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The Relationship between Air Pollution caused by Gas flaring and Lung function in the Niger Delta.

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List of Abbreviation

ECRHS	European Community Respiratory Health Survey
EEA	European environment agency
FEV_1	Forced Expiratory Volume in one Second
FOE	Friends of Earth
Km	Kilometre
LGA	Local Government Area
PEF	Peak Expiratory Flow
PM	Particulate Matter
SPSS	Statistical program for social sciences
TLC	Total Lung Capacity
TSP	Total suspended particle
US-EPA	United State Environmental Protection Agency
FVC	Forced Vital Capacity

1. Zusammenfassung

Zusammenhang zwischen Luftverschmutzung durch Abfackelung von Erdgas und Lungenfunktion in Niger-Delta

Hintergrund/Ziel

Die Niger-Delta-Region von Nigeria hat viele Jahre der Rohölexploration und Abfackelung von Erdgas erlebt. Eins der zahlreichen Gesundheitsprobleme, die im Zusammenhang mit der Abfackelung von Erdgas noch nicht bewertet wurde ist die Entwicklung einer Lungenerkrankung. Dieses Projekt untersucht, wie die Lungenfunktion von Einwohner einer solchen Region, in der Abfackelung von Erdgas stattfindet, mit solcher Exposition zusammenhängt.

Methode

179 Personen wurden ausgewählt, die Gesundheitszentren (Primary Health Centers) im Bundesstaat Rivers, Nigeria besuchten. Bei den Ausgewählten wurden Lungenfunktionstests mittels eines Handspirometers durchgeführt. Die Auswahl der Probanden erfolgte anhand des ECRHS-Fragebogens (ECRHS 2). Raucher und Personen mit zuvor diagnostizierte Lungenerkrankungen wurden ausgeschlossen. Alter der Probanden: 18-63 Jahre. 103 Frauen sowie 76 Männer nahmen an den Tests teil.

Ergebnis/Schlussfolgerung

Die Probanden wurden entsprechend der Nähe ihrer Häuser zu Abfackelstellen in drei Gruppen eingeteilt: Gruppe 1, Probanden, die 1-3 km von Gasfackelstellen entfernt leben, Gruppe 2: Probanden, 3,5-11 km entfernt lebend, Gruppe 3: Probanden, die 11-30 km entfernt leben. Der mittlere FEV1-Wert in Gruppe 1 war 1.94L in Gruppe 2: 2.23L und 2.46L in Gruppe 3 mit einer Standardabweichung von 0.51L, 0.64L, 0.80L in den Gruppen 1, 2 und 3 jeweils. Der mittlere Tiffeneau-Index (FEV1/FVC) war 72,79 %, 76,53 % und 77,90 % mit einer Standardabweichung von 19,32 %, 12,08 %, 9,07 % für die Gruppen 1, 2 3 beziehungsweise. Bei Personen, die näher an Gasfackelstellen leben, wird eine verminderte Lungenfunktion festgestellt im Vergleich zu anderen, die weit weg leben.

Die Ergebnisse zeigen eine Zunahme der Atemwegssymptome, wenn Probanden näher an einer Fackelstelle wohnen. Alle Personen im Test hatten eine beträchtliche Anzahl von Jahren (fünf Jahre) in dieser Region gelebt und das durchschnittliche Ergebnis zeigt eine Verringerung der Lungenfunktion in allen Gruppen. Gruppe 1, die sich aus Personen zusammensetzte, die sehr nahe an einer Gasfackelstelle in einem Umkreis von bis zu 3 km lebten, zeigte mehr

Atemwegsprobleme, wie Husten, Keuchen, Kurzatmigkeit und eine stärker reduzierte Lungenfunktion.

Die Tests zeigen einen durchschnittlichen VC-Wert in allen Gruppen (Gruppe 1 und 2) mit Probanden, die nah am Abfackelungsort wohnen, der unter dem normalen Erwartungswert (Erwartung bezogen auf Alter und Geschlecht, Größe und Ethnizität) von mindestens 5. Perzentil liegt, und der durchschnittliche FEV1-Wert lag ebenfalls in gleichen Gruppen unter dem Erwartungswert. Obwohl der durchschnittliche Tiffeneau-Index in allen Gruppen normal war, hatten 14 Personen in Gruppe 1, 10 in Gruppe 2 und 7 in Gruppe 3 niedrigere Werte als die erwarteten Normalwerte.

Dies entspricht unserer anfänglichen Befürchtung, dass das Leben in der Nähe einer Gasfackelstelle zu mehr Atemproblemen und einer schlechteren Lungenfunktion führen würde. Strengere Vorschriften wären erforderlich, um eine weitere Eskalation der durch das Abfackeln von Gas verursachten Luftverschmutzung zu verhindern, und wir empfehlen, die Abfackelstellen weiter von Wohngebieten entfernt zu verlegen. Die beste Lösung wäre jedoch der Bau von Gasspeichern und -Infrastruktur sowie die ordnungsgemäße Nutzung des erkundeten Gases zur Energiegewinnung.

