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Effects of Gas Flaring on Drinking Water Quality in Ibeno and Esit Eket Local Government Areas, Akwa Ibom State, Nigeria

by

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Abstract

This study examined the effect of gas flaring on drinking water quality in Ibeno and Esit Eket local government areas. The physicochemical and bacteriological quality of drinking water in 20 randomly sampled communities in the study area was investigated and water temperature was tested in-situ at the sampling locations. Other physicochemical parameters in the samples collected from drinking water sources at different sampling locations in the study area were analyzed in the laboratory. Physical, chemical and microbial properties were tested to measure water quality from 20 geographically referenced points of drinking water sources were also analyzed. Pearson Product Moment, Analysis of Variance, chi-square and simple percentage statistical tools were adopted. Dry and wet seasons indicated significance difference in the water quality of the study area using the approved standards. Findings suggested that gas flare pollutants accounted for high concentration of water pollutants resulting in water and other environmental pollution, increased in environmental temperature mostly in area with close proximity to the flare sites. Also, wind pressure from Atlantic Ocean aided spatial dispersion of air pollutants which accounts for acid rain in the study area. The followings recommendations were; regular monitoring of drinking water sources quality within the study area; routine medical examination for residents of the study area mostly for elderly, women and children for contaminated water and related sickness and diseases. Petroleum Industry Act should be strictly complied with and offenders should be punished according to the law. The environmental and socio-economic problems occasioned by gas flaring should be mitigated through adopting sustainable approaches.

Key words: Gas flaring, Drinking Water Quality, Physicochemical;

I) Introduction

According to World Bank (2022), Global Gas Flaring Tracker Report shown that top 10 gas flaring countries accounted for 75% of all gas flaring and 50% of global oil production in 2022. The report indicated that 7 of the top 10 gas flaring countries have held this position constantly for the last 10 years: Russia, Iraq, Iran, the United States of America, Venezuela, Algeria and Nigeria. The flaring resulted in burning 144 billion cubic metres of gas in 2021. The report further highlighted that 144 billion cubic metres gas in 2021 was flared around the globe that is, one quarter of current power consumption in African continent.

Since after the discovery of oil in commercial quantities in the Niger Delta Region of Nigeria most of the associated petroleum gas (APG) had been flared, with attendant environmental degradation on the air, water bodies, health of the people, vegetation, soil, ecosystem, socio-economic and buildings. Due to incessant gas flaring operations with more than 123 gas flaring sites ([Tawari and Abowei, 2012](#)), the Niger Delta region has been plagued with socio-economic issues, civil unrest, militancy, health problems, environmental and ecological degradation. These pollutants cause acid rain, which damages ecosystems and agriculture (Sedanur 2010). People living in villages near the flare sites suffer from polluted air and water, and contract asthma and cancer as a result of breathing flare smoke. Gas flaring is one of the environmental degradations that erodes ecosystems and combustion of such gases release tons of greenhouse gases into the atmosphere, while emitted Sulphur (iv) oxide, Nitrogen oxide, Methane, Carbon (ii) and Carbon (iv) oxide, Benzene and toxic substances that are disastrous to humans, animals, plants, and entire physical environment return to the soil as acid rain (Donwa *et al.*, 2015; Adamu and Umar, 2013). Gas flaring activities are partly linked to acid rains and drinking water source pollution (Medilinkz, 2010).

The pollutants resulting from the flaring contribute to acid rain deposition, contamination of water and air quality, visibility impairment (Nduka and Orisakwe, 2010). The pollutants have harmful effects on the ecosystems, humans and animals particularly near flaring sites. Air pollution deteriorates ecological condition, and it is the alteration in any atmospheric constituent from the value that would have existed without human activity. For many decades after the discovery of oil in commercial quantities in Niger Delta Nigeria, most of associated petroleum gas (APG) is flared, with attendant environmental degradation on the air, water bodies, health of the people, ecosystem, socio-economic and buildings. 144 billion cubic metres gas in 2021 was flared around the globe that is, one quarter of current power consumption in African continent (World Bank, 2021). The report indicated that over 400 million tons of CO₂ were injected into the world's atmosphere while Nigeria alone in 8 months of year 2022 flared a total of 4.162 billion cubic gas of which numerous gas flare stations are located in Ibeno and Esit Eket Local Government Areas which has enormous flared gas output that are responsible for enormous environmental consequences in the study area.

Efforts have been made in the past decades to minimize gas flaring such as the construction of a liquefied natural gas plant in Brass in Bayelsa State, a pipeline to evacuate gas to some neighbouring countries such as Ghana and recently, the enactment of the Petroleum Industrial Act. Effort has been garnered over the years by successive individuals, government, non-governmental organizations, World Bodies and different protocols have been signed also and Researchers have highlighted numerous approaches

to address the persistent environmental degradation occasioned by gas flaring in the Niger Delta Region. Scholars in their research works have attempted to address the persistent problems associated with gas flaring. The impacts of gas flaring have degraded the study area with increase impacts. These exploitative activities on crude oil extraction require urgent attention in the study area.

The above studies broaden their investigation on pollutant impacts on the environment of the study area but their recommendations were not considered by the authority concerned which might have resulted in government inaction over the years. In view of this, this research becomes imperative due to the unabated environmental degradation occasioned by gas flaring and venting during the production of petroleum products in Ibeno and Esit Eket Local Government Areas, this is an empirical study with wider parameters is recommendable to enhance the realization of Sustainable Development Goals. This research investigates the effects of gas flaring as the pollutants released into the study area which effects are responsible for drinking water pollution.

