

# Impact of Abandoned Oil and Gas Extraction Wells on Otuabagi/Oloibiri Communities in Nigeria

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**Abstract** - Unplugged or improperly plugged, orphaned or abandoned oil wells have become major environmental concern to crude oil producing and neighborhood communities. They provide potential conduits for fluids to migrate between formations and into the fresh water zones. Emissions can also seep to the surface and potentially cause fire-outbreak or risk to health and property. This can result from inadequate hydraulic conditions leading to excessive buildup of pressure. The Oloibiri Oilfield was abandoned since 1978 without recovery plan to drain the estimated 21.3 million barrels of crude left-over. This had spurred serious concerns due to recent oil/gas well blowout incidents across the Niger Delta region. On this basis, research work became necessary to study and identifies some of these legacy oil and gas wells abandoned for decades with a view to assessing potential leaks and analyzing the risks. The vicinity of 7 out of 21 abandoned Oil/Gas Well Heads were sampled at distances of 0m, 2m, 5m, 10m, 15m, 20m and 25m radius in north, east, south and west directions off the wellheads over a period of 6 weeks. In this report analysis of direct onsite emissions of methane at the radius distances of the abandoned oil and gas well heads at Oloibiri and Otuabagi are presented. The Aeroqual S200 Multi-Gas Monitor was used to instantaneously sample detectible limits of Methane gas leaks (Townsend-Small and Hoschouer, 2021). The study area showed significant excess Methane loads over four (4) to twenty (20) times above the naturally expected atmospheric condition of 2.2 ppm by volume. The sustained buildup in concentration is therefore sufficiently high enough to cause direct or indirect impact on animate life, hence the ecosystem, as the hydraulic pressure of methane and other gaseous emissions in the annular casing continues unabated in the long run.

**Keywords:** Legacy oil wells, Plugged, Hydraulic Pressure, Gaseous Emissions, Methane, Otuabagi.

## I. INTRODUCTION

There are no known publicly documented and verified number of abandoned oil and gas wells with listed operators and locations in Nigeria. Abandoned oil and gas wells fit into

the description of wells taken out of production that are either plugged, unplugged, or improperly plugged, including in active, shut-in, dormant, idle or temporarily abandoned (EPA 2020). The prevailing understanding is that before the 1950s abandoned wells were either “unplugged” or inadequately plugged with very little cement often with mud which failed to harden the seals against leaks. In some cases, before modern standardization, plugging was done with “well-seasoned, round wooden plugs” (API, 1952). Although, some progress has been made in the choice of plugging materials, such as the use of additives to customize cements and muds, the use of basic technologies of water-based cement slurries and drilling mud still persist (NPC, 2011). Achang *et al* (2020) however noted with optimism that innovations towards advancing the use of new materials are critical “to achieving permanent plugging and abandonment (P&A) or decommissioning in the future.”

Although in terms of global view the drilling of oil and gas has been over a century, in Nigeria the practice may have evolved in the late 1930s. However, it was much later (1958) that Nigeria joined the league of crude oil exporting countries after the discovery of crude oil in commercial-value at the Otuabagi/Otuogidi, then Oloibiri District of Ogbia, in 1956 (Ifenkwe *et al.*, 2018). The “Oloibiri Oilfield” alone is said to host 21 oil wells. The eventual upscale growth in the nation’s petroleum activities created over 170 offshore oil and gas installations (Nwapi, 2010). The experience has therefore left behind disturbing footprints of orphaned, unplugged or improperly abandoned oil and gas wells with the potential effects of leaking large amounts of harmful Methane (CH<sub>4</sub>) into the atmosphere. These have contributed to extensive public health, security and safety risks due to leaching of pollutants into the air and water bodies in the Niger Delta.

Several studies have reported that abandoned wells leak large volumes of CH<sub>4</sub> including oil, brine, and drilling byproducts into the environment (Townsend-Small *et al.*, 2016). Methane is a known powerful greenhouse gas and volatile organic compounds (VOCs) which has serious implications for local air quality. Several dangerous explosions have also been reported from abandoned wells leaking gas or

CH<sub>4</sub> in Nigeria including the recent Santa Barbara Oil Well 1 gas explosion November 2021.

The instantaneous accounts of such releases can be used as emission factors to represent annual estimates generally, relative to the number of abandoned oil wells sampled (Kang *et al.*, 2016). There are no known estimates on plugged/unplugged offshore/onshore abandoned oil and gas wells or methane emissions data of any time scale for legacy oil wells in Nigeria (*to my knowledge*). It may also be difficult to determine the original operators of these wells with detail documentation and history of abandonment considering that the period of disengagement predates present global standards.