2. Introduction

2.1. Preamble

Air pollution has long been a global issue with enormous health challenges for both developing and developed countries. As developed countries enact regulatory laws to curb this menace the rise of industrialization in developing countries and mid-income countries has become the greatest force contributing to the increase of pollutants affecting nature, the earth and its inhabitants. These pollutants, mostly compounds of sulphur, nitrogen and carbon cause great damage to the health of individuals exposed to them.

2.2. Definition

Air pollution is the presence in the air of one or more substances at a concentration or for a duration above their natural levels, potentially producing an adverse effect. As stated by Seinfeld and Pandis (2006) '*a condition of "air pollution" may be defined as a situation in which substances that result from anthropogenic activities are present at concentrations sufficiently high above their normal ambient levels to produce a measurable effect on humans, animals, vegetation, or materials. This definition could include any substance, whether noxious or benign; however, the implication is that the effects are undesirable'* .[1]

Air pollution, as defined by environmentalpollutioncenters.org, unequivocally denotes the existence of hazardous chemicals or compounds, including those of biological origin, in the air, which poses a significant threat to our health. Moreover, air pollution encompasses the existence of chemicals or compounds in the air that are not usually present, leading to a decline in air quality or alterations to our quality of life, such as the depletion of the ozone layer or contributing to global warming. [2]

Many authors have classified air pollution into various categories, namely: man made or natural, as well as indoor (household) or outdoor (ambient) air pollution. The world health organization (WHO) recognizes this differentiation as well.[3, 4] As at the time of working on this project the WHO has issued different guidelines to mitigate the problem of household air pollution, as well as ambient air pollution. While Household air pollution is generated by the use of inefficient and polluting fuels and technologies in and around the home, ambient air pollution refers to the pollution of the outdoor air.

2.3. Types of Pollutants

The definition above covers the range of items that pollute the air we breathe, and does not restrict such items to their origin, be it man-made, like human industrial activities or natural occurrences, like volcanic eruption. In addition, the definition allows for a categorization of pollutants to include not just gases only. Solid substances too, such as particulate matter contribute immensely to polluting the air.[5]

Human industrial activities, like mining and drilling of crude oil have recorded the highest levels of pollutants. Crude oil drilling and other activities involved with the drilling and refining process, like gas flaring contribute to the emission of sulphur, nitrogen as well as carbon compounds, which pollute the air. Other human activities like the use of petrol/diesel cars, manufacturing, bush burning, and even agricultural methods like animal husbandry have contributed their fair share to air pollution.[5]

According to the medical axiom 'sola dosis facit venenum' (the dose alone makes the poison), the concentration of a substance determines its potential harm to human health. Air pollution may occur due to natural events such as volcanic eruptions, microbial decay of plants and animals, and wildfires. Even naturally occurring carbon dioxide can be harmful in large amounts, as it competes with oxygen to bind to hemoglobin, and can lead to asphyxiation.

From the definition of air pollution, we acknowledge also that solid substances contribute to polluting the air. These solid substances come in various sizes and are classified under the term Particulate matter (PM). Particulate matter, also known as particle pollution, is a mixture of solid particles and liquid droplets found in the air. [6] The US Environmental Protection Agency (US-EPA) defines it as such. Some particles, like dust, dirt, soot, or smoke, are visible to the naked eye because they are large or dark. Others are too small to be seen without an electron microscope. There are two main types of particle pollution: PM_{10}, which includes inhalable particles with diameters of 10 micrometres or less, and $PM_{2.5}$, which includes fine inhalable particles with diameters of 2.5 micrometres or less. The size of these particles determines the level of health damage that they can cause an individual who inhales them. Smaller particulate matter can even travel through the bloodstream to various organs, leading to enormous health challenges.[6]

2.4. The Niger Delta Situation

The Niger Delta region of Nigeria in sub-Saharan Africa is a region with a tropical climate. Just like most regions in developing economies, the prevalent form of air pollution is indoor, due to the lack of access to clean fuel source for cooking.[4] The WHO estimates that 923 million people in sub-Saharan Africa lacked access to clean fuels and technologies in 2020.[4]

In addition to the effects of indoor air pollution, outdoor air pollution is also on the rise in many cities and suburb. A cross sectional study conducted in Ibadan, a city in Nigeria that shares certain similarities with the Niger Delta region, showed that locations with more intensive human activities in Ibadan recorded higher PM_{10} concentrations. PM_{10} levels across four site locations used in the study were at least twice as high as the WHO daily guideline limits.[7]

One major causes of ambient air pollution in the Niger Delta region is gas flaring, as well as other industrial processes dealing with the drilling and processing of crude oil. In the Niger-Delta region of Nigeria gas flaring activities have taken place for over half a century and have contributed largely to polluting the air in this region. Gases emitted from automobiles, especially those emitted because of incomplete combustion of fuels have as well contributed to the menace of air pollution in the Niger-Delta. The recent rise in illegal refineries too has added to the already worsening situation and the effects seen in towns and cities in the region.