Gas flaring alters physicochemical parameters of drinking water quality. According to Dami *et al.* (2012) taste, colour, electrical conductivity, total dissolved solid, salt and alkalinity were altered in Okpai and Beneku area of Delta State when compared to the permissible limits by USPEPA and WHO. Gas flare pollutants causes acid rain which result in acidification of water bodies. Amadi, (2014) affirmed that acidified water may leach these pollutants, metals from watershed and these heavy metals in drinking water sources resulted in the number of serious human health impact.

According to Inam *et al.* (2010), when precipitation turns acidic it attacks the cation exchange capacity (CEC) of the soil. When this capacity is depleted, Aluminium hydroxide and in the presence of high sulphate concentration, Aluminium oxide are transform into basic soluble sulphate. These sulphates eventually percolate into aquifer thereby polluting drinking water sources like borehole water, groundwater and well water. Nwankwo and Ogagarue (2011) and Ezenwaji *et al.* (2013) affirmed that gas flare areas contained higher concentrations of heavy metals when compared to non- flared area ($p < .05$). Etuk *et al.* (2017) and Umoh *et al.* (2016) whose work examined metal pollution index and GIS modelling of some trace metals in water, sediments and based assessment of surface water pollution all in Qua Iboe River. Damil *et al.* (2012) in their assertion on effects of gas flaring and oil spillage on rainwater collected for drinking in Okpai and Beneku Delta State Nigeria pointed out those pollutants from petroleum related activities influence drinking water quality.

Braide *et al.* (2016) and Uywoha and Omenogor (2017), suggested that distortions in water samples was a direct consequences of the flaring activities which are capable of distorting physicochemical parameters of drinking water in affected areas. The polluted water has the tendency to adversely affected the health of the populace as well as biological, economic and socio-cultural elements of the oil bearing communities of Nigeria (Efeke *et al.*, 2015). The activities of gas flaring result in direct consequences of drinking water quality pollution in oil-bearing communities (Ekpenyong and Udofia, 2015); Ugwoha and Omengor 2017.

According to Udofia (2009), the quality of ground water is often threatened by the presence of excess quantities of heavy metals, certain radioactive isotopes, faecal coliforms bacteria, phosphorus, pathogens and viruses as well as organic chemicals such as pesticides and herbicides. The author affirmed that groundwater contamination can be

caused by petroleum related activities, excess fertilizers or pesticides on farm fields, among other pollution loading sources.

The objectives of this study are to:

- (i) examine the impacts of gas flaring on drinking water sources in the study area compared to National Environment Safety and Regulation Enforcement Authority (NESREA) and WHO water quality standards.
- (ii) assess the effect of gas flaring variation in the concentration of the water pollutants in the study area and the control site.

2) Study Area

The study area for this research were Ibena and Esit Eket L.G.A., in Akwa Ibom State, Nigeria and is situated between Latitudes 4° 33'54''N - 4°39' 8''N and Longitudes 8° 4' 21E - 8° 7' 39''E. Ibena Local Government Area lies southward occupying a vast coastal area of over 1,200 sq.km. It is bounded in the South by the Atlantic Ocean. Gas flaring and venting as one of the petroleum exploration processes in the study area makes drinking water sources susceptible to pollution. The geology of Ibena and Esit Eket local government area was formed by the accumulation of sedimentary deposit transported by the Niger and Benue Rivers (Moffat, 1995). The area is underlain by sedimentary formation of late tertiary and Palaeocene ages, deposit of recent alluvium and beach ridge and sands occur along the coast and the estuaries of the Qua Iboe River.

The vegetation of Ibena L.G.A is dominated by Mangrove trees and wetland ecosystem which developed very extensively on the Qua Iboe Rivers and grows best under brackish water conditions (Bakpo, 2014), while in Esit Eket L.G.A, the green foliage of trees and shrubs subsist. Ibena and Esit Eket local government areas experience two seasons; the dry and wet seasons with mean annual temperature lies between 25°C to 31°C, and according to Udoh and Udofia (2014) as cited in Ituen and Koffi (2018) and mean annual rainfall decreases northward from the coast with the figures ranging from 2100mm to about 4050mm. The main economic activities of Ibena and Esit Eket L.G.As are people artisanal fishing and farming (Ekpo and Essien-Ibok, 2013). The crops grown especially in Ibena are those that can thrive on acid soils associated with gas flaring and venting.

This study area is the hosts and operational base of Mobil Producing Nigeria Unlimited (MPNU), a subsidiary of ExxonMobil and the current highest oil and condensate producer in Nigeria with its operational base and an oil terminal, the Qua Iboe terminal (QIT) located at Ibena, besides MPNU, other oil companies like Network Exploration and Production Nigeria Ltd, Frontier Oil Ltd; Shell Petroleum Development Company Ltd; Elf Petroleum Nigeria Ltd and Nigerian Agip Energy, a subsidiary of the Italian ENI E & P operate onshore where gas flaring activities is on the increase. According to National Population Census, (2021), the projected population of Ibena and Esit Eket was approximately 105,100 and 81,000 people respectively. This oil companies account for continuous gas flaring which might have been responsible for numerous effects in the study area. Figure 1 shows the study area.

