as that of the entire country<sup>[28]</sup>.

### Techniques

A pilot origin categorization and separation was carried out at the company and its environ in Lagos metropolis of Nigeria from July 2021 to October 2022 for gathering of data on water attributes as well as composition, generation level and compliance rate of waste management.

### Air emission

Air emissions associated with the operations of the study zones are basically gaseous emissions and particulate matter. The sources of particulate emissions include the general depot operations, loading and offloading activities and truck



Fig. 1 Study region showing Koko village in Warri North Local Government Area, Nigeria.

movement (Fig. 3), while sources of gaseous emissions within zones includes working losses, fugitive losses and generator operations, as well as operations of trucks. Therefore, Suspended Particulate Matter (SPM), Volatile Organic Compounds (VOCs), Carbon monoxide (CO), Sulphur dioxide (SO<sub>2</sub>), Hydrogen Sulphide (H<sub>2</sub>S), Oxides of Nitrogen (NO<sub>x</sub>), in the ambient environment were measured during the study. The *in-situ* ambient air quality measurements were carried out in line with regulatory requirement to ascertain outdoor air condition of the facility's environment (Tables 1 & 2).

*Particulate, gaseous emission and environmental conditions level measurement*

Airborne particulates were collected from several sampling locations using a Bosean Airborne Particulate Counter. The dust monitor was zeroed and set at the run mode 15 s. This is to directly measure the exact concentration of the air borne particulates in 1 l of air. The concentrations of the air borne particulates were then read off the screen of the monitor. Sampling and measurement for temperature and humidity was

carried out using same Bosean Equipment (Fig. 4). Noise level was carried out using the Bosean Noise Level Monitor capable of measuring wind speed and wind flow, equipped with backlit LCD dual display and a variety of choice of readings in km/h, knots, or m/s. These instruments like any other digital instrument is powered by a battery cell and is hand held.

**Results and discussion**

**Ambient air quality and sound outcome**

Parameters measured to determine air quality in the study area include, sulphur dioxide, nitrogen dioxide, carbon monoxide and suspended particulate matter (SPM), volatile organic carbon (VOC) and so forth, the results and contagion effects are displayed in Fig. 5 and Tables 3 & 4. SPM are particles ranging from aggregates of a few molecules to pieces of dust readily visible to the eyes, which are found in the atmosphere. The particles (dust, smoke and other aerosols) may be of anthropogenic and/or natural origin. The most significant of these are the particles of less than 10 µm in diameter, usually referred to as PM<sub>10</sub>.

These smaller particles have greater tendency to scatter light and are mostly inhaled into the lungs<sup>[21,25]</sup>. Exposure to these particles may result in respiratory disorders and susceptibility to respiratory infections. The SPM levels in the study ranges from 69.8–85.4 µg/m<sup>3</sup> for PM<sub>10</sub>. The values obtained in the current study were below FME<sub>nv</sub> and NMDPRA limit of 250 and 90 µg/m<sup>3</sup> respectively. Hydrogen sulphide (H<sub>2</sub>S) is a toxic, odorous and corrosive gas, which is rapidly oxidized to sulphur dioxide (SO<sub>2</sub>) in the atmosphere<sup>[3,7]</sup>. Anthropogenic sources include hydrocarbon storage tanks and process vents. Exposure to concentrations in excess of 0.01 ppm can be fatal, the value

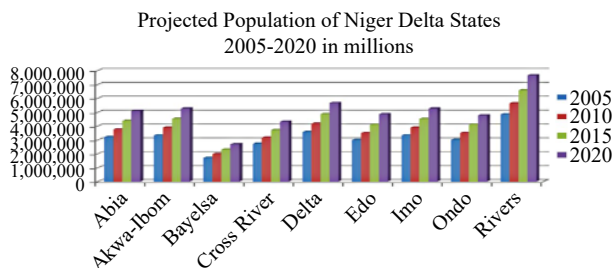


Fig. 2 Niger Delta state population projection based on NPC data and growth rates.



Fig. 3 Typical tank farm and fire pump station.

Table 1. Measurement techniques with its water attributes physiognomies.

Parameters	Unit	Acronyms	Techniques and instruments
Total Suspended Particle		TSP	Temptop PMD 351 Handheld air borne aerosol meter, (HPPC 6+) sum efficiency ~50.0% @0.30µm
Temperature, dew point, relative humidity and wind speed		T (°C), DP, RH and WS	Kestrel 5500 weather meter was utilized for the microclimate measurement.
Heavy metals Manganese, Lead, Copper, Nickel, Cadmium, Cobalt, Zinc		Mg, Pb, Cu, Ni, Cd, Co, Zn	APHA 3111B, UNICAM 969 AAS
Microbiology (cfu/mi) Coliform, Ecoli, Staphylococcus, Vibrio, Total coliforms, Aerobic plant count, Yeast & Mould			APHA 9215C
Anions Nitrate, Nitrite	(mg/l)	NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup>	APHA 4500, UN spectrophotometer
Sulphate, Phosphate	(mg/l)	SO <sub>4</sub> , PO <sub>4</sub> <sup>3-</sup>	APHA 4500B, UN spectrophotometer
Calcium	(mg/l)	Ca	APHA 4500A, UN spectrophotometer
Physico-chemical Hydrogen ion concentration		pH	pH meter/insitu
Colour	(Pt.Co)		APHA 2120A
Dissolved oxygen	(mg/l)	DO	APHA 5220A, DO meter
Conductivity	(µs/cm)	Cond	APHA 2510A, multi- parameter
Chloride	(mg/l)	Cl <sup>-</sup>	APHA 4500 B, titration
Total dissolve solids	(mg/l)	TDS	APHA 2540A, gravimetric
Total suspended solids	(mg/l)	TSS	APHA 2540D
Appearance			APHA 2110
Acidity	(mg/l)		APHA 2310B
Ammonia Nitrogen	(mg/l)	NH <sub>3</sub> C	APHA 4500
Turbidity	(mg/l)	Turb	APHA 2130B, turbidity meter
Bacterial oxygen demand	(mg/l)	BOD	APHA 5210B, Incubator/winkler
Chemical oxygen demand	(mg/l)	COD	APHA 5220D, K2C-207 reflux
Alkalinity	(mg/l)	Alk	APHA 2320B, Titration
Detergent	(mg/l)		APHA 5540C
Oil and grease	(mg/l)		APHA 5520B