Discreet estimates from studies have shown that the emissions from abandoned oil well sources become constant (Riddick *et al.*, 2019; Kang *et al.*, 2021) and become bioavailable in space over time. High-gas emitting abandoned wells have been shown to be of the same order of magnitude after measurements are replicated extensively over time (Kanget al., 2016).

In comparison with landfills, the emissions are biogenic methane or trace gases in nature and are variable due to environmental instability caused by temperature changes and atmospheric pressure. This is mainly attributable to ensuing colder temperatures affecting methanotrophic and methanogenic bacteria activities (Riddick *et al.*, 2017; Mønster *et al.*, 2015). Adverse effects from atmospheric pressure will naturally cause CH<sub>4</sub> to flux hydraulically from landfills (Riddick *et al.*, 2018; Saint-Vincent *et al.*, 2020), and depends on the organic matter rate of decomposition.

There are a total of 75 Oil company operators running 159 Oil Fields with 7,296 oil wells in Nigeria, of which about 2,678 are operated by SPDC from 1937 to 2020 (Nairametrics, 2022). With the petroleum industry gaining more economic momentum globally, the question arises over the potential consequences on the host environment when the serviceability life span of the oil/gas infrastructures expire. This calls to view the concept of decommissioning, and whether Nigeria has adequately addressed this critical issue in the Petroleum Industry Act (PIA) 2021 as it portends sustainability as relating the environment and public safety.

When the life cycle of the onshore and offshore operations is completed and the facilities are no longer viable economically, the wells have to be properly plugged and abandoned or decommissioned (Hemmingson, 2020; Khalifeh and Sesaan, 2020; Townsend-Small and Hoschouer, 2021).

However, if a well does not undergo a proper plugging or undergo any plugging at all, the well can become environmentally devastating in the course of time (Ted

Boettner, 2021). This is because if a well is not plugged, the oil and gas reservoir fluids are allowed to migrate to other soil strata with time and contaminate other soil formations and freshwater aquifers (Daniel Raimi, 2020). Unplugged oil and gas wells therefore pose a serious threat to the environment as they allow a large amount of harmful CH<sub>4</sub> to leak into the atmosphere. Methane is a greenhouse gas that contributes to climate change, and also as a volatile organic compound, it can reduce air quality, thereby, posing a serious threat to human health (Ted Boettner, 2021).

Production activities in the Oloibiri Oilfield stopped in 1978 and the field was abandoned without any recovery plan to drain some of the 21.26 million barrels (3,380,000 m<sup>3</sup>) of hydrocarbon left on the field (BMWA, 2012). This onshore Oilfield, located in Ogbia Local Government Area of Bayelsa State, produced over 20 million barrels of oil during its 20 years' life cycle. The abandonment has left the wellbore to deteriorate over time, thereby causing harm to the surroundings. Greenhouse gas CH<sub>4</sub> is roughly 30 times as powerful as carbon dioxide and can be bioavailable for over 100 years (IPCC, 2013) if allowed to persist into the atmosphere. The United Nation have emphasized reduction of CO<sub>2</sub> emissions but CH<sub>4</sub> is 21 times more potent greenhouse gas than CO<sub>2</sub> with considerable disproportionate impact, and should therefore be taken seriously (Mohajan, 2012; OIES, 2017).

The basis of this study is to identify some of these legacy oil/gas wells that have been abandoned for decades in the foremost Oloibiri Oil Field with a view to assessing potential leaks using the Aeroqual S200 Multi-Gas Monitor for detectable limits of Methane and to analyze the results for risks. The outcome of the study has shown sufficient concerns to local methane buildup in the atmosphere, whose concentration is sufficiently high compared to the expected threshold. This trend may therefore imply ongoing consistent buildup over the past decades of abandonment history. This can ultimately impact the wellhead environment to explosive limits as the hydraulic pressure of methane and other gaseous emissions in the annular casing continues unabated in the long run.

### Study Background and Description of Location

Oloibiri, at 4°40'18.15"N; 6°18'47.77"E was a district headquarters of Ogbia in the defunct Eastern Region. Otuabagi at 4°42'39.00" N; 6°21'53.01"E is one of the relatively small communities (Fig. 1). Both are rustic agrarian settlements now in Ogbia Local Government Area (LGA) of Bayelsa State. Their basic preoccupation span farming, logging, palm wine tapping and fishing.

These communities became famous when in the second half of the 20th century workers of Shell Darcy congregated on them in search of the black gold (Crude Oil). In June 1956, the oil/gas prospecting company, Shell, made history when it discovered crude oil in Otuabagi/Otuogidi communities in the Oloibiri District of Ogbia. Thus Oloibiri became the first district in West Africa where crude oil was discovered in commercial quantity. This escapade launched Nigeria into prominence in the world as it joins the league of crude oil producing and exporting nations in 1958.