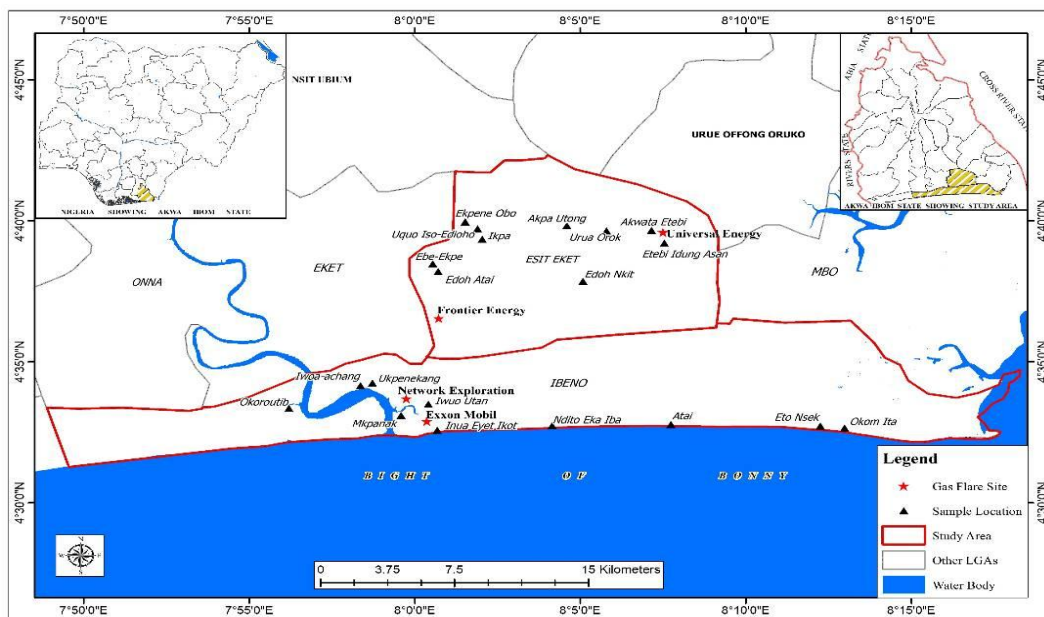


Figure 1: Map of Study Area showing Gas Flare Locations

Source: *Office of the State Surveyor General, Uyo, Akwa Ibom State (2021).*

3) Materials and Methods

This research adopts experimental and survey research design methods. Boreholes, dug well and streams were randomly sampled. using the Table of Random Numbers to select the sample sites to avoid bias. A Control site was selected 55km away from flare station at Ikot Akpa Ekeang, Uruan L.G.A and has no history of gas flare of oil exploration.

Drinking water sources samples were collected using sterilized 1.5 litres polyethenylene bottles also, measure drinking water pollutants (Colour, pH, total Dissolved Solids, Chlorides, Nitrates, Nitrites, Total hydrocarbon Content, Electrical Conductivity, Dissolved Oxygen, Total Hardness, Sulphate, Phosphorus, Sodium, Potassium, Temperature, Copper, Heavy metals (Zinc, Aluminium, Lead, Nickel, Cadmium, Iron, Chromium, Arsenic, Manganese), Microbial Parameters (*Total Viable Bacteria Count, Echerichia coli, Total Coliforms, Streptococcus Faecalis and Clostridium Perfringens.*)

This research relied heavily on both primary and secondary sources of data. The primary source of data was field measurement and laboratory experimentation results obtained. Data from drinking water sources was derived from the results of analytical procedures conducted from each-twenty (20) samples. The data set from the perception of the effects of gas flaring by the residents of the study area was qualitative and was derived through administration of structured questionnaire to selected households. Data for both parameters air and water pollutants are indicated in Table 2. Stratified and Random sampling technique was used to select 20 villages in both Ibeno and Esit Eket local government areas. The Table of Random Number was used to select 10 villages from the population in each local government area for samples collection to avoid bias. Control site was selected at Ikot Akpa Ekeang, Uruan Local Government Area, and a

distance of 55Km where neither industrial nor commercial activities take place. According to Enoh (1997), the population of sampling was sampled using sampling fraction percentage of not less than 10%.

Table 1 indicates sample codes, description of sample sites and the coordinates of each sample locations in both local government areas.

Table 1: Study Area with Coordinates of Sampling

Location in Ibeno		L.G.A				Coordinates of Sampling		Location in Esit Eket L.G.A			
Sample Code	Description of the Location	Northing	Easting		Sample Code	Description of the Location	Northing	Easting			
A1	Inua Eyet Ikot	04 ^o 11"	33'	08 ^o 37"	00'	B1	Edo Nkit	04 ^o 31"	59'	08 ^o 3"	1'
A2	Atai	04 ^o 35"	32'	08 ^o 30"	01'	B2	Edo Atai	04 ^o 27"	38'	08 ^o 6"	1'
A3	Upenekang	04 ^o 34"	34'	07 ^o 50"	58'	B3	Ebe-Ekpe	04 ^o 53"	38'	08 ^o 0' 7"	
A4	Iwoa-Achang	04 ^o 16"	34'	07 ^o 08"	58'	B4	Uquo Iso-Edioho	04 ^o 21"	39'	08 ^o 9"	2'
A5	Okoroutib	04 ^o 20"	33'	07 ^o 25"	56'	B5	Ikpa	04 ^o 27"	39'	08 ^o 2' 9"	
A6	Ndito Eka Iba	04 ^o 32"	33'	08 ^o 16"	00'	B6	Akpa Utong	04 ^o 30"	39'	08 ^o 3' 6"	
A7	Iwuo Utan	04 ^o 30"	33'	08 ^o 25"	00'	B7	Urua Orok	04 ^o 43"	39'	08 ^o 6' 6"	
A8	Eto Nsek	04 ^o 37"	32'	08 ^o 13"	00'	B8	Akwata Etebi	04 ^o 48"	39'	08 ^o 8"	7'
A9	Mkpanak	04 ^o 59"	33'	07 ^o 26"	59'	B9	Etebi Idung Asan	04 ^o 25"	39'	08 ^o 7' 2"	
A10	Okom Ita	04 ^o 23"	32'	08 ^o 05"	00'	B10	Ekpene Obo	04 ^o 52"	39'	08 ^o 0"	1'