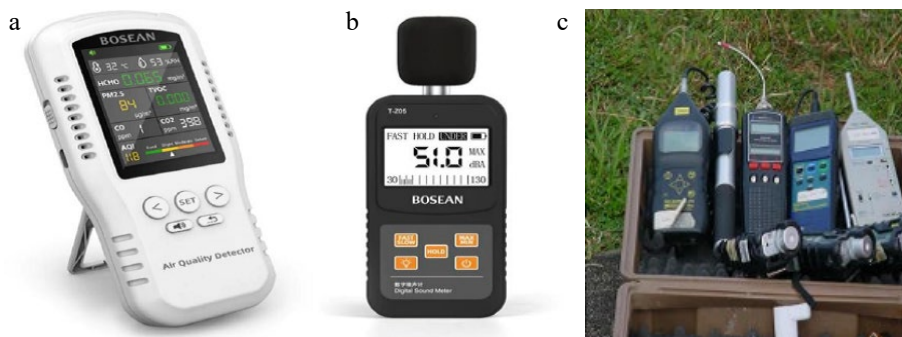
Table 2. Scrutiny techniques and some health impact of contagions.

Parameters	Instrument	Techniques	Above permissible limit health impact
Sulphur IV oxide (SO <sub>2</sub> )	SO <sub>2</sub> Gas Alert test meter	Direct reading	Causes irritation of the respiratory tract
Particulate matter (PM)	Gas Alert test meter	Gravimetric	Causes catarrh, cough, lung infections and other respiratory diseases
Combustible gas (CHN)	Gas Alert test meter	Direct reading	Induces a despondent and depressed state
Carbon monoxide (CO)	CO test meter	Direct reading	Lessens the oxygen-carrying blood capability to damage of the central nervous system
Oxides of Nitrogen (NO <sub>x</sub> )	NO <sub>x</sub> test meter	Direct reading	Causes inflammation of the lungs but less toxic
Noise	Noise meter, Rion sound level meter, NA model	Direct Reading	

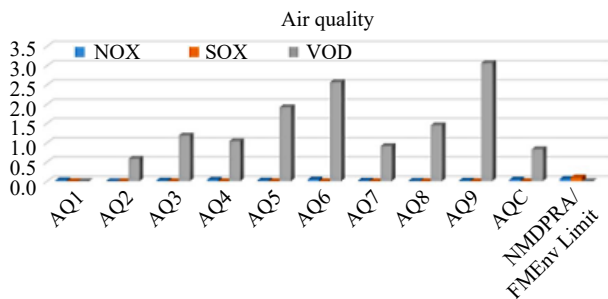
observed for this research was nil. Volatile Organic Compound (VOC) such as methane (CH<sub>4</sub>), ethane (C<sub>2</sub>H<sub>4</sub>), propane (C<sub>3</sub>H<sub>8</sub>), and other derivatives of aliphatic and aromatic organic compounds are emitted from man-made and natural sources (fugitive emissions, emissions from vents and incomplete combustion of fuels), particularly where fuel to air ratio is high. Most members of the group are significantly toxic, and exposure to

high concentrations (> 8.53) could interfere with oxygen intake<sup>[29]</sup> and cause acute leukaemia. VOC concentration in the study region ranged from 0.58–0.58 ppm.

Nitrogen dioxide (NO<sub>2</sub>) is a member of the family of highly reactive gases called nitrogen oxides or oxides of nitrogen. Together with hydrocarbons, oxides of nitrogen are the basic chemical constituents in photochemical reactions leading to



**Fig. 4** Bosean. (a) Airborne particulate. (b) Noise level monitor counter. (c) Multigas monitor.



**Fig. 5** Comparison of VOC, NO<sub>2</sub> and SO<sub>2</sub> concentrations with regulatory standards.

**Table 3.** Some contagions and effects.

Contagions	Health impacts	
	Short term	Long term
Ethylbenzene	Dizziness, eye and throat irritation	Blood disorders
Benzene	Skin blister and irritation, upper respiratory tract	Developmental and reproductive disorders
n-Hexane	Headache, giddiness and nausea.	Blurred vision, fatigue, extremities and headaches
Toluene	Sleep difficulty, dizziness, skin and eyes irritation	Birth defects
Xylenes	Nose, gastric and throat irritation, neurological, vomiting and nausea	Nervous system disorder

**Table 4.** Outcome of ambient air and noise quality at Delta state.

Parameter	Unit	NMDPRA/ FMEEnv Limit	Sites					Limit (%)	
			A1	A2	A3	A4	A5	Within	Not
Ambient temp	°C	30	31.7	32.4	33.2	32.8	30.7	0	100
Wind velocity	m/s	N/A	2	1.8	1.5	1.9	1.7	–	–
Wind direction		N/A	SW	SW	SW	SW	SW	–	–
Atm. pressure	hPa	N/A	1,011	1,011	1,012	1,011	1,011	–	–
Rel. humidity	%	N/A	72.4	67.2	64.1	66.5	76.9	–	–
Noise level	dB(A)	80–100	58.7	62.8	52.0	50.5	53.7	100	0
SPM	µg/m <sup>3</sup>	90/250	69.8	72.7	81.4	70.1	85.4	100	0
NOx	ppm	0.04–0.06	0.026	<0.001	0.018	0.035	0.02	100	0
SOx	ppm	0.01	0	0	0	0	0	–	–
CO <sub>2</sub>	ppm	425	289	296	320	288	279	100	0
CO	ppm	0.03	2	1.65	0.38	1.24	1.96	0	100
H <sub>2</sub> S	ppm	0.008	0.01	0.01	0.01	0.01	0.01	0	100
VOC	ppm	8.53	0.75	0.58	1.19	1.04	1.92	100	0
Ozone	ppm	N/A	0.05	0.05	0.06	0.06	0.05	–	–
NH <sub>3</sub>	ppm	No limit	<0.001	<0.001	<0.001	<0.001	<0.001	–	–
CH <sub>4</sub>	ppm	250	<0.001	<0.001	<0.001	<0.001	<0.001	–	–

formation of ground-level ozone and smog which directly impact human health. Nitrogen dioxide like other members of the oxides of nitrogen family is a strong oxidizing agent that reacts with air and water to form nitric acid as well as toxic organic nitrates. Anthropogenic emissions of NO<sub>2</sub> such as fuel combustion at high temperatures from motor exhaust have been reported to cause adverse health effects including pulmonary diseases<sup>[10,19]</sup>. Nitrogen dioxide recorded in the study region below 0.001 ppm.

