Environmental Impact of Flare Gas on the Physicochemical Parameters of Surface Water Around LNG Gbarain, Niger Delta Region, Nigeria

Amolo Igwe Richard[1] and Kokobaikeme Dornubari Lawrence[2]
[1]Department of Science Laboratory Technology, School of Applied Sciences, Bayelsa State Polytechnic Aleibiri. P.M.B 168, Ekeremor, Bayelsa State, Nigeria.
[2]Department of Electrical/Electronic Engineering Technology, School of Engineering Technology, Bayelsa State Polytechnic Aleibiri, P.M.B 168, Ekeremor, Bayelsa State, Nigeria.

DOI: 10.56201/rjpst.v6.no3.2023.pg119.130

ABSTRACT

The impact of flared gases by LNG on Gbarain environment in Bayelsa State, Niger Delta Region, Nigeria was holistically determined to examine the level of degradation. Ten priority constituents of interest parameters namely; temperature, pH, electrical conductivity, TDS, TSS, COD, BOD, Turbidity, Chloride and Dissolved Oxygen were investigated to evaluate their water quality index at a distance of about 100-500meters in and out from the flare stack. Surface water samples were collected from three stations within the study area and analyzed for their physicochemical properties. The obtained results revealed that the mean values for water quality index physicochemical properties for LNG Gbarain were substantially lower than those of Ebocha-Egbema except for Temperature values that was higher than WHO STD as obtained indicating that gas flaring exerts adverse ecological effect on the water, air and soil ecosystem within LNG Gbarain.

KEYWORDS*: Gbarain, Water quality, Environmental impact, Flare gas, Physicochemical parameters*

INTRODUCTION

Flare gas is a combustion of gas that is seen lightning on a flare stack in an open air from oil and gas exploration. This combustion of gas flaring by which the natural gas associated with petroleum extraction is burned off in the atmosphere rather than being removed by alternative means such as subterranean re-injection or confinement to storage tanks for eventual sale, is particularly worrisome (Obanijesu et al., 2009). This flare gas released numerous toxins and hot heat that negatively impacts on humans' health and by extension other living organisms as well as their surroundings. Nigeria has an estimated gas reserve of $803.4 trillion cubic feet. The quest for speedy industrialization to satisfy humans' endless growing needs is one of the many consequences responsible for open gas flaring within the scope of their operation not until reports of global warming became a source of worry to humankind from one geographical location to another (Raimi and Sabinus, 2017). Moreso, igneous radiation from Sunlight get hot and hotter by the day signaling deforestation due to periodic open gas flare impact in the region that is naturally endowed with mangrove swamp forest and heavy rainfalls depicting one of the coolest temperature. Contrarily this connotes large socioeconomically wasteful flare of natural gas that could have been used for wealth generation rather than damaging the flora, fauna, human health and the livelihood of their Host Communities. Findings have shown that gas flaring in Nigeria contributes toxic pollutants such as carbon dioxide, chlorofluorocarbons, methane, nitrous oxide, polycyclic aromatic hydrocarbons, soot and sulfur dioxide into the atmosphere, which could lead to environmental problems like acid rain, as well as the generation of greenhouse gases that contribute to global climate change than the combined contribution from Sub-Saharan African Countries (Osuji and Avwiri, 2005).