Source: *Field Data (2021)*.

4.1 Methods of Data Collection

Physicochemical and bacteriological parameters of water were measured in the laboratory of Akwa Ibom State Ministry of Environment through standard analytical procedures. Water from drinking water sources such as boreholes, dug well and streams were sampled. At respective sampling points, geophysical referencing was made using GPS EXTECH. The anemometer was Multi-functional anemometer which had the capacity to measure temperature in °C, Absolute Pressure in Pascal, and Relative Humidity was employed to record meteorological parameters in the study area.

Laboratory Techniques for Water Analyses: Water samples collected were subjected to standard analytical procedures for physicochemical and bacteriological parameters. The analytical procedures included: Titrimetry analysis, Turbidimetric method, and Atomic Absorption Spectrometry (AAS).

4.2 Method of Data Analysis

Analyses employed the use of descriptive statistics to determine the average, range, mean and standard deviations of investigated samples. The water pollutants are indicated in Table 3. Some 27 of both physicochemical and microbial parameters were examined expressed in their respective S.I units. The results of both in-situ test and laboratory analyses were treated using Statistical Package for Social Scientists (SPSS) version 20.0 to determined average, range, mean and standard deviations of each pollutant. Pearson's

Product moments was used to evaluate correlations between water quality parameters during dry and wet seasons in the study area and were subsequently compared with NESREA and WHO air quality standards and the control site using Analysis of Variance (ANOVA).

5) Results and Discussion

5.1 Impacts of gas flaring on drinking water sources in the Study.

Table compared with water quality standards

Table 2: Comparison of the Physicochemical Parameters in the Study Area with the Standards

Season	physicochemical parameters	Ibeno	Esit Eket	Standards	
				WHO (2021)	NESREA (2007)
Dry season	Temperature	26.46±0.21	26.56±0.27	27-28	Ambient
	Colour	23.60±23.95	7.00±4.47	5	5
	Turbidity	30.38±40.17	1.10±0.96	5	5
	pH	6.29±0.26	6.30±0.22	6.5-8.5	6.5-8.5
	EC	1.88±0.04	1.88±0.13	1000	-
	TDS	250.20±38.78	252.59±71.31	500	500
	DO	119.96±16.64	112.11±12.19	-	6
	Chloride	0.79±0.38	0.75±0.43	0.5-1.5	0.5-1.5
	Nitrate	83.14±12.87	81.07±9.60	50	50
	Total Hardness	2.21±0.81	2.06±0.90	-	150
	Nitrite	11.82±1.93	13.15±1.92	1	-
	Sulphate	0.70±0.47	0.29±0.40	-	100
	Phosphorus	1.48±0.34	1.38±0.31	3.50	-
	THC	0.34±0.38	0.19±0.29	10	10
Sodium (Na)	38.29±48.45	18.22±35.85	-	200	
Potassium(K)	1.72±0.75	1.88±0.54	-	-	
Wet season	Temperature	25.96±0.65	25.76±0.54	27-28	Ambient
	Colour	23.26±10.43	15.07±11.74	5	5
	Turbidity	18.52±10.04	15.26±8.97	5	5
	pH	5.76±0.12	6.05±0.58	200	-
	EC	3.38±4.64	4.81±5.08	1000	-
	TDS	173.20±125.90	123.46±133.33	500	500
	Dissolved Oxygen (DO)	81.79±60.57	62.54±65.47	-	6
	Chloride	4.17±4.57	1.51±0.51	0.5-1.5	0.5-1.5
	Nitrate	63.27±84.23	410.12±808.38	50	50
	Total hardness	3.05±2.17	4.29±4.06	-	150
	Nitrite	17.45±22.22	26.94±36.61	1	-
	Sulphate	2.47±1.01	3.00±1.82	-	100
	Phosphorus	1.02±0.88	0.83±1.08	3.50	-
	THC	1.97±1.11	1.19±1.68	10	10
Sodium (Na)	3.35±1.34	2.63±0.94	-	200	
Potassium (K)	1.98±0.31	2.17±0.39	-	-	

T= temperature, C=Colour, Total H=Total Hardness, EC=Electrical conductivity, TDS=Total dissolve solid, DO=Dissolve Oxygen, Na=Sodium, K=Potassium and THC=Total Hydrocarbon Content.

Source: Field Data (2021).