Interestingly, out of the 21 oil wells drilled, widely known as “Oloibiri oilfield”, 18 were located in Otuabagi including the famous Oloibiri Oil Well 1 (*designated site for the Oloibiri Oil Museum*) which was bored at a depth of 12,008 ft in June 1956. However, these oil wells were later abandoned in the 1970s for the reason of becoming dry or non-producing and Shell stopped operation and abandoned the Oloibiri oilfield over some decades now, even with the knowledge that 21.26 million barrels (3,380,000 m<sup>3</sup>) of hydrocarbon was left undrained in the field (BMW, 2012).

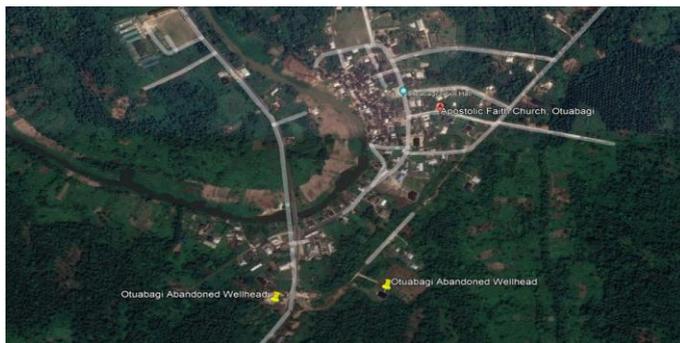


Figure 1: Map of Otuabagi community with some abandoned oil/gas wells in Oloibiri Oil Field

With time the expectations of the people waned after years of despoliation occasioned by the activities of Shell, leading to the abandonment of their preoccupations. In addition, and highly worrisome to the community, is the fact that the supposedly dried-up and/or plugged oil/gas wellheads have been seen to spew and leak crude oil affecting farm crops and continuously polluting the air, surface water, soil and groundwater.

## II. MATERIALS AND METHOD

The procedure entailed direct source emissions measurements requiring data collection at the potential emission location using the portable Aeroqual S200 multi-gas detector with Sensor Heads (Townsend-Small and Hoschouer, 2021). Detailed emission measurement was achieved from seven (7) abandoned oil/gas wells in the field and application of analytic methods to interpret implications of the emissions on the environment. The height of the well heads ranged between 4ft and 7fts from the ground surface. The

experimental design, materials used and data collection method have been described in detail in the foregoing sections and sub-sections.



Figure 2: Showing one of such Oil/Gas Well Head and the Aeroqual S200 multi-gas detector with Sensor Heads

## Experimental Design and Equipment

The field experiment was designed to access the vicinity of the twenty-one (21) abandoned oil and gas wells in Oloibiri and Otuabagi communities. Historically, eighteen (18) of the abandoned wells were said to be located in Otuabagi and three (3) in Oloibiri communities. Due to the high risk of personnel exposure, site access authorization, communal and time constraints, the direct source emissions measurement study concentrated on sampling seven (7) of the Wells including the “Oloibiri oil well 1”, the height of which ranged between 4ft and 7fts from the ground surface. Two (2) of the wells sampled were found in the midst of farmlands, three (3) by roadside and two (2) a few meters away from the Otuabagi River (all in Otuabagi community). During the site verification exercise prior to the commencement of sampling, no known landfill site (s) that emits biogenic methane or trace gases was found in and around the vicinity of the sampled oil/gas wells.

Strict adherence to safety considerations due to the potential high risk of personnel exposures to combustible atmosphere and/or air toxics was needed. The Aeroqual S200 tool with sensor heads was commissioned to quantify methane and VOC concentration to determine methane (CH<sub>4</sub>) and volatile organic compounds (VOCs) emission concentration (PPM) over radius distance, percentage volume and excess load at the various oil/gas well locations. The Aeroqual S200 apparatus is a multi-air pollutant gas (CO<sub>2</sub>, CO, NO<sub>2</sub>, CH<sub>4</sub>, VOCs) detector in-situ. The duration of sampling of the oil/gas wells span over a period of 6 weeks. Other sets of tools included a leather carry bag holding work gloves, 15.0m measuring tape, a global positioning system (GPS) for Well Head location recording, field record sheets (log book) and pens, paper towels, and two (2) hand held machetes for clearing clogged access pathways. Personal protective equipment, such as, hardhat, fire retardant clothing with high visibility vest, steel-toed boots and eye shades for use as safety goggles, and a TECNO POP4 Promobile phone for use as emergency phone.