flared gas: A global trend

Gas flaring is a wasteful practice that burns valuable energy source that could be reused to enhance economic development, provide increased energy security, and potentially replace dirtier energy sources. The 144 bcm of natural gas flared in 2021 could have potentially generated some 1,800 Terawatt hours (TWh) of energy, almost two-thirds of the European Union's net domestic electricity generation. Tackling gas flaring is also critical, given its role in global methane emissions. Methane is a more potent greenhouse gas than CO_2 but has a shorter atmospheric lifetime. Therefore, reducing methane emissions is one of the fastest, most effective ways to slow the rate of climate change. Gas flaring is a direct source of methane and efforts to eliminate flaring also eliminate the associated methane emissions. However, flare elimination efforts also support methane reductions from other sources, such as venting and fugitive releases. Without an outlet to export or utilize the gas, any methane conserved from these sources will ultimately be sent to flare and while there may be an overall emissions reduction, methane is still released, and this valuable energy source is still wasted. The GHGs emitted during gas flare promote sea level rise and ozone layer depletion (Climate Change). Gas flaring is a common phenomenal among International Oil Companies (IOCs) during exploration activities in the Niger Delta Region of Nigeria, thus posing hazardous health problems to vast populations and the surrounding. Preceding oil exploration activities, a considerable amount of gas is found as a by-product and usually disposed off by burning, using a process known as flare stack. It occurs as a result of technical regulator or economic constraints (Ekpoh & Obia, 2010; World Bank, 2016). It is a process by which air pollution occurs. Crude oil was first discovered in large commercial quantities at Oloibiri Oilfield on Sunday 15 January 1956 by Shell Darcy signaling the commencement of heavy discharge of gaseous fuel into the atmosphere as well as flare gas (Allen, 2018). It is an established fact that gas flaring activities in Nigeria emits noxious chemical substances, which negatively affect Communities and Public health (Allison et al., 2018). Flared Gas connotes GHGs and toxic compounds triggering climate change resulting in e.g. erosions and floods thereby affecting agriculture, which leads to food insecurity hence in furtherance of public and community health. Outbreak of diseases and acid rain are also bedeviling features of constant gas flare (Adewale & Mustapha, 2015; Idris, 2007). Recalling a study carried out by Maduka and Tobin-West (2017) in the Niger Delta Region of Nigeria, indicate a significant relationship between flare gas and hypertension. Findings have equally shown that numerous pollutants from gas flare cause respiratory problems such as, insomnia, headache, cancer, bronchitis and depression, blood disorders, damage to the skin, asthma and anaemia (Adienbo & Nwafor, 2010; Ajugwo, 2013; Gobo et al., 2009; Maduka & Tobin-West, 2017b). There are detailed reviews on these phenomena (Obi, Akuirene, et al., 2021; Obi et al., 2021). This investigation was painstakingly conducted to measure the impact of gas flaring on the health of host communities within the Niger Delta region of Nigeria with a view to understand community knowledge and mitigation efforts by IOCs and Government at all levels. Equally extant regulatory bodies such as Petroleum Industry Act 2021, the Nigerian Upstream Petroleum Regulatory Commission and the Nigerian Midstream and Downstream Petroleum Regulatory Authority should as a matter of urgency swing into action. Data from the Nigerian Bureau of Statistics showed that 63% of persons living within Nigeria (133 million people) are multidimensionally poor. The National MPI is 0.257, indicating that poor people in Nigeria experience just over one-quarter of all possible deprivations. 