Result in Table 2 showed that in the dry season, Zn (Zinc), Al (Aluminium), Ni (Nickel), Cd (Cadmium) and As (Arsenic) in Ibeno and Esit Eket were above the recommended WHO and NESREA standards while other heavy metals were below these standards. For wet season, Zn, Al, Pb (Lead), Ni (Nickel), Cd, Cr (Chromium) was above

WHO and NESREA standards while other heavy metals were below both WHO and NESREA standards.

Table 3 shows the comparison of the heavy metals in water quality in the study area with WHO (2021) and FMEnv/ NESREA standards’.

Table 3: Comparison of the Heavy Metals in Water Quality in the Study Area with Standards

Season	Physicochemical parameters	Ibeno	Esit Eket	Standards	
				WHO (2021)	NESREA (2007)
Dry season	Cu	0.440±0.230	0.284±0.139	2.00	1.00
	Zn	0.268±0.465	0.432±0.821	0.10	0.10
	Al	2.690±0.371	3.300±2.632	0.1- 0.2	0.01-0.2
	Pb	0.004±0.002	0.122±0.267	0.01	0.01
	Ni	1.069±1.101	0.510±0.559	0.07	0.020
	Cd	0.337±0.094	0.757±1.294	0.03	0.05
	Fe	0.004±0.001	0.018±0.035	0.30	0.30
	Cr	0.242±0.178	0.156±0.145	0.50	0.50
	Ar	0.007±0.005	0.032±0.019	0.005	0.005
	Mn	0.001±0.001	0.003±0.002	0.400	0.200
Wet season	Cu	0.216±0.185	0.260±0.303	2.00	1.00
	Zn	0.415±0.327	0.716±0.833	0.10	0.10
	Al	2.120±2.038	1.585±2.168	0.1- 0.2	0.01-0.2
	Pb	0.018±0.023	0.013±0.024	0.01	0.01
	Ni	0.800±0.861	1.338±1.834	0.07	0.020
	Cd	0.166±0.249	0.006±0.013	0.03	0.05
	Fe	0.049±0.102	0.034±0.031	0.30	0.30
	Cr	0.964±0.954	0.951±1.052	0.50	0.50
	Ar	0.027±0.028	0.031±0.037	0.005	0.005
	Mn	0.075±0.117	0.101±0.122	0.400	0.200

Source: *Field Data (2021)*.

Result in Table 3 shows that Ar (Argon) and Mn (Manganese) in Esit Eket were significantly higher than those of the control site while between the control site and Ibeno, there was no significant difference in Ar and Mn ($p>.05$). Other heavy metals were not significantly different between the three sites ($p>.05$). For wet season, there was no significant difference in heavy metals between Ibeno, Esit Eket and the control site ($p>.05$).

Result in Table 4 indicated that microbial parameters investigated such as Total Viable Count ($1230.400±1358.698$) during dry season in Ibeno L.G.A was higher than Esit Eket L.G.A ($1037.000±1677.901$), *E.coli during dry season was also higher in Ibeno L.G.A was higher than Esit Eket L.G.A.* however, in wet season parameters such as Total Viable count, Total coliform and *Streptococcus faecal were higher in wet season in Esit Eket L.G.A than Ibeno L.G.A.,* but most of the microbial variables were higher in both L.G.A during wet season than dry season.

Table 4: Comparison of the Bacteriological Parameters in Water with the Standards in the Study Area

Season	Bacteriological parameters	Ibeno	Esit Eket	Standards
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				WHO (2021)	NESREA (2007)
Dry season	Total viable bacteria count	1230.400±1358.698	1037.000±1677.901	0	0
	Total coliform	6.600±2.408	7.200±6.140	0	0
	<i>Escherichia coli</i>	3.000±2.000	2.400±2.608	-	0
	<i>Streptococcus faecal</i>	0.600±0.894	0.600±0.716	0	0
	<i>Clostridium Perfringens</i>	0.059±0.036	0.065±0.053	0	0
Wet Season	Total viable bacteria count	1480.043±2031.463	1580.029±1446.335	0	0
	Total coliform	1649.000±2247.497	1742.800±2382.400	0	0
	<i>Escherichia coli</i>	4.400±3.847	2.800±3.347	-	0
	<i>Streptococcus faecal</i>	2.200±2.950	2.800±3.899	0	0
	<i>Clostridium Perfringens</i>	0.600±0.874	1.400±1.517	0	0

Source: *Field Data (2021)*.

Table 5: Comparison of the Physicochemical Parameters in Water Quality in Ibena, Eket and the Control Site