### Sampling Technique and Data Collation

The said abandoned Oil Well Heads were each sampled at distances of 0m, 2m, 5m, 10m, 15m, 20m and 25m radius (Fig. 3) for three (3) days in each week for six (6) weeks period (between December, 2022 and January, 2023), that is about eighteen (18) days of direct on-site emission inventory in the study area. At each of the Oil Well Head locations CH<sub>4</sub> and VOC readings were taken off the Aeroqual S200 screen in north, east, south, and west directions as observed and recorded with the field logbook. This implies that at the point of well head (0m), four (4) CH<sub>4</sub> and VOC readings are taken in parts per million (ppm) and averaged for recording. This is taken as a representative concentration value of the gas for 0m, and the procedure repeated for 2m, 5m, 10m, 15m, 20m and 25m radius off the well head (Fig. 3). The Oloibiri Well 1 was designated Well 1, but the designations Well 2, Well 3, etc. was done during the progress of sampling process in the field, and so does not represent their official name.

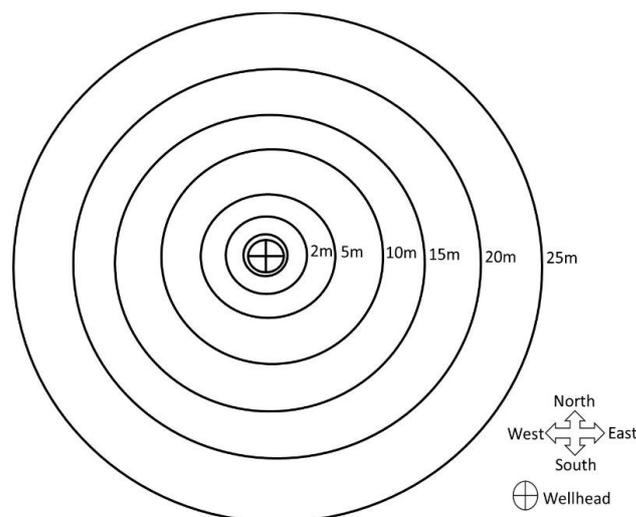
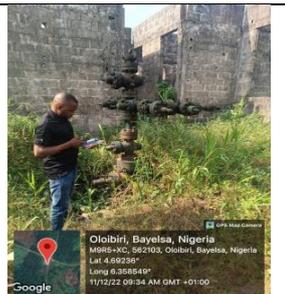


Figure 3: Direct source emissions measurement at ground surface from wellbore center at radius distances 0m, 2m, 5m, 10m, 15m, and 25m

Table

1: Sample template of data generation process in the field, Otuabagi (inset: Surface Wellhead with horizontal variation of valves)

Radius Distance from Wellhead (m)	Mean Methane (ppm)	Mean VOCs (ppm)
0		
2		
5		
10		
15		
20		
25		



The Aeroqual S200 has different sensors for each gas, implying the CH<sub>4</sub> sensor was used to detect methane and for concentration of VOCs, the VOC sensor was used. This was repeated for about six (6) weeks and at varying times, (such as evening and morning hours) of the day. The purpose was to obtain a near precise value of methane and VOCs gas concentration leaking into the atmosphere from the well head in these communities daily. A GPSMAP 625 which has 5ft - 12ft margin of error was used to record the coordinate (location) of each of the Well Heads sampled.

Table 2: Methane and VOCs Averaged Emission Rate in ppm and margin of error with location coordinates

Oil/Gas Wellhead	Mean Methane (ppm)	Mean VOCs (ppm)	Location Coordinates
WELL 1	10.1186±0.0299	20.1657±0.1429	4.692337N 6.358585E
WELL 2	05.2543±0.0970	11.4400±0.1815	4.697622N 6.358617E
WELL 3	07.9257±0.0857	17.7714±0.1439	4.700343N 6.353922E
WELL 4	12.3671±0.0798	23.0714±0.0398	4.703045N 6.358633E
WELL 5	35.0229±0.0395	43.9342±0.5722	4.697223N 6.350526E
WELL 6	24.7971±0.1656	29.9871±0.3216	4.694827N 6.363212E
WELL 7	14.0800±0.0332	21.9443±0.2279	4.696731N 6.371195E