65% of the poor (86 million people) live in the North, while 35% (nearly 47 million) live in the South. Poverty levels across States vary significantly, with the incidence of multidimensional poverty ranging from a low of 27% in Ondo to a high of 91% in Sokoto. Over half of Nigeria population are multidimensionally poor and cook with dung, wood or charcoal, rather than cleaner energy source like gas. High deprivations are also apparent nationally in sanitation, time to healthcare, food insecurity, and housing. Meanwhile, Nigeria has, in the first 152 days of 2021 alone flared about 85.4 billion standard cubic feet of natural gas, translating to monetary loss of about $510 million (N209 billion), a figure, averaging the three per cent funding to host communities in the 2021 Petroleum Industry Act. Children in the host communities are adversely impacted by gas flaring, with many suffering from respiratory diseases, fever, and diarrhoea. They also experience stunted growth, wasting, and underweight issues. Toxic pollutants similarly damage the environment, killing off plants and animals, despoiling the soil and water, while impoverishing communities. In 2022 Nigeria loss about N150 billion to flaring between January and April 2023 and other substantial losses spanning over 10 years period. NOSDRA'S 2022 estimate Nigerian Gas Flare Tracker showed that Nigeria lost tonnes of gas, including useful natural gas valued at $790 million, to gas flaring. This equated to enough potential electricity that could provide for over 511 million persons. Statistics made available from the National Oil Spill Detection and Response Agency (NOSDRA) indicates that gas flaring increased by 10 percent to 138.7 million metric standard cubic feet (scf) for the period of January to June of 2023 from 126.1 million scf in the corresponding period of 2022. In 2021, the top 10 flaring countries (on an absolute volume basis) accounted for 75 percent of all gas flaring and 50 percent of global oil production. Seven of the top 10 flaring countries have held this position consistently for the last 10 years: Russia, Iraq, Iran, the United States, Venezuela, Algeria, and Nigeria. The remaining three; Mexico, Libya, and China, have shown significant flaring increases in recent years. When we consider flaring intensity, fragile, conflict-affected, and insecure countries, such as Venezuela, Syria, and Yemen are among the worst performers, flaring more gas per barrel of oil produced than any other country. The intensity perspective also suggests there are opportunities to improve flaring performance in oil-producing countries such as Algeria, the Republic of the Congo, Gabon, and Turkmenistan. Considering again the top 10 flaring countries on a volume basis, Russia, Iraq, the United States, Nigeria, and Mexico have all committed to the World Bank's Zero Routine Flaring by 2030 (ZRF) Initiative, which commits governments and companies to (a) not routinely flare gas in any new oil field development, and (b) to end routine flaring in existing oil fields as soon as possible and no later than 2030 (2022 Global Gas Flaring Tracker Report). However, over the past decade, only the United States has successfully improved the flaring intensity of its oil production. Although one of the Commendable gesture of Government presently was the National Gas Policy and the Nigerian Gas Flare Commercialization Programme (the NGFCP) targeted at deepening and accelerating the growth of the gas sector and ultimately wowing investors in the commercialization of flare gas in Nigeria. Without further delay, gas flaring should be stopped altogether due to its prevalence of disease including delineation of opinion from perception.