Oxides of sulphur are components of trace gases and aerosols occurring in gaseous and particulate forms which include sulphur monoxide, sulphur dioxide and sulphur trioxide. Sulphur oxide have both natural (sea-salt, volcanic emissions) and anthropogenic (biomass burning, industrial combustions) sources. Sulphur oxides have been observed to cause a wide variety of health and environmental impacts as they react with other substances in the atmosphere to form acid rain. It has been reported to affect the cardio respiratory system, causing respiratory irritation, broncho-constriction and several cardiovascular abnormalities<sup>[21,26]</sup>. Exposure to above 0.01 ppm is considered immediately dangerous to life and health. SO<sub>2</sub> was not detected in this research. Carbon monoxide (CO) is an atmospheric pollution that is generally formed from incomplete combustion of fossil fuels (gas, oil, coal and wood). Natural sources of CO include volcanoes, wildfires and man-made fires. CO is colourless and odourless but highly toxic. It displaces oxygen from oxyhaemoglobin to produce carbon

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haemoglobin causing suffocation<sup>[1,6]</sup> and can be fatal at concentrations above 0.03 ppm or 12–17 ppm for 8 h<sup>[30]</sup>. Prolonged exposure to CO concentration of 200 ppm and 800 ppm for about 45 min to 3 h may result in severe headache, dizziness, nausea and convulsion. All CO values measured above the limit tolerated, ranging from 0.38–2.00 ppm. Noise is usually sound that bears no information and whose intensity usually varies randomly over time. Noise is often used to mean unpleasant sound, which interferes with human hearing and is likely to be physiologically harmful. The use of ear-protectors is mandatory in areas where noise levels are 90 dBA or above. Noise measurements from all the sampling stations ranged from 51.5 dBA to 69.8 dBA, which is within NMDPRA as well as FMEnv limit of 90 dB (A) for an 8 man-h exposure.

**Outcome of water physico-chemistry**

The outcomes of physico-chemical variables obtained from groundwater within the project region (Table 5 & Fig. 6) indicated that the conductivity (1,094.0, 1,695.0 and 1,695.1 mg/l), Calcium (109.1, 108.9 and 109.2 mg/l), Ammonia (0.48, 0.47 and 0.49 mg/l), DO (2.07, 2.06 and 2.07 mg/l) and total dissolved solid (847.2, 847.4 and 847.3 mg/l) values were high, indicating freshwater aquifer. The turbidity values (1.00–1.13 NTU) reveal that all the sampled boreholes were well within the standard for hygienic water criterion of 5 NTU. The pH values displayed neutral measurements due to the bicarbonate quantity with values within 30.0–500.0 mg/l CaCO<sub>3</sub> WHO limit. The carbonate alkalinity perceived in the sampling was very low. TD values of the groundwater samplings vary between 51.8 mg/L CaCO<sub>3</sub> as well as 48.6 mg/L CaCO<sub>3</sub>. Discrepancy between the TD

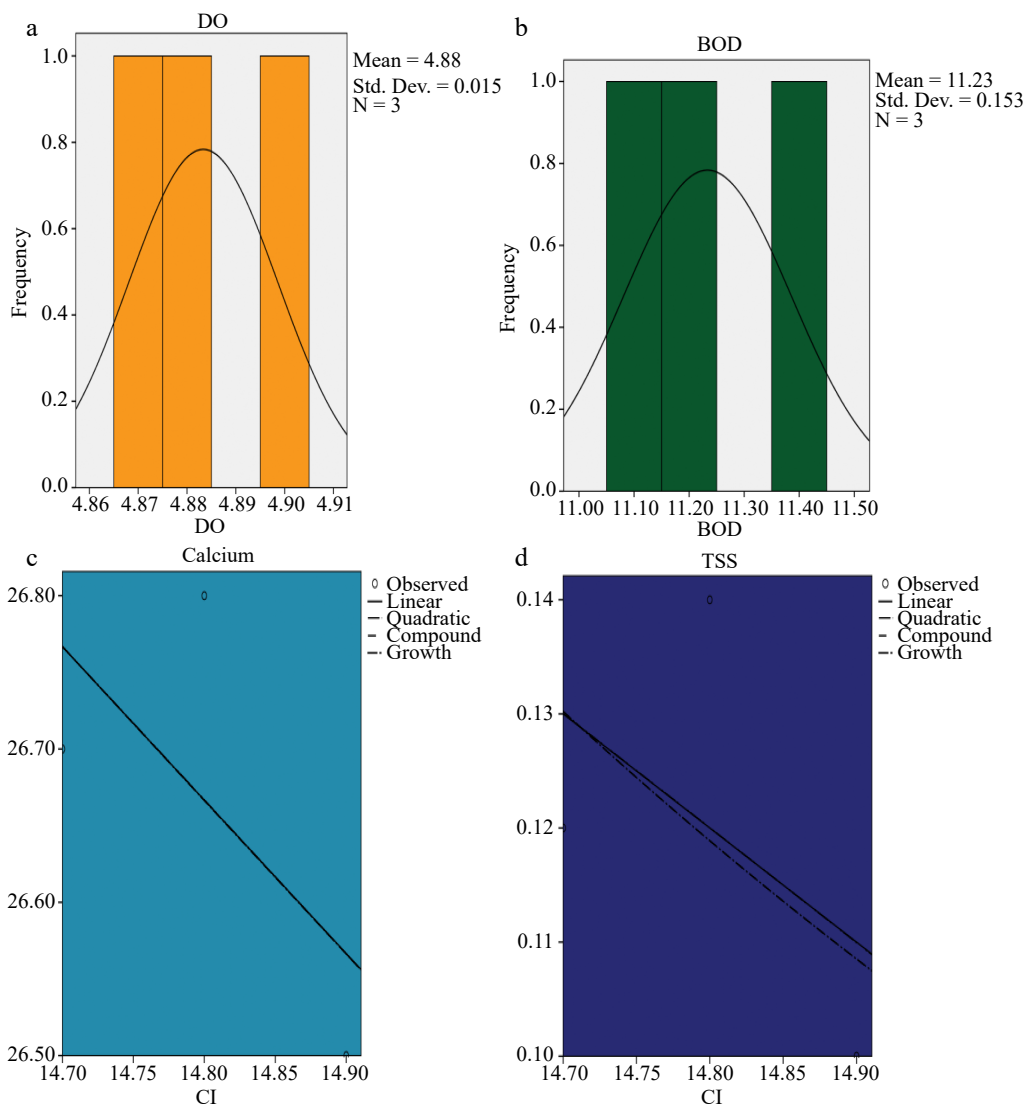
values for the boreholes was awfully low, signifying recharge from the equivalent origin. Hardness in water encompasses calcium plus magnesium as the key constituents. For instance, magnesium ions quantified in the groundwater varied from 39.7–39.8 mg/L respectively, Small phosphate, chloride, and sulphate amounts were seen in groundwater samplings compared to the WHO limits. Likewise, small anions quantities substantiate the airiness of groundwater from the research site. Sulphide and Nitrate ions were not perceived in the groundwater sampling. Oil and grease (O&G) were not detected within the facility area, two of the sample points were below instrument detection limit. Total hydrocarbon was not detected in the ground water samplings of the project influence zone. The origin can, however, be ascribed to biogenic instead of anthropogenic involvement since petroleum hydrocarbon correlated deeds was not seen in the region during this period of research.