### III. RESULTS AND ANALYSIS

The data resulting from the field sampling exercise were analyzed and are presented as shown in Table (2) and Figs. (4 to 13). Table (2) shows averaged emission rates in percent by volume of CH<sub>4</sub> and VOCs in the atmosphere with margin of error. The averaged data of the methane and VOCs emission

levels were plotted against the radius distance. In Figures (4 to 10), the mean concentration (ppm) of CH<sub>4</sub> and VOCs are plotted against the radius distance as observed from the oil/gas well heads. The observed trend in Fig. (4) Showed the CH<sub>4</sub> to relatively vary from a higher concentration of about 0.001025% by volume in the atmosphere as radius distance increased, indicating that spatial difference might be a factor

in the sensor's ability to detect the concentration events. This signifies about 5 times excess methane load here, since naturally the presence of methane in the atmosphere is just about 1.7 parts per million (ppm) by volume (NASA, 2005). The fitted model in the observed VOCs concentration data described a slightly different trend relative to the CH<sub>4</sub>, showing little variation with space. At Well 2 (Fig. 5) the concentration of CH<sub>4</sub> also decreased relatively with increasing radius distance from the well. The concentration of VOCs similarly varied with distance. Figure 6 showed the variations of CH<sub>4</sub> and VOCs concentration (ppm) at Well 3 with radius distance. The concentration (ppm) of methane in the atmosphere decreased from the well head at about 8.0 ppm to 7.5 ppm and the VOCs ranged between 18.0 ppm and 17.0 ppm up to 25m radius distance. However, it's interesting to note that CH<sub>4</sub> concentration (ppm) was relatively the same from the well head to the 25m radius distance, only varying from about 12.0 ppm to 12.5 ppm as shown in Fig. 7. Also, VOCs concentration varied little between 23.0 ppm and 23.3 ppm for the same distance considered. At Well 5 (Fig. 8), methane concentration (ppm) varied between about 34.9 ppm and 35.2 ppm while the VOCs relatively fluctuated from 41.0 ppm to 45.0 ppm with location. The graph in Fig. (9) representing observations in Well 6 showed CH<sub>4</sub> concentration (ppm) to be almost stable with increasing radius distance in contrast with the VOCs which fluctuated. In Fig. (10) of Well 7, the concentrations of both CH<sub>4</sub> and VOCs fluctuated with radius distance, as CH<sub>4</sub> and VOCs varied between about 14.2 ppm and 14.0 ppm and 22.6 ppm and 21.4 ppm respectively.

Further, the mean percentage (%) volumes of CH<sub>4</sub> and VOCs observed with radius distance at each Well head was analyzed (Fig. 11). The analysis showed that the percentage volumes of CH<sub>4</sub> and VOCs fluctuated from 0.001% to 0.0035% and 0.002% to 0.0045% in the atmosphere respectively over the seven (7) wells investigated. The results imply that the CH<sub>4</sub> and VOCs percentage volumes at Well 5 was much higher than the rest six (6) wells considered in the study, accounting for over 35 ppm and 45 ppm respectively. These results can be translated to excess methane and VOCs load in the local atmosphere. In Figs. (12 and 13), the study shows that the excess load of methane varied between 4 and 20 times higher than naturally expected atmospheric conditions (OME, 1987; NASA, 2005). This trend may imply ongoing consistent build up over the past decades of abandonment history and can ultimately impact the environment negatively as the buildup continues uninterrupted over a long period of time.

#### IV. CONCLUSION

The vicinity of 7 out of 21 legacy Oil and Gas Well Heads in Oloibiri Oilfield were sampled at various radius distances of up to 25m over a period of 6 weeks, with a view to assessing potential emissions or presence of methane gas and VOCs in the atmosphere and analyzing the risks in relation to air quality. The direct source emissions measurement approach was applied using the Aeroqual S200 apparatus, a portable multi-air pollutant gas (CO<sub>2</sub>, CO, NO<sub>2</sub>, CH<sub>4</sub>, VOCs) detector in-situ (Townsend-Small and Hoschouer, 2021). Each of the 7 wellheads was found to be emitting methane and VOCs ubiquitously at rates far above the naturally expected atmospheric conditions of 2.2 ppm by volume. Methane makes up 0.00017% (1.7 ppm) to 0.00022% (2.2 ppm) by volume of the atmosphere (OME, 1987; NASA, 2005; Shappo, 2020).