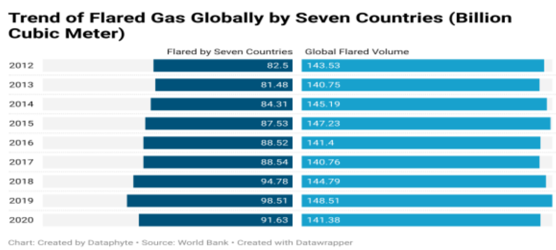


Figure 1 Trend of flared gas globally by seven countries

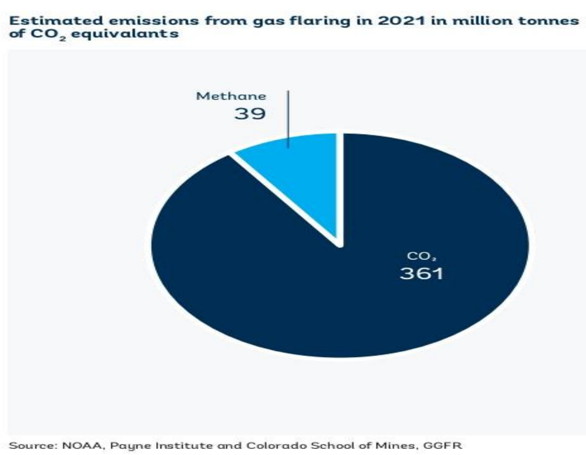


Figure 2: Estimated emissions from gas flaring in 2021

Figure 3: Gas flaring Site Onshore

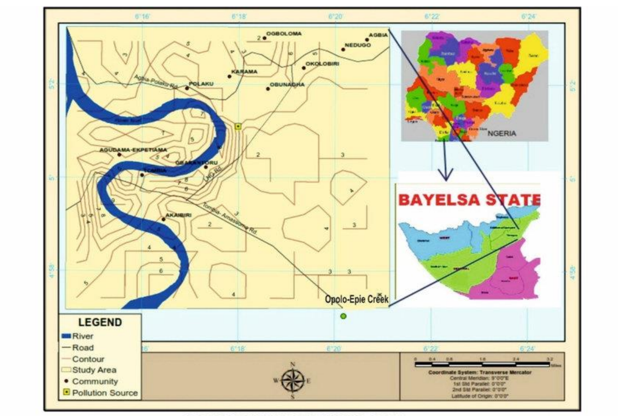
Figure 4: Gas flaring Site Offshores

Materials and Methods

Study Area

Gbarain/Ekpetiama Clan is a town in Yenagoa Local Government Area that lies on the geographical coordinates of Latitude 4° 48' 0'' N, and Longitude 5° 54' 0'' E, of the (Central Niger Delta) area of Bayelsa State, Nigeria. The study area is a wetland have two major seasons (dry and wet seasons). It has an elevation of 4 meters above sea level. It is located around the Taylor creek. Gbarain settlement have several communities which includes: Ikpetiama, Agbia, Koroama, Polaku, Obunagha, Nedugo and Ogboloma. The LNG flow station belongs to Shell Petroleum

Development Company of Nigeria (SPDC) is one of the oil fields feeding the Nigeria Liquefied Natural Gas (NLNG), Bonny Island, River State, Nigeria. They specialized in fishing and its alluvial soil that support large scalefarming as their main income earners although some of them are employee of the oil firm. Gbarain can be located through the Tombia Amasoma road and enroot Okolobiri Nedugo road.



LOCATION MAP OF STUDY AREA

Figure 5: Study Area

Sample Collection

In order to analyze the physicochemical parameters, water samples were collected using pre-rinsed 1litre plastic containers. Pre-rinsed water samples for heavy metal analyses was collected with nitric acid of 1litre containers as well as treated with 2ml nitric acid (assaying 100%, Trace Metal Grade, Fisher Scientific) prior to storage. These were done to stabilize the metals oxidation conditions. Surface water samples was collected in two groups of 250ml glass-stoppered-reagent bottles per sampling location for Biological Oxygen Demand (BOD), and Dissolved Oxygen (DO) determinations. The BOD samples have been properly filled without air trapping as well as the bottles covered in black polythene bags. This was done to eliminate light, which is present in the samples and capable of producing DO by autotrophes (algae). The BOD samples were incubated for five days, which was added to 2ml of each sample. In order to retard additional biological activities, Winkler solutions I and II use different dropping pipettes to each sample. The bottles was vigorously stirred to precipitate the floc, which lay at the bottom of the bottles. Further, Winkler solution I is a solution of manganese sulphate, while solution II is sodium or potassium iodide, sodium or potassium hydroxide, sodium azide (sodium nitride) and sodium hydroxide. The DO samples was collected in clear bottles and also tightly stoppered. With samples of dissolved oxygen preserved on the spot with Winkler I and II solutions similar to that of the BOD samples. All samples had been clearly identified and controlled at 4°C for easy identification. Determination was carried out on site to know the concentrations of unstable as well as sensitive water quality characteristics including total dissolved solids (TDS), total suspended solid (TSS), electrical conductivity (EC), pH, dissolved oxygen (DO), bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), chloride (Cl) and Turbidity (NTU). Thus, the fundamental approaches for investigating the surface water composition are described in figure 2 below.

Sample Preservation and Analysis

The standard methods outlined in American Public Health Association (APHA) Edori et al. (2021); Wesley et al. (2017): Morufu and Clinton have been strictly followed by water sampling, conservation, transportation as well as analysis. Insitu measurements of the following parameters viz: pH, electrical conductivity (EC), dissolved oxygen (DO), total suspended solid (TSS), turbidity and total dissolved solids (TDS) were carried out in the field using HANNA water quality checker (APHA, 2012). Dissolved oxygen (DO), biochemical oxygen demand and chemical oxygen demand was analyzed using the modified Winkler-azide method whereas, chloride was analyzed using DPD colorimeter.