**Outcome of sediment physico-chemistry**

The outcome of physicochemical parameters observed is displayed in Fig. 7 and Table 6 which signifies that pH values obtained for sediment ranged from 7.47 to 7.92, while electrical conductivity values observed varied between 0.61 and 0.87 with mean value of 0.74 mS. For nutrient status, the mean concentrations of chloride, sulphate, phosphate, ammonium, nitrate, and nitrate were 201.06, 9.61, 1.57, 0.95, 0.29 and 1.75 mg/l respectively. Likewise exchangeable cations that are essential for optimal primary and secondary productivity in aquatic ecosystems such as sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg) in sediments samples were 37.35 to

**Table 5.** Outcome of water attributes.

Variables	Unit	Sites			Limits					Compliant status (%)	
		1	2	3	FEPA	WHO	USEPA	NIS	EU	Compliant	Non-within
pH		7.08	7.09	7.07		6.5–8.5			6.5–8.5	100	0
Conductivity	µs/cm	1,694.9	1,695.0	1,695.1	1,000	–	1,000	1,000	2,500	0	100
Calcium	mg/l	109.1	108.9	109.2		–		75		0	100
Phosphate	mg/l	1.01	1.00	1.00	<5.0	–	–	NS	–	100	0
Ammonia	mg/l	0.48	0.47	0.49				0.05		0	100
TSS	mg/l	0.09	0.08	0.10	<10	–	–	NS	–	100	0
Temperature	°C	25.4	25.5	25.3				Ambient		100	0
Turbidity	NTU	0.01	0.02	0.01	5	5	5	5	–	100	0
Total acidity	mg/l	61.4	61.3	61.4				NS		–	
TDS	mg/l	847.2	847.4	847.3	500	–	500	500	–	0	100
Total hardness	mg/l	272.4	272.3	272.4	200	80-100	–	150	–	0	100
Total alkalinity	mg/l	408.4	408.2	408.3	–	–	–	200	–	0	100
Total solids	mg/l	1,039.9	1,040.2	1,040.3				NS		–	
Magnesium	mg/l	39.8	39.7	39.8				20		0	100
Sodium	mg/l	10.7	10.8	10.6				200		100	0
Chloride	mg/l	26.8	26.9	26.7	250	250	250	250	250	100	0
DO	mg/l	2.07	2.06	2.07				2		0	100
Nitrite	mg/l	0.13	0.14	0.12				0.2		100	0
Manganese	mg/l	0.23	0.22	0.21				0.2		0	100
Total iron	mg/l	<0.01	<0.01	<0.01				0.3		100	0
Sulphate	mg/l	50.2	50.3	50.1	500	250	250	250	250	100	0
Silica	mg/l	3.93	3.94	3.92				40		100	0
Salinity	%	0.09	0.08	0.07				NS		–	
Nitrate	mg/l	<0.01	<0.01	<0.01	50	50	50	50	50	100	0
Total oil/grease	mg/l	0.08	0.09	0.10				10		100	0
Colour	TCU							15		100	0
Appearance		Colourless						Colourless			
Odour		Objectionable						Unobjectionable			
Taste		Objectionable						Unobjectionable			



**Fig. 6** Water attribute scrutiny outcome for: (a) DO, (b) BOD, (c) calcium and (d) TSS.

53.27 mg/l, 11.82 to 16.86 mg/l, 65.86 to 93.93 mg/l and 16.91 to 24.23 mg/l respectively.

Clearly the results shows that parameters such as chlorine, ammonia, iron, copper, zinc and magnesium have extreme values that are above the recommended values by the regulatory authorities, which indicates a negative impact on the environment and the populace.

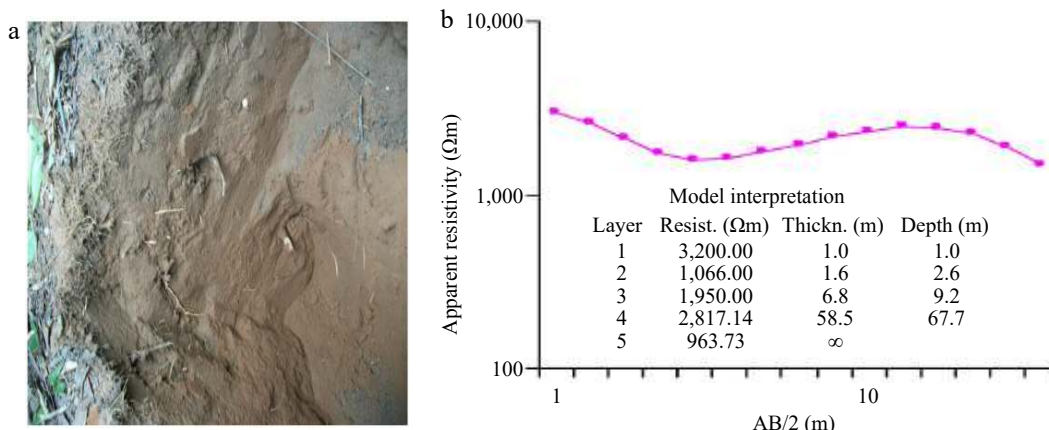
Total Hydrocarbon Content (THC) describes hydrocarbon content in sediment, Total Petroleum Hydrocarbon (TPH) and BTEX was below the equipment detection limit of 0.01. The complexes and forms in which different metals occur in sediments have a profound effect on their bioavailability and toxicity to aquatic organisms. Most metals in solid, stable forms in sediments are derived from natural weathering, erosion and surface runoff. However, anthropogenic inputs from such sources as mine tailings, dredged material and oil well drilling may be important locally. More important sources of metals in sediments are physical and chemical reactions taking place in the water column. Metals introduced in soluble or colloidal forms into estuarine and coastal waters tend to either precipitate or adsorb to suspended particulate and colloidal or