Season	Physicochemical parameters	Ibena	Esit Eket	Control Site
Dry season	Temperature	26.46±0.21 ^a	26.56±0.27 ^a	26.30±0.28 ^a
	Colour	23.60±23.95 ^a	7.00±4.47 ^a	5.00±0.00 ^a
	Turbidity	30.38±40.17 ^a	1.10±0.96 ^a	0.61±0.12 ^a
	pH	6.29±0.26 ^a	6.30±0.22 ^a	6.59±0.11 ^a
	EC	1.88±0.04 ^a	1.88±0.13 ^a	1.70±0.14 ^a
	TDS	250.20±38.78 ^a	252.59±71.31 ^a	20.91±10.46 ^a
	Dissolved Oxygen	119.96±16.64 ^b	112.11±12.19 ^b	9.32±4.67 ^a
	Chloride	0.79±0.38 ^a	0.75±0.43 ^a	0.92±0.54 ^a
	Nitrate	83.14±12.87 ^b	81.07±9.60 ^b	7.82±0.25 ^a
	Total hardness	2.21±0.81 ^b	2.06±0.90 ^b	0.68±0.59 ^a
	Nitrite	11.82±1.93 ^a	13.15±1.92 ^a	11.36±0.51 ^a
	Sulphate	0.70±0.47 ^a	0.29±0.40 ^a	0.10±0.14 ^a
	Phosphorus	1.48±0.34 ^a	1.38±0.31 ^a	1.27±0.37 ^a
	THC	0.34±0.38 ^a	0.19±0.29 ^a	0.06±0.04 ^a
Sodium (Na)	38.29±48.45 ^a	18.22±35.85 ^a	0.40±0.57 ^a	
Potassium (K)	1.72±0.75 ^a	1.88±0.54 ^a	2.00±0.0 ^a	
Wet Season	Temperature	25.96±0.65 ^a	25.76±0.54 ^a	26.95±0.64 ^a
	Colour	23.26±10.43 ^b	15.07±11.74 ^b	2.89±2.98 ^a
	Turbidity	18.52±10.04 ^b	15.26±8.97 ^b	1.76±1.12 ^a
	pH	5.76±0.12 ^a	6.05±0.58 ^a	6.25±0.63 ^a
	EC	3.38±4.64 ^a	4.81±5.08 ^a	18.65±13.65 ^b
	TDS	173.20±125.90 ^b	123.46±133.33 ^b	15.44±3.99 ^a
	Dissolved Oxygen	81.79±60.57 ^a	62.54±65.47 ^a	10.55±3.11 ^a
	Chloride	4.17±4.57 ^a	1.51±0.51 ^a	3.27±1.94 ^a
	Nitrate	63.27±84.23 ^a	410.12±808.38 ^a	4.00±5.37 ^a
	Total hardness	3.05±2.17 ^a	4.29±4.06 ^a	7.81±5.53 ^a
	Nitrite	17.45±22.22 ^a	26.94±36.61 ^a	0.10±0.14 ^a
	Sulphate	2.47±1.01 ^a	3.00±1.82 ^a	1.02±0.73 ^a
	Phosphorus	1.02±0.88 ^a	0.83±1.08 ^a	0.04±0.04 ^a
	THC	1.97±1.11 ^a	1.19±1.68 ^a	0.00±0.00 ^a
Sodium (Na)	3.35±1.34 ^b	2.63±0.94 ^b	0.40±0.57 ^a	
Potassium (K)	1.98±0.31 ^b	2.17±0.39 ^b	0.46±0.20 ^a	

Similar superscripts letters means not significantly different (p>.05) while different superscripts letters means significantly different (p<.05).

Source: *Field Data (2021)*.

Result in Table 5 indicated that physicochemical parameters investigated such as temperature was not significant in both the Study Area and the Control Point in dry and wet season. The average mean colour of the water in Ibeno L.G.A ranged from 23.60 ± 23.95 - 23.26 ± 10.43 NTU in the dry and the wet season respectively indicating high water contamination. Parameters in the Control Site were lower than the Study Area with exception of few that recorded higher values than the study area such as Chloride during dry season was higher in the control site, Mean Temperature, pH and EC during wet season were all higher in the control site that the study area.

5.2 *Gas Flare Effects on Drinking Water Sources of Ibeno and Esit Eket L.G.A*

This study suggested that the concentrations of the air pollutants varied across the study area of Ibeno and Esit Eket Local Government Areas. Gas flaring is not only having impact on the air parameters but by physicochemical, microbial and seasonal variations when compared with WHO and NESREA standards. The results suggested that drinking water sources from gas flared areas have high levels of pollutants as data in Table 2 indicates, the mean values of physicochemical parameters (colour, Turbidity, Total Dissolved Solids, Nitrates, Nitrites and Chlorides) in the study areas were 23.6 HU, 30.38 NTU, 83.4mg/l., 13.15mg/l, 0.74 to 4.17mg/l. respectively, seasonal change might have been responsible in variation in the concentration of pollutants as wet season tends to have more concentration of pollutants in the drinking water source than dry season in the study area also, since most of parameters investigated such as Nitrates and Nitrites and chlorides are products of gas flaring activities from the multinational oil companies causes acidification of water bodies and these pollutants eventually percolate into aquifer thereby polluting drinking water source like borehole water, groundwater and well water, the distortions in water samples might be a direct consequences of the flaring activities which are capable of distorting physicochemical parameters of drinking water in affected areas. The polluted water has the tendency of adversely affected the health of the populace as well as biological economic and socio-cultural element of the oil bearing communities of Nigeria and the result ($p < .05$) of this work is in tandem with the research by Nwakwo and Ogagarue (2011); Dami, *et al.*, (2012), Emumejaye (2012); Hagra, (2013); Amadi, (2014), and WHO (2015).

While the result in Table 3 showed that the mean values of heavy metal pollution in the drinking water sources in the study area were higher than the recommended thresholds such as Zn ranged from 0.208 to 0.432 mg/l, Al, ranged from 2.690 to 3.300 mg/l, Ni 1.07 mg/l, Cd ranged 0.34 to 0.76 mg/l and others parameters investigated were higher than both WHO and NESREA standards. These heavy metals pollution might have resulted from gas flaring in the study area and since precipitation of the pollutant may turn acidic, it attacks the cation exchange capacity (CEC) of the soil and when the capacity is depleted, Aluminium hydroxide ($Al(OH)_3$) in the present of high sulphate concentration, transform Aluminium oxide into basic soluble sulphate which pollute the drinking water source. Also, seasonal change might have been responsible for percolation of these flared gas pollutants as this result corroborates with the work performed by Umoh *et al.* (2016) and Etuk *et al.* (2017) on metal pollution index and GIS modeling of some trace metals in water, sediments and based assessment of surface water pollution all in Qua Iboe River.