Quality Assurance and Quality Control (QA/QC)

Additionally, employing high purity analytical reagents as well as solvents, all analytical procedures were closely monitored with quality assurance as well as control techniques. Calibration standards were applied to the instruments. Procedure blanks, triplicate analysis as well as the analysis of certified reference materials (CRM) was performed through the analytical technique validation. For every organic pollutant from the groundwater samples, the limit of detection (LoD), repeatability, reproducibility, precision, as well as accuracy was established.

Results and Discussion

The obtained results for the physicochemical parameters analysis carried out on different water samples as shown in tables 1 below. Indicate that most parameters of interest for physico-chemical parameters gotten from the three stations was within the World Health Organization (WHO) permissible limit for potable drinking water except for Turbidity with the highest value of 16.2 NTU in sampling station 3 at LNG Gbarain flow station. The pH level varied with distance away from the gas flare stack. The results evidently showed that pH level increases per distance away from the flare stack. This is because the area nearest to the flaring site was supposed to have high emission of NOX and H2S that reacted with water molecules to produce acidic rain. The acidic rain could be directly involved for the abrupt increase in acidic concentration of the swamp water nearest to the flare stack when compared to swamp water at a distance of 3000meter used as control. Increase in acidity concentration of surface water affects water quality, nutritional value and anthropogenic usage (Nwaogu and Onyeze, 2020). The Temperature gradient at the various sampling station ranged from 30.7 to 30.9°C as indicated in Tables 1 which depicting higher values than WHO STD. Temperatures range was far more above the regulatory limits for domestic water acceptability. The high observed figures is influence by open gas flare and could as well affect the solubility and toxicity of metals in the water, that can result into corrosion of pipes and also affects cells of the mucous membranes. The high temperature represent increased heat emanating from the flares. The analytical results for Electrical Conductivity (EC) in water sample was within the

Federal Ministry of Environment (FMENV) approved limit across the three stations. But was in conformity with (Edori et al. 2021) the high electrical conductivity values observed may be attributed to evaporation resulting in the concentration of constituents in the water. Federal Ministry of Environment (FMENV) permissible limits for electric conductivity in water for domestic and industrial usage is 500µS/cm. Electrical conductivity depict ionic strength, which exert influence by dissolved ionic substances. Which act as a major contributing factor in determining quality water taste and acceptability.

Table 1: Physico-chemical analysis of water sample

Parameters	SA1	SA2	SA3	WHO Std	Mean	STD
Temp (°C)	30.9	30.8	30.7	25-27	30.8	0.1
pH	6.3	6.1	5.8	6.5-8.5	6.1	0.25
EC (µS/cm)	41.48	29.28	43.92	500	38.23	7.84
TDS (mg/L)	20.74	14.64	4.96	2,000	13.45	7.96
TSS (mg/L)	12.891	9.472	13.528	30.0	11.96	2.18
COD (mg/L)	10.734	12.356	9.294	40.0	10.79	1.71
BOD (mg/L)	7.14	8.632	6.194	10	7.32	16.26
Turbidity (NTU)	15.7	12.3	16.3	15	14.77	2.16
Chloride (mg/L)	13	15	14	200	10.89	3.94
DO (mg/L)	3.25	4.10	4.34	7.5	3.89	0.57