dissolved organic matter. These precipitate, adsorbed or complex metals may be deposited in a more or less labile, bioavailable form in surficial sediments<sup>[10,18]</sup>.

### Outcome of soil characteristics

Table 7, Figs 7 and 8 display the outcome of analysis carried out on a total of eight samples collected, profiled at surface and sub-surface depths of 0–15 cm and 15–30 cm respectively. The soil and its components are essential resources to human life. It influences the distribution of plant species and provides a habitat for a wide range of organisms. However, the pressure due to population growth has made these resources scarce and resulted in its abuse in many parts of the world. Therefore, proper allocation of this resource based on its capability necessitates detailed soil studies.

However, parameters such as Iron, Zinc, potassium and copper were above their prescribed limits as stated in Guidelines for Noise, Industrial Effluent, and Gaseous Emissions Limitations<sup>[31]</sup>. A pH of between 5.76–7.55 indicates that the sample is moderately acidic and also within the stipulated regulatory limit of 6.5–8.5 (Tables 6 & 7). Microbial analysis was also carried out on the raw water sample and the result for Salmonella was



**Fig. 7** (a) Friable poorly sorted loose sandy-silt (0.05–0.002) with moderately frequent roots inclusions and, (b) response PNG-VES data for environmental geophysical investigation.

**Table 6.** Outcome of physicochemical characteristics of sediments within the study vicinity.

Parameter	Unit	Site 1	Site 2	Site 3	Mean	Limit
EC	mS	0.87	0.63	0.74	0.74	
pH		7.47	7.90	8.21	7.87	6–9
TOC	%	2.12	1.72	2.39	2.08	
R/POL	mV	–167.8	–181.2	–298.8	–215.93	
Salinity	Psu	0.04	0.03	0.04	0.04	
Cl	mg/kg	236.38	165.74	201.06	201.07	100
CO <sub>3</sub>	mg/kg	<0.01	<0.01	<0.01	<0.01	
T/N	%	0.09	0.06	0.08	0.08	10
PO <sub>4</sub>	mg/kg	1.84	1.29	1.58	1.59	
SO <sub>4</sub>	mg/kg	11.30	7.93	9.61	9.62	100
NO <sub>3</sub>	mg/kg	2.11	1.48	1.65	1.76	
NO <sub>2</sub>	mg/kg	0.35	0.25	0.27	0.28	
NH <sub>4</sub>	mg/kg	1.15	0.81	0.90	0.95	
Na	mg/kg	53.27	37.35	45.31	45.31	
K	mg/kg	16.87	11.82	14.33	14.34	
Ca	mg/kg	93.93	65.87	79.70	79.71	
Mg	mg/kg	24.23	16.99	20.61	20.62	1.0
THC	mg/kg	<0.01	<0.01	<0.01	<0.01	
TPH	mg/kg	<0.001	<0.001	<0.001	<0.001	
BTEX	mg/kg	<0.001	<0.001	<0.001	<0.001	
Phenol	mg/kg	<0.001	<0.001	<0.001	<0.001	
PAH	mg/kg	<0.001	<0.001	<0.001	<0.001	
THB	cfu/g	5.78	4.74	5.12	5.22	
THP	cfu/g	1.56	1.28	1.38	1.41	
HUB	cfu/g	2.83	2.33	2.54	2.56	
HUF	cfu/g	0.65	0.54	0.58	0.59	
Fe	mg/kg	506.69	355.26	130.97	330.98	1.0
SKB	cfu/g	1.97	1.6	1.74	1.78	
Cu	mg/kg	<0.001	<0.001	<0.001	<0.001	
Cr	mg/kg	0.64	0.45	<0.001	0.25	
Pb	mg/kg	0.12	0.09	<0.001	0.10	
Cu	mg/kg	92.68	50.96	61.82	68.50	1.0
Ni	mg/kg	4.82	3.45	<0.001	4.14	
V	mg/kg	<0.001	<0.001	<0.001	<0.001	
Zn	mg/kg	265.62	186.24	37.23	163.03	5.0
Hg	mg/kg	<0.001	<0.001	<0.001	<0.001	
Ba	mg/kg	<0.001	<0.001	<0.001	<0.001	

negative. Wastewater (effluent) from the region encompasses depot operations which arises from mixture of minor spills and water as well as wastewater from the laboratory, kitchen, equipment maintenance etc. can impact negatively on the environment if discharged directly to public drains without

treatment. The contagions in such wastewater might encompass soluble macrobiotic chemicals creating exhaustion of heavy metals, DO, suspended solids plus volatile materials, hydrocarbons, bases or acids (displayed as small or high pH). Though some depot’s installed OWS works to skim out the oil from the water and ensure it is tested and treated before discharge.