The consistent detection of methane across the vicinity of all seven (7) wellbore centers implies that the gas occurs at elevated temperatures and pressures in the sedimentary strata. The results of the analysis are profound with Wellheads 5 and 6 (Figs. 8 and 9 respectively) having the highest CH<sub>4</sub> and VOCs percentage volumes, accounting for over 35 ppm and 45 ppm by volume respectively. The results show significant excess Methane loads over four (4) to twenty (20) times above the naturally expected atmospheric condition of 2.2 ppm by volume. This suggests high emission events and the employment of a more dynamic and integrated assessment strategy is advised to enable the evaluation of daily and annual emission rates with seasonal conditions. Conversely, to limit site constraints and reduce costs, measurements can also be limited to about three (3) to five (5) hours per day to represent approximate behavior of the emissions for twenty-four (24) hours. This study provides a further certainty to several other research findings that abandoned oil and gas wells emit gaseous pollutants such as combustible methane and VOCs into land, air and water courses (Lebel *et al*, 2020; Saint-Vincent *et al*, 2020; Shappo, 2020; Townsend-Small and Hoschouer, 2021). This study recommends stakeholders in the oil and gas industry to help reduce the risks by locating, monitoring, and plugging the numerous abandoned wells in the country and initiate Well integrity program. There are several benefits from plugged oil and gas wells as against wells not plugged or not properly plugged after production life span. The leaching as a result of spills on soil and into groundwater mostly is accounted to casings or cement that allow oil, gas, and brine to seep into the freshwater aquifers and the surface water. Well plugged oil and gas wells help to reduce methane and VOCs leaks that can eventually contribute to greenhouse gas emissions and harm air quality, posing risks to human health and the environment (Lebel *et al*, 2020; Shappo, 2020). These chemicals are known carcinogens (e.g.,

benzene) which are linked to leukemia and low birth weights. The emission demonstrated in this study proves that there exists a loss of well integrity in the casings or plugs in all the wells, and this has allowed fluids or gases to freely escape into the atmosphere (Lebel *et al.*, 2020). The study therefore further recommends a bond failure or hydraulic pressure tests to verify if cementing had been conducted to ensure hydraulic isolation at the tops of all the cement plugs prior to abandonment. This is to further verify if the detected limits of methane concentration here are of thermogenic origin with a view to managing the annular hydraulic pressure profile. In addition to forestall the high risk of exposure of people and ecosystems in the host communities to the persisting combustible and toxic atmosphere, and taking responsibility with government to strictly adhere to safety considerations.

The mixture of methane gas with atmospheric air at concentration levels from 50,000 to 150,000 ppm (5% to 15%) by volume in air can cause significant fire outbreak with potential explosive hazards (US EPA, 2020; Shappo, 2020). The settlements of Oloibiri/Otuabagi axis may not have witnessed or experienced such an explosive encounter of this nature yet but with combustible methane and VOCs, the potential health consequences may be many. The air they breathe, the soil they cultivate on, threat of fire ignition, effect on drinking water, mental health disorders, physical/physiological effects, etc., are among the plausible hazards that can trigger immunological abnormalities in human, aquatic organisms and plants, which could further engender mortality issues (Shappo, 2020). Several dangerous explosions have also been reported from abandoned wells leaking gas or CH<sub>4</sub> in Nigeria including the recent Santa Barbara Oil Well 1 gas explosion, November 2021 (Samuel, 2021). Methane gas is a VOC and reacts in air to form water vapour (H<sub>2</sub>O) and CO<sub>2</sub> and has been described as 26 to 36 times more effective at trapping air than CO<sub>2</sub> which can linger for over 80yrs to 100yrs period respectively (USEPA, 2022).