Turbidity values obtained for LNG Gbarain sampling station 3 were the highest value. Although station 1 is equally higher than WHO Standard of 15 NTU followed by station 2 having a significantly higher value of 12.3. However, values of the three sampling station measured during the was grossly higher when compared with the WHO standard limit for potable drinking water. This high values might be may due to open gas flare, effluent discharge of untreated industrial wastes activities of the oil Companies into various water bodies. According to Okeke and Adinna (2013), gas flaring activities create nuisance to the surrounding solid waste material and soil particles transported by runoff from urban activities into the river may increase the turbidity of the river. Turbidity affects fish and aquatic life by interfering with sunlight penetration. Park (2009) is of the view that drinking water should be free from turbidity on aesthetic grounds. The swamp water sample gotten from Gbarain showed higher values for Chloride when compared to that of Ebocha-Egbema from Effects of Gas Flaring on the Physicochemical and Microbiological Quality of Water Sources. This result agrees with the report of Edori et al (2021). Physical and chemical characteristics of water from Okamini Stream, Obio/Akpor, Rivers State, Niger Delta, Nigeria. This compounds is essential for normal metabolism in plants and animals, as it serve as nutrients. When the plants eventually die, their debris undergoes aerobic biodegradation leading to anoxic conditions in water, that had detrimental effects on aquatic organisms that require dissolved oxygen. Depletion of stratospheric ozone layer occurs which leads to increase in the solar UV-B radiation (280-315mm) at the surface of the earth. The harmful effects of UV radiation include cataracts in the eyes, permanent or temporary blindness, skin cancers, DNA damages, lung diseases, suppression of immune responses to skin cancer, infectious diseases (Anwar et al., 2015).

CONCLUSION

Despite government moratorium on eliminating routine flaring of gas which took effect in 2008, the abysmal obtained results revealed holistically sustained upward trend of flared gas cutting across various oil and gas companies within the scope of the Niger Delta Region, precluding areas of close proximity to the rural populists. Not minding the growing international focus on methane emissions to global warming and knowing the important role played by multinational oil and gas industry in achieving climate goals, we are canvassing for governments and IOCs to up their games and pay more attention to ending this wasteful industry practice in order to reach Zero Routine Flaring by World Bank projection in 2030. Technologically and innovatively speaking the skills required to end open gas flare is readily available to nip this ugly menace in the board, though what is lacking is the political will and leadership in developing appropriate markets and infrastructures to recover and utilize the gas. Thousands of Nigerians obviously live within areas estimated to have high ambient temperatures significantly above the normal approved tropical heat, but however prevailing economic reality kept them back due to paucity of funds despite the hazardous health effects. The negative impact of environmental degradation includes food insecurity, increasing risk of disease, acid rain, soots, rain corrosion of buildings and the rising costs of extreme weather damage resulting from toxins such as benzene in the air. Ultimately decarbonization of natural gas can help reduce the carbon intensity of the global energy mix, with the proximities to replace coal and liquid fuels quickly, allowing time for the development and implementation of low and no carbon sources such as renewables and green hydrogen.

REFERENCES

Allen, F. (2018). Politics of State/Oil Multinational Alliance and Security Response. In The Political Ecology of Oil and Gas Activities in the Nigerian Aquatic Ecosystem (pp. 295-305). Elsevier.

Allison, C., Oriabure, G., Ndimele, P., & Shittu, J. (2018). Dealing with oil spill scenarios in the Niger Delta: Lessons from the past. In The political ecology of oil and gas activities in the Nigerian aquatic ecosystem (pp. 351-368). Elsevier.

Adewale, O. O., & Mustapha, U. (2015). The Impact of Gas Flaring in Nigeria. International Journal of Science, Technology and Society, 3(1), 40-50. https://doi.org/https://doi.org/10.11648/j.ijsts.20150302.12.

Adienbo, O., & Nwafor, A. (2010). Effect of Prolong Exposure to Gas Flaring on some Haematological Parameters of Humans in the Niger Delta Region of Nigeria. Journal of Applied Sciences and Environmental Management, 14(1).

Ajugwo, A. (2013). Negative effects of gas flaring: The Nigerian experience. Journal of Environment Pollution and Human Health, 1(1), 6-8. https://doi.org/http://dx.doi.org/10.12691/jephh-1-1-2.