**Outcome of conflict analysis and resolution**

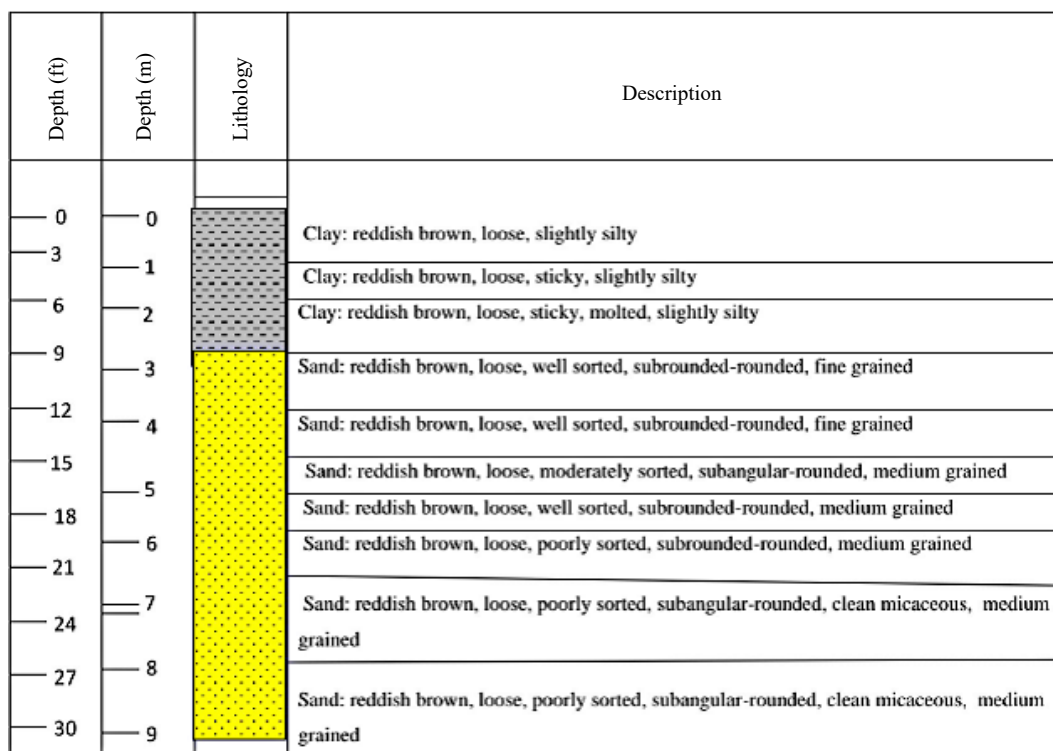
Conflict investigation and its possible resolution are demonstrated in Table 8, Figs 9 and 10. Community consultations, focus group discussion (FGD) and responses from the administered questionnaires indicated that the resident populations are not in any way against oil and gas tank farms and their operations in the host community. Continued fulfillment of promises and terms as contained in MoU is regarded as vital in maintaining and improving the oil and gas companies relations to the host communities. It is important to point out here that, one of the causes of the crises that affected the whole Niger Delta region was attributed to unemployment; although unemployment is becoming a global issue. Often seen are youth delinquency, land dispute, chieftaincy tussle, inter-family problems, inter-village conflict, alcoholism/prostitution. Youth delinquency and unemployment are identified to be among the highest of the social problems in the area corresponding to 35.2% and 20.2% respectively. Also 12.4% (land dispute), 19.55 (alcoholism/prostitution), 3.4% (chieftaincy tussle), 3.7% (inter-family problems) and 5.6% (inter-village conflict). From the study region narratives, conflicts and contentious issues are often resolved in the community in conjunction with the traditional head, Council of Elders, Community Management Authority, youth groups and women groups. The rungs of power are many as revealed by the well-organized leadership structures from the family heads, quarter heads, all through the various organs and ends at the feet of His Royal Highness<sup>[4,12–14]</sup>. In the case that a community member goes contrary to the law, the issue is handled from the lower organ, youth or womens group and whoever is found guilty pays fines or is punished according to the level of the offence.

**Agricultural produce and productivity**

Though agriculture is not the main occupation of the resident population in the scrutiny region owing to oil and gas hazard, about 9.4% respondents are farmers however (Table 9

**Table 7.** Outcome of soil properties within the study vicinity.

Parameters	Unit	Sites								Limit
		1	2	3	4	5	6	7	8	
Sand	%	41.2	34.7	46.3	41.1	86.4	86.3	37.3	33.8	
Silt	%	37.3	40.9	36.8	37.5	6.8	6.3	43.1	42.7	
Loam	%	21.4	24.4	17.7	21.4	4.8	7.4	19.6	23.3	
pH		6.9	7.55	6.22	6.12	6.01	5.99	5.76	6.00	6.5–8.5
EC	mS	0.17	0.09	0.08	0.06	0.05	0.01	0.09	0.07	
TOC	%	2.87	2.38	2.64	2.16	0.64	0.47	3.05	2.47	
T/N	%	0.07	0.06	0.06	0.05	0.01	0.01	0.07	0.06	
NO <sub>3</sub>	mg/kg	13.34	7.07	6.27	4.70	3.92	2.35	7.12	4.66	
NO <sub>2</sub>	mg/kg	1.82	0.91	0.79	0.59	0.49	0.30	0.92	0.58	
NH <sub>4</sub>	mg/kg	6.94	3.58	3.11	2.33	1.94	11.7	3.55	2.38	
Na	mg/kg	5.71	2.96	2.62	1.97	0.84	0.50	3.02	1.97	28.0
K	mg/kg	1.34	0.67	0.58	0.44	0.36	0.22	0.71	0.45	0.05
Ca	mg/kg	13.8	7.28	6.45	4.84	1.03	0.62	7.31	4.85	
Mg	mg/kg	44.49	23.40	20.78	15.38	6.99	4.19	23.55	15.60	
THB	cfu/g	5.46	3.51	5.04	3.25	1.36	0.97	5.80	3.72	
THF	cfu/g	1.47	0.95	1.36	0.87	0.37	NO	1.36	1.08	
HUB	cfu/g	2.68	1.72	2.47	1.59	0.67	0.48	2.84	1.82	
HUF	cfu/g	0.61	0.39	0.67	0.37	NO	NO	0.65	0.43	
Fe	mg/kg	1142	864.5	1719	1214	74	52.03	265.5	311	1.0
Cd	mg/kg	<0.001	<0.001	<0.067	<0.058	<0.001	<0.001	<0.001	<0.001	
Cr	mg/kg	2.48	1.96	2.30	1.57	<0.001	<0.001	2.78	2.32	
Pb	mg/kg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Cu	mg/kg	1.68	0.49	0.82	0.78	1.37	1.05	0.58	1.47	0.01
N	mg/kg	3.83	2.96	2.19	1.76	<0.001	<0.001	<0.001	<0.001	
V	mg/kg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Zn	mg/kg	3.83	2.65	3.43	2.47	0.27	0.17	3.90	3.21	0.1
Texture		Loam	Loam	Loam	Loam	Loam	Loam	Loam	Loam	