Table 4 shows the comparison of the bacteriological parameters in water with standards in the study area. The presence of coliform count showed that water with vulnerable to contamination by more harmful microorganisms. The presence of *E.coli* in water samples indicated faecal contamination such as bacteria, viruses and parasite. The result of microbial parameters investigated in the study area was all found to be higher than the standards. The groundwater, borehole and well water contamination might have been caused by petroleum related activities such as gas flaring, oil spillage, excess fertilizers or pesticides on farm fields, of excess quantities of heavy metals, certain radioactive isotopes, faecal coliforms bacteria, phosphorus, pathogens and viruses as well as organic chemicals such as pesticides and herbicides among other pollution loading sources. The result of the present study as shown in Table 6 indicated mean of total bacteria count of 1230.400 ± 1358.698 , faecal coliform bacteria counts of 6.600 ± 2.408 and *Escherichia coli* 3.000 ± 2.000 . The high microbial parameters probably may have seen the consequence of gas flaring activities and this research corroborates with the work of Dada and Ekanem (2020), Braide *et al.*, (2016), (Ekpenyong and Udofia 2015); Ugwoba and Omengor (2017), Udofia (2009), James, Essien and Etim (2019).

Results also showed that total coliform and Faecal *coliform* were significant above recommended limits for Total and Faecal coliform bacterial in drinking water and were therefore not suitable for human consumption (drinking) without proper adequate treatments and might cause diarrhea, dysentery, typhoid fever, cholera and other water borne related diseases.

5.3 Assessment of gas flaring effect on the concentration of drinking water pollutants in the Control Site

Table 6: Comparison of the Heavy Metals in Water Quality in Ibeno, Eket and the Control Site

Season	Physicochemical parameters	Ibeno	Esit Eket	Control Site
Dry season	Cu	0.440±0.230 ^a	0.284±0.139 ^a	0.215±0.148 ^a
	Zn	0.268±0.465 ^a	0.432±0.821 ^a	0.035±0.021 ^a
	Al	2.690±0.371 ^a	3.300±2.632 ^a	0.180±0.170 ^a
	Pb	0.004±0.002 ^a	0.122±0.267 ^a	0.001±0.001 ^a
	Ni	1.069±1.101 ^a	0.510±0.559 ^a	0.000±0.000 ^a
	Cd	0.337±0.094 ^a	0.757±1.294 ^a	0.000±0.000 ^a
	Fe	0.004±0.001 ^a	0.018±0.035 ^a	0.000±0.000 ^a
	Cr	0.242±0.178 ^a	0.156±0.145 ^a	0.040±0.000 ^a
	Ar	0.007±0.005 ^a	0.032±0.019 ^b	0.006±0.006 ^a
	Mn	0.001±0.001 ^a	0.003±0.002 ^b	0.000±0.000 ^a
Wet season	Cu	0.216±0.185 ^a	0.260±0.303 ^a	0.030±0.014 ^a
	Zn	0.415±0.327 ^a	0.716±0.833 ^a	0.175±0.247 ^a
	Al	2.120±2.038 ^a	1.585±2.168 ^a	0.001±0.001 ^a
	P	0.018±0.023 ^a	0.013±0.024 ^a	0.000±0.000 ^a
	B			
	Ni	0.800±0.861 ^a	1.338±1.834 ^a	0.000±0.000 ^a
	Cd	0.166±0.249 ^a	0.006±0.013 ^a	0.000±0.000 ^a
	Fe	0.049±0.102 ^a	0.034±0.031 ^a	0.040±0.000 ^a
	Cr	0.964±0.954 ^a	0.951±1.052 ^a	0.001±0.001 ^a
	Ar	0.027±0.028 ^a	0.031±0.037 ^a	0.000±0.000 ^a
Mn	0.075±0.117 ^a	0.101±0.122 ^a	0.001±0.001 ^a	

Similar superscripts letters means no significantly different ($p > .05$) while different superscripts letters means significantly different ($p < .05$).

Source: Field Data (2021).

Table 7: Comparison of the bacteriological parameters in water quality in Ibeno, Eket and the control site.

Season	Bacteriological parameters	Ibeno	Esit Eket	Control Site
Dry Season	Total viable bacteria count	1230.400±1358.698 ^a	1037.000±1677.901 ^a	0.011±0.013 ^a
	Total coliform	6.600±2.408 ^a	7.200±6.140 ^a	70.000±80.610 ^a
	Escherichia coli	3.000±2.000 ^a	2.400±2.608 ^a	3.000±4.243 ^a
	Streptococcus Faecal	0.600±0.894 ^a	0.600±0.894 ^a	0.500±0.707 ^a
	Clostridium Perfringens	0.059±0.036 ^a	0.065±0.053 ^a	0.000±0.000 ^a
Wet Season	Total viable bacteria count	1480.043±2031.463 ^a	1580.029±1446.335 ^a	108.500±26.163 ^a
	Total coliform	1649.000±2247.497 ^a	1742.800±2382.400 ^a	5.000±1.414 ^a
	Escherichia coli	4.400±3.847 ^a	2.800±3.347 ^a	1.000±0.000 ^a
	Streptococcus Faecal	2.200±2.950 ^a	2.800±3.899 ^a	0.000±0.000 ^a
	Clostridium Perfringens	0.600±0.894 ^a	1.400±1.517 ^a	1.000±1.414 ^a

Source: Field Data (2021).