American Public Health Association (APHA) (2012). Standard methods for the examination of water and wastewater, 22nd edn. American Public Health Association, Washington, DC.

Anwar, F., Chaudhry, F., Nazeer, S., Zaman, N., & Azam, S. (2015). Causes of ozone layer depletion and its effects on human. Atmospheric and Climate Sciences, 6(1), 129-134.

DPR (2020) FUNCTIONS – Department of Petroleum Resources. Functions of DPR. https://www.dpr.gov.ng/functions-of-dpr/.

DPR.GOV.NG (2021) ACTS AND REGULATIONS—Department of Petroleum Resources. The Department of Petroleum Resources. https://www.dpr.gov.ng/acts-and-regulations/

Edori, O S, Amolo, I R; Anate, S G (2021). Physicochemical Properties of Surface Water from Ogbia Axis of Kolo Creek, Bayelsa State, Nigeria. Journal of Scientific and Engineering Research, 8(12): 2394-2630.

Edori, O. S. & Udongwo, A. M. (2021). Physical and chemical characteristics of water from Okamini Stream, Obio/Akpor, Rivers State, Niger Delta, Nigeria. GSC Advanced Research and Reviews, 8(1): 175-182.

Ekpoh, I., & Obia, A. (2010). The role of gas flaring in the rapid corrosion of zinc roofs in the Niger Delta Region of Nigeria. The Environmentalist, 30(4), 347-352. https://doi.org/10.1007/s10669-010-9292-7.

Environmental Guidelines and Standards for the Petroleum industry in Nigeria, EGASPIN (2002). Environmental Guidelines and Standards for the Petroleum industry in Nigeria. Department of Petroleum Resources, Lagos.

Federal Ministry of Environment National Guidelines and Standards for water Quality in Nigeria, FMENG&S (1991). Federal Ministry of Environment National Guidelines and Standards for water Quality in Nigeria. Federal Ministry of Environment, Housing and Urban Development, Lagos.

Global Gas Flaring Tracker Report (2022). International Bank for Reconstruction and Development / The World Bank 1818 H Street NW Washington DC 20433 Telephone: 202-473-1000 Internet:www.worldbank.org.

Gobo, A., Richard, G., & Ubong, I. (2009). Health impact of gas flares on Igwuruta/Umuechem communities in Rivers State. Journal of Applied Sciences and Environmental Management, 13(3).

Idris, R. (2007). Impacts of Oil Spillage and Gas Flaring On The Population And Distribution Of Birds In Niger Delta Region Of Nigeria. A Brief Interim Report Prepared Submitted to ABC Conservation Awards, ABC Conservation Fund United Kingdom.

IPCC. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. C. U. Press.

Maduka, O., & Tobin-West, C. (2017). Is living in a gas-flaring host community associated with being hypertensive? Evidence from the Niger Delta region of Nigeria. BMJ Glob Health, 2(4), e000413-e000413. https://doi.org/https://dx.doi.org/10.1136%2Fbmjgh-2017-000413.

Monica Cheesbrough. (2006). Laboratory practice in tropical countries. 2nd edition, Cambridge university press, 146-153.

Morufu R and Clinton E (2017). Assessment of Trace Elements in Surface and Ground Water Quality. LAP Lambert Academic Publishing. Mauritius. ISBN: 978-3-659-38813-2. www.omniscriptum.com.

NESREA (2020) National Environmental Standards & Regulations Enforcement Agency (NESREA). Our Functions. https://www. nesrea.gov.ng/our-functions/.

NGFCP-DPR (2021) Nigerian Gas Flare Commercialization Programme. Nigerian Gas Flare Commercialization Programme. https://ngfcp.dpr.gov.ng/.

Nigerian Gas Flare Commercialization Project. (2019). Nigeria's Gas Flare Landscape. https://ngfcp.dpr.gov.ng/about-us/our-mandate/our-vision/.