**Fig. 8** Delta soil contents in borehole log.

& Fig. 10). Crops grown in the area are yam, plantain, cassava, oil palm, banana, maize, melon, pepper and vegetables. Agricultural yield within the surveyed community showed reduction over the years and over time oil exploration activities in the

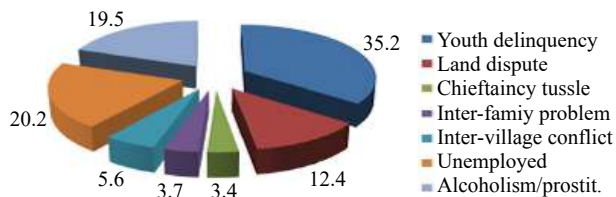
area were attributed to the reduction. More so, analysis shows insufficient land 23.2%, inadequate capital 43.4%, poor technology 20.2%, insufficient labour 7.5% and others 5.7% were reasons for lower farm production (Fig. 11).



Oil impact on the Delta populace

**Table 8.** Weight and height of the populace in the studied community.

Age (months)	Mean weight (kg)	Mean height (m)	Weight for age (normal range) (kg)
0–11	6.72	0.55	3.5–9.5
12–23	9.18	0.77	9.6–12.3
24–35	11.46	0.91	12.6–14.5
36–47	12.61	0.95	14.6–17.5
48–60	13.97	1.03	17.6–19.5



**Fig. 9** Outcome of various conflict issues.

**Outcome of impact scrutiny**

Impact analysis on delta inhabitants recognizing the political leadership of the community as the stakeholders which can in one way or another create much relevance in community leadership (Tables 10–12 & Fig. 12). The perceived benefits attached to these positions have made elections into these positions very competitive and fierce, and this has given rise to violent behaviors that breeds bitterness and hostility among community members. The acquisitions of land for various purposes especially for the project site and its operations even though it has been acquired for years may have resulted in a loss of farm land and minimizing sources of fishing, wildlife and forest products. And so, every land acquired for whatever purpose should be adequately compensated to the appropriate individual, family or community. Also in-migrant workforce and oil and gas operations increase the quest for accommodation within the host communities. This leads to competition on local housing, toilet facilities, market, school enrolment, water supply and other basic amenities with its attended increase in natural resource depletion<sup>[12–15]</sup>. Thus the companies should make effort to recruit and train especially unskilled workforce from the community and its environs, as this can reduce to a large extent the migrant workforce.

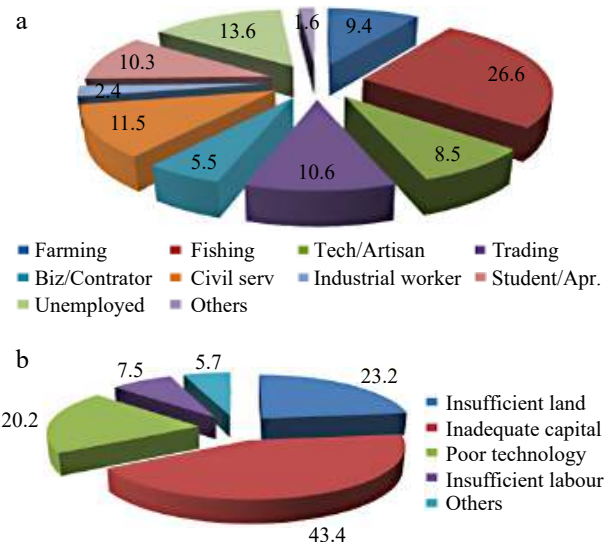
**Outcome of health management, projection and mitigation**

Most of the villages where oil and gas tank farms are don't have good health care but depend on herbal medicine practices or go to other towns for their health care issues. Some

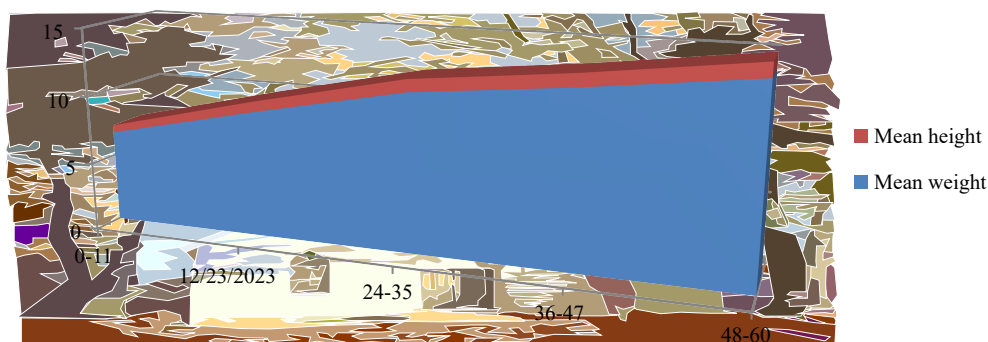
medicinal plants abound in the area, their uses and health management are given in Table 9. Generally, where a structure is already on ground, the chances for impact aversion are constricted and the main issue is how to curtail and reimburse for inevitable impacts. Conversely, these dissimilarities are not inflexible and chances for artistic mitigation must be determined at all phases of assessment and task management. The rudiments of mitigation are structured into a hierarchy of deeds (Fig. 8) based on the principle of avoidance, minimize/reduce, remedy and/or compensate namely: Circumvent helpful impacts as far as possible *via* use of precautionary actions;

**Table 9.** Common medicinal plants and their uses in the region.

Local names	Botanical names	Medicinal uses
Alligator pepper plant	Fromomum melegueta	Sore throat, malaria, purgative
Banana plant	Musa spp.	Fever treatment
Lemon orange	Citrus aurantium	Abdominal upset and a base for other treating malaria
Pawpaw leaves	Carica papaya	Malaria treatment
Cashew fruit, leaf & bark	Amarcardium occidentale	Malaria treatment
Guava tree leaves & bark	Psidium guajava	Treatment of malaria, diarrhoea & menstrual disorders