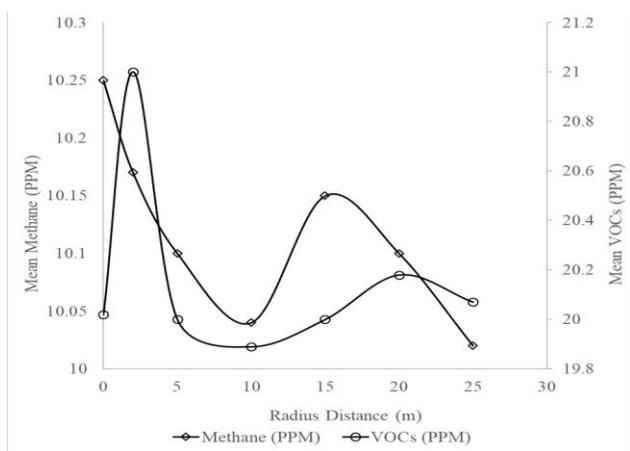


Figure 4: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 1

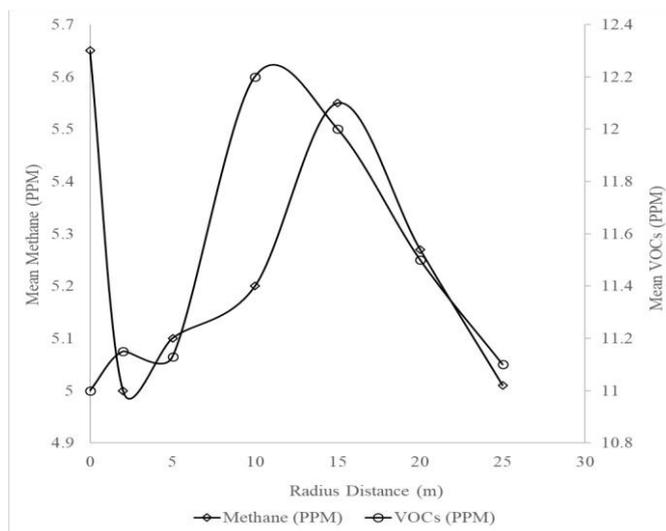


Figure 5: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 2

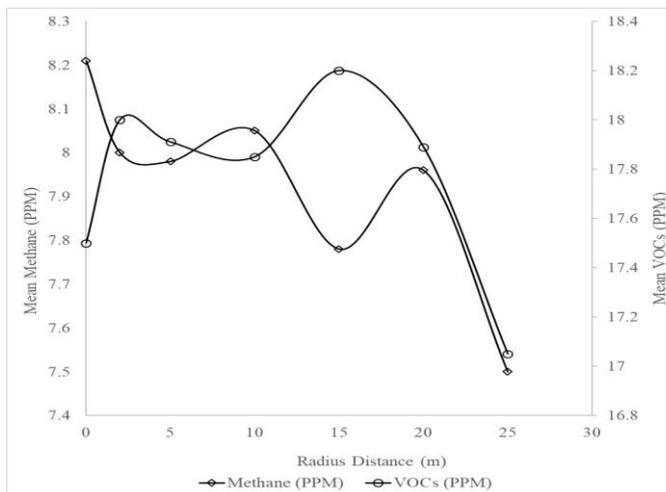


Figure 6: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 3

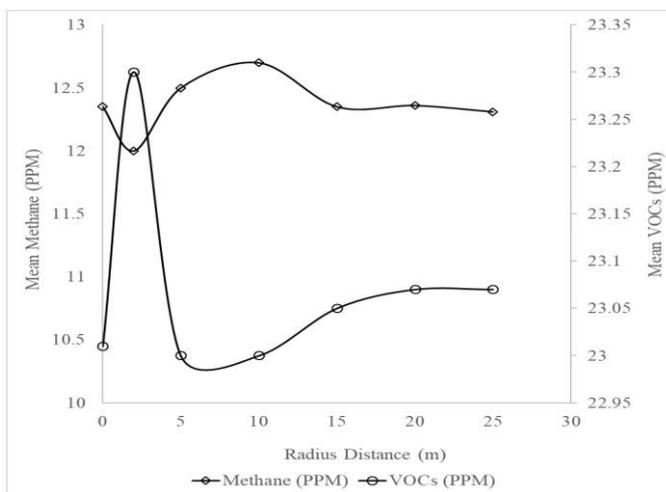


Figure 7: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 4

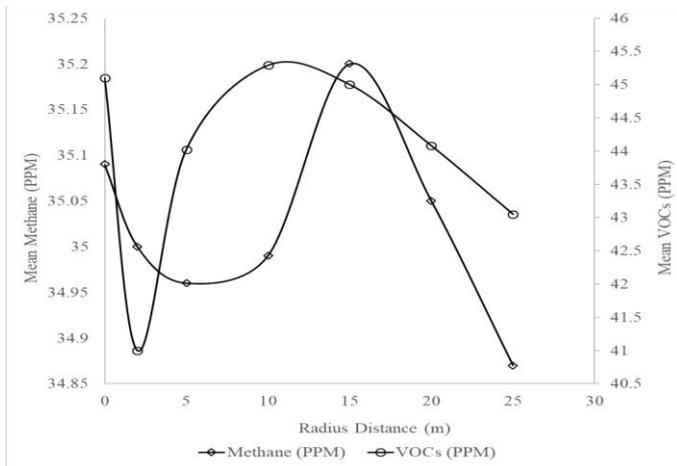


Figure 8: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 5

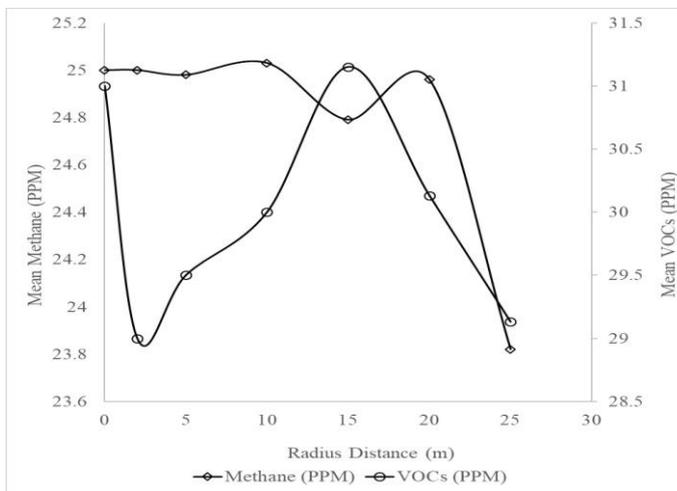


Figure 9: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 6