NOAA/GGFR. (2018). Gas flaring data 2013-17 (billion cubic meters). https://www.worldbank.org/en/programmes/gasflaringreduction#7.

Nwaogu L.A and Onyeze G. O. C (2020). Environmental impact of gas flaring on Ebocha-Egbema, Niger Delta, Nigeria. International Journal of Energy and Environmental Research 8(1)1-11.

Nwaogu, L., & Onyeze, G. (2010). Environmental impact of gas flaring on EbochaEgbema, Niger Delta. Nigerian Journal of Biochemistry and Molecular Biology, 25(1), 25-30.

Obanijesu, FE. Adebiyi, J. Sonibare, and O. Okelana (2009). Air-borne SO2 Pollution Monitoring in the Upstream Petroleum Operation Areas of the Niger Delta, Nigeria. Energy Sources, Part A (31):223-231. Available here.

Obi, N., Akuirene, A., Bwititi, P., Adjene, J., & Nwose, E. (2021). Community health perspective of gas flaring on communities in Delta region of Nigeria: narrative review. Int J Sci Rep, 7(3), 180-185. https://doi.org/https://dx.doi.org/10.18203/issn.2454-2156.IntJSciRep20210547.

Obi, N. I., Bwititi, P. T., & Nwose, E. U. (2021e). Public Health Impact of Environmental Pollution in Areas with Gas Flares. Journal of Complementary and Alternative Medical Research, 16(1), 1-8. https://doi.org/https://doi.org/10.9734/jocamr/2021/v16i130276.

Okeke, P. N. & Adinna, E. N. (2013). Water Quality Study of Otamiri Otamiri-oche River in Owerri, Nigeria. Universal Journal of Environmental Research and Technology, 3(6) pp 641-649.

Osuji L and Avwiri G (2005). Flared Gases and Other Pollutants Associated with Air Quality in Industrial Areas of Nigeria: An Overview. Chemistry & Biodiversity (2):1277-1289. Available here.

Park, K. (2009). Park's Textbook of Preventive and Social Medicine. India, M/S Banarsidas Bhanot Pub, pp. 659-661. Servicon Services.

Raimi M. O and Sabinus C. E (2017) An Assessment of Trace Elements in Surface and Ground Water Quality in the Ebocha-Obrikom Oil and Gas Producing Area of Rivers State, Nigeria. International Journal for Scientific and Engineering Research (Ijser): Volume 8, Issue 6, July Edition. ISSN: 2229-5518.

Wesley. B., Nwachukwu J., Adeleye S.A., and Egbadon E.O (206). Effects of Gas Flaring on the Physicochemical and Microbiological Quality of Water Sources in Egbema, Imo State, Nigeria. International Letters of Natural Sciences. 56(7-13) 2300-9675, DOI: 10.18052/www.scipress.com/ILNS.56.7.

WorldBank. (2016). New Data Uptick in Global Gas Flaring. Retrieved 10th October 1017 from https://www.worldbank.org/en/news/press-release/2016/12/12/newdata-reveals-uptick-in-global-gas-flaring.

World Bank (2005). Defining an Environmental Development Strategy for the Niger Delta. Washington DC: World Bank.

World Bank. (2015). Countries and Oil Companies Agree to End Routine Gas Flaring. https://www.worldbank.org/en/news/pressrelease/2015/04/17/countries-and-oil-companies-agree-to-end-routine-gasflaring.

World Bank. (2018). New Satellite Data Reveals Progress: Global Gas Flaring Declined in 2017. https://www.worldbank.org/en/news/pressrelease/2018/07/17/new-satellite-data-reveals-progress-global-gas-flaringdeclined-in-2017.

World Bank. (2022). Global Gas Flaring Tracker Report. http://pubdocs.worldbank.org/en/503141595343850009/WB-GGFR-ReportJuly2020.pdf.

World Health Organization, WHO (2003). pH in Drinking Water. Published in Guidelines for Drinking water quality 2nd edition, vol. 2. WHOGeneva.