**Fig. 11** Respondent (a) occupations and (b) farmer constraints.



**Fig. 10** Graphical displaying of weight and height of the populace in the scrutiny commune.

**Table 10.** Monitoring programme for environmental matrices (components).

Environmental components	Indicator parameters	Frequency	Responsibility
Soil	pH, salinity, heavy metals, TPH etc.	Monthly	HSE/Regulator
Air quality, noise and Vibration	SO <sub>2</sub> , NO <sub>2</sub> , CO, VOC, particulate etc.	Weekly	HSE/Regulator
Surface/ground water quality	pH, nutrients content, BOD, suspended solids, hydrocarbon	Monthly	HSE/Regulator
Vegetation	Diversity and abundance of flora and fauna, endangered species	Quarterly	HSE/Regulator
Common health	Contagion diseases within the host communities	Quarterly	Oil & gas medical officer

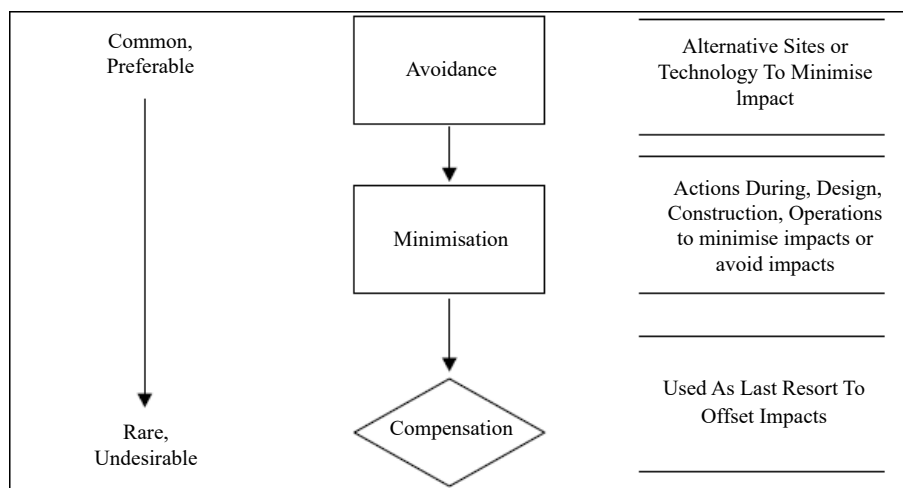
Components	Techniques	Responsibility	Evidence
Solid waste	Excavation waste should be reused or backfilled. The site should have waste receptacles With bulk storage facilities at convenient Points to prevent littering.	Management	Presence of well-maintained eceptacles and central collection point.
Security	Control of secondary businesses Round the clock security Adequate lighting and an alarm System installed at strategic points	Contractor & Management	Number of business around the site and level of crime in the region.
First Aid	Maintaining of well-stocked first aid kit by qualified personnel	Management	Contents of the first aid kit

**Table 11.** Impacts and proposed mitigation measures.

Environmental	Proposed mitigation measures	Monitoring indicator
Air contagion	Control speed and operation of vehicles, prohibit idling of vehicles, spray water on dusty areas. Workers should be provided with dust masks when working in sensitive regions.	Amount of dust produced and level
Noise contagion	Maintain plant equipment Workers to wear ear muffs if working in noisy sections. Noise should be kept within reasonable	Amount of noise
Soil erosion & compaction	Provide soils conservation structures on the areas prone to soil. There should be designated pathways and driveways for movement.	Paved and landscaped areas

**Table 12.** Probability trends and impact consequences on the Delta populace.

Consequence					Increasing probability				
					A	B	C	D	E
Severity	People	Asset damage	Environmental effect	Reputation	Never heard of in the industry	Has occurred in the industry	Incident has occurred in	Happens several times/year	Happens several times/year
0	No injury	None	None	None	Low risk				
1	Slight injury	Slight	Slight	Slight					
2	Minor injury	Minor	Minor	Limited					
3	Major Injury	Localised	Localised	Considerable	High risk				
4	Single fatality	Major	Major	National					
5	Multiple fatalities	Extensive	Massive	International					



**Fig. 12** Outcome of mitigation fundamentals for Delta.

## Oil impact on the Delta populace

curtail undesirable impacts to 'as low as convincingly practicable' (ALARP) states. Likewise, main ethics for the usage of mitigation must be unswerving and to include: preference to avoidance together with preventive measures; choose realistic substitutes for the proposal as well as ascertain the preeminent practicable ecosystem preference; spot outmodified measures to lessen each of the key impacts envisaged; appropriate environment reverberation and cheap; and use reimbursement or curative measures as a final remedy<sup>[2,10]</sup>.

## Conclusions

The analytical results for soil, surface and ground water compared favourably with regulatory limits. The results obtained for aquatic studies indicated abundances in relation to the nutrients and chemical composition of the ecosystems. This generally implies that, the existing tank farm and the associated facilities have minimal negative impacts on the biophysical environment.

The outcomes flaunt that the presence and concentration of Nitrogen -iv- oxide (NO<sub>2</sub>) were less than 0.01 ppm thus within stipulated limit of 0.113 ppm, whereas 100% CO and 30% of CO<sub>2</sub> measured was above regulatory limits. Prolonged exposure to CO concentration of (200 and 800 ppm) for about 45 min to 3 h may result in severe headache, dizziness, nausea and convulsion. All CO values measured above the tolerated limit, ranging from 0.38–2.00 ppm, while total hydrocarbon content (THC), total petroleum hydrocarbon (TPH) and BTEX was below the equipment detection limit of 0.01. Mitigation and enhancement measures were proffered to ensure that the operations of the tank farm continue in an environmental friendly and suitable manner.

## Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Igibah CE, Agashua LO, Ufuah E; data collection: Ilaboya IR, Iyeke SD; analysis and interpretation of results: Igibah CE, Agashua LO, Ilaboya IR; draft manuscript preparation: Igibah CE, Agashua LO, Iyeke SD. All authors reviewed the results and approved the final version of the manuscript.

## Data availability

All data generated or analyzed during this study are included in this published article.

## Conflict of interest

The authors declare that they have no conflict of interest.

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