Correlation in both dry and wet seasons are showed in Appendix 1 and Appendix II which indicated that there was a significant impacts of gas flaring on drinking water sources in Ibeno and Esit Eket local government areas than the control site. The result of this work suggested a variation in the concentration of the gas flare pollutants in the polluted area and the non-polluted area located in Ikot Akpa Ekang Uruan L.G.A. Drinking water pollutants assessed in this study indicated that physicochemical parameters such as colour, Turbidity, Total Dissolved Solids, Nitrates, Nitrites and Chlorides) in the study areas were 23.6 HU, 30.38 NTU, 83.4mg/l., 13.15mg/l, 0.74 to 4.17mg/l respectively, Zn, Al, Ni, Cd for bacteriological pollutants, Total Viable Bacteria, Total Coliform and others parameters investigated were higher than both WHO and NESREA standards were of higher concentration of pollutants in the study area as discussed in Table 2, Table 3 and Table 4. Variation in the pollutant of heavy metals and bacteriological parameters between the study area and control site indicate that result in Table 5, Table 6 and Table 7 for both dry and wet seasons, there were no significant difference physicochemical, heavy metals and bacteriological parameters in the three locations ($p > .05$) though bacteriological parameters were higher in Ibeno and Esit Eket compared with control site. Pollutants in the control site were low, perhaps due to low or no gas flaring activities thereby making drinking water sources more contaminated than the study area. This probably implies that water pollutants decrease as the distance increases. This research corroborates the works of Seiyaboh and Izah, (2019). Uzoekwe and Ajayi, (2018); Seiyaboh and Izah (2017) and Aigberua *et al.*, 2016a, b, 2017.

7) Conclusion and Recommendations

Physicochemical and microbial load of drinking water sources of the study area when compared to control site and NESREA /WHO permissible standards were higher. Gas

flaring in the study area accounted for acid rain in the study area among other environmental degradation tendency. The finding indicated the possible end to flaring activities in the study area if the Petroleum Industrial Act 2022 and SDG 2030 are fully implemented.

The study has shown that gas flaring has impacted negatively in the study area for decades. In view of the established result the following recommendations were made:

- i) Regular monitoring of heavy metals in borehole water pollutants within the study area in order to prevent potential health and water contamination in the study area is highly recommendable.
- ii) The Petroleum Industry Act recently enacted for the establishment of legal, fiscal and regulatory framework for the Petroleum industry in Nigeria and for other related matters should be strictly complied according to the law.
- iii) The environmental and socio-economic problems occasioned by the emission of air pollutants and other emissions from flare and vent systems should be mitigated by adopting sustainable approaches.

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APPENDIX 1

Correlation among physicochemical parameters during wet season

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Temperature	1															
Colour	-.708*	1														
Turbidity	-.660*	.379	1													
pH	-.258	.067	.083	1												
E.C	.102	-.158	-	.708*	1											
			.237	*												
TDS	-.735**	.954**	.443	.194	-.039	1										
DO	-.727**	.938**	.435	.223	-.031	.997**	1									
Chloride	.295	-.280	.022	.016	.035	-.448	-.477	1								
Nitrates	-.312	.429	.150	.386	.026	.493	.519	-.222	1							
Total Hardness	-.171	.182	-	.861*	.741**	.233	.249	-.021	.252	1						
Nitrites	-.759**	.652*	.527	.440	.135	.779**	.796**	-.313	.440	.336	1					
Sulphate	-.818**	.707*	.496	.426	-.021	.752**	.771**	-.200	.558	.352	.919*	1				
Phosphorus	-.751**	.910**	.377	.307	.036	.964**	.965**	-.445	.396	.372	.845*	.802*	1			
THC	-.567	.613*	.699	.258	.027	.654*	.652*	.147	.303	.071	.802*	.724*	.656*	1		
Sodium (Na)	-.701*	.894**	.522	-.062	-.338	.890**	.877**	-.416	.246	-.063	.620*	.595*	.865**	.604*	1	
Potassium	-.312	.206	.358	-.442	-.710**	.071	.054	.096	-.008	-.563	.098	.219	.069	.261	.405	1

**correlation is significant at 5% (p<.05), **correlation is significant at 1% (p<.01).*

Source: Field Data (2021).

APPENDIX II

	1	2	3	4	5	6	7	8	9	10
Cu	1									
Zn	.420	1								
Al	.403	.840**	1							
Pb	.304	.862**	.880**	1						
Ni	.888**	.575	.440	.321	1					
Cd	.418	.883**	.929**	.987**	.434	1				
Fe	.339	.868**	.904**	.998**	.355	.994**	1			
Cr	.241	.564	.666*	.437	.227	.497	.469	1		
Ar	-.204	.256	.410	.400	-.113	.381	.411	.080	1	
Mn	.315	.779**	.873**	.850**	.420	.869**	.864**	.323	.638*	1

Correlation among heavy metals during dry season **correlation is significant at 5% (p<.05), **correlation is significant at 1% (p<.01).*

Source: Field Data (2021)