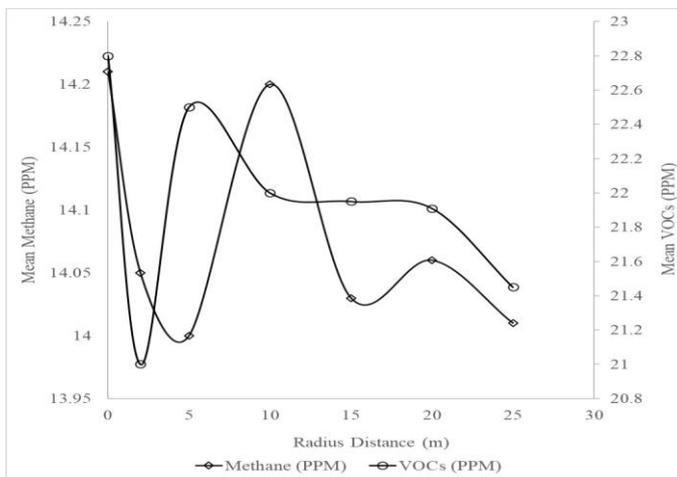


Figure 10: Graphical analysis of CH<sub>4</sub> and VOC records in PPM as observed with distance at Well 7

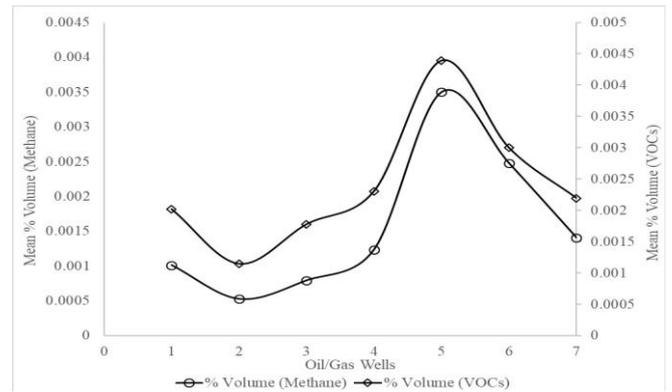


Figure 11: Graphical analysis of percentage volumes of CH<sub>4</sub> and VOC observed with distance at each Well

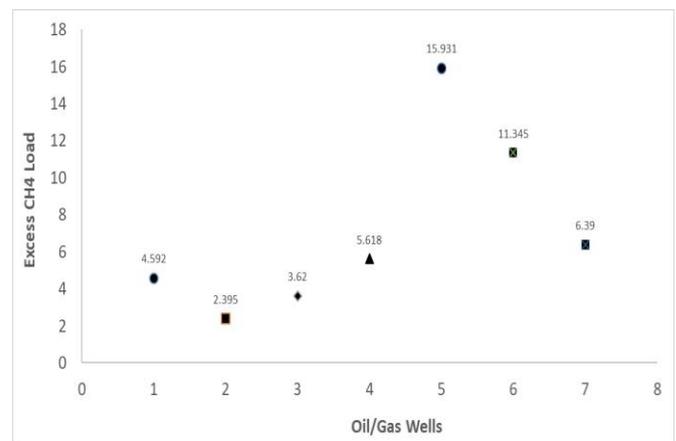


Figure 12: Graphical presentation of Excess CH<sub>4</sub> Load from the analysis at each Well relative to xxxx

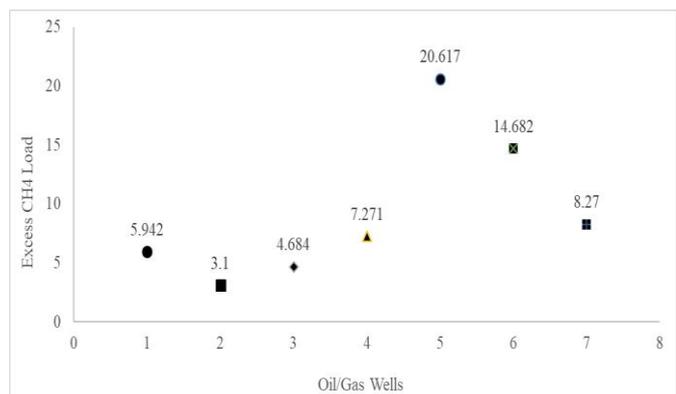


Figure 13: Graphical presentation of Excess CH<sub>4</sub> Load from the analysis at each Well relative to xxxx

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