2.5. What is gas flaring?

Gas flaring is the burning of the natural gas associated with oil extraction.[8] It is a common practice by oil exploring firms to flare associated gas that is gas found with crude oil during the drilling process. Most companies would have facilities to store this gas in order to minimize the amount being flared, yet others due to lack of such facilities end up flaring the entire amount of gas found while drilling. These gas flares contain high amounts of particulate matter and carbon compounds, especially methane.[8]

It is a well-established fact that areas where oil exploration occurs, and gas is flared have significantly higher levels of particulate matter. A study conducted in the gas flaring community of the Niger Delta, Igrwuta in 2009 found that particulate matter concentration levels during the rainy season ranged from $0.4 \pm 0.4 \mu g/m^3$ in June to a staggering $25 \pm 5.4 \mu g/m^3$ in May. The concentration levels of particulates were particularly alarming in December and January, exceeding the allowable regulatory limits for Total Suspended Particulate (TSP), PM_{10}, and PM_7 at all sites. These findings leave no room for doubt regarding the impact of gas flaring on air quality in surrounding communities.[9]

A study carried out in Alberta, Canada revealed that even a small-scale gas flaring operation of 8,600 m^3 per day could lead to an increase in particulate matter levels by 0.23 µg/m^3 at 1,325 meters from the flare, and benzene levels by 0.025 µg/m^3 at 5,000 meters from the flare.[10] When compared to estimated values from gas flaring sites in the Niger Delta, the findings are alarming. For instance, a gas-flaring site in Bayelsa State, in the Niger Delta in Nigeria is estimated to flare about 800,000 m^3 of gas per day. This level of emission may elevate ambient air levels of particulate matter by 21 µg/m^3 at 1,325 meters from the flare, and benzene levels by 2.3 µg/m^3. These emissions can have a significant impact on the health of a large number of people.[10]

Amongst several environmental hazards like acid rain[11], which is common in the Niger Delta region, health problems are prevalent as well. One study in the Niger-Delta region has linked gas flaring to hypertension, a cardio-vascular disorder.[12] Despite many years of crude oil exploration in this region, little has been done to show the effects of gas flaring on the pulmonary system of individuals living in this region. Also, studies with regard to occupational hazard of gas flaring in the Niger Delta are rare.

Diagram 1: Example of gas flaring site.[13] (Copyright Chebyshev1983)

Diagram 2: Example of gas flaring site.[14]

2.6. Effects of Air pollution

Air pollution can be toxic to the environment and to humans. In some case, it could lead to an explosion, as is the case with methane gas. In addition, the emission of greenhouse gases into the atmosphere exposes not just humans and the environment, but also wildlife to a mixture of dangerous gases, whose ill effect may be underestimated.

This, as well as the constant depletion of the ozone layer and the rising level of carbon dioxide have spearheaded discussions about global warming. Global warming in itself leads to the melting of glaciers in the arctic and Antarctic regions, which in turn leads to rising sea levels, then to flooding of fresh water bodies, killing wildlife living in streams and rivers and causing a chain of other reactions that leave the environment devastated.

Air pollution is a serious issue that poses a threat to both humans and wildlife. Gas flaring is a major contributor to air pollution and is known to cause acid rain. This type of rain can have devastating effects on lakes, streams, and vegetation. Studies conducted by Friends of Earth have shown that the primary culprits behind acid rain are emissions of Sulphur dioxide (SO2) and nitrogen oxides (NO). These emissions react with atmospheric moisture to create sulfuric and nitric acid, respectively. It is important that we take action to address this issue and reduce the harmful effects of air pollution on our environment. [10] In addition, doctors have recorded complaints like eye irritation, irritation of the airways, skin irritation, dizziness, neurologic disorders, cardiovascular problems as well as a range of respiratory problems with individuals exposed to polluted air.

The World Bank reports that exposure to particulate matter causes a significant increase in adverse health effects. Every 1 ug/m^3 per 100,000 persons results in 6.72 premature deaths, 1,690 respiratory illnesses in children, and 32,600 asthma attacks annually. These estimates are conservative, and the actual number of clinical cases could potentially be much higher. Furthermore, the worst-case scenario has not yet been determined, and additional health issues may arise. The US Environmental Protection Agency (EPA) has established that exposure to 1.0 ug/m^3 of benzene represents a 1:100,000-lifetime risk of cancer. It is crucial to take immediate action to reduce exposure to these harmful pollutants to protect public health.[10]

Air pollution can cause various respiratory problems, as pointed out by the US EPA. These include Chronic Obstructive Pulmonary Disease (COPD), reduced lung function, pulmonary cancer resulting from inhalation of carcinogenic chemicals, mesothelioma associated with exposure to asbestos (which usually occurs after 20-30 years), and pneumonia.[15]

Although Nigeria is one of the leading gas flaring countries in the world, little has been done to evaluate the health threat caused by gas flaring on individuals living in such polluted regions. One study in the Niger-Delta region has linked gas flaring to hypertension, a cardio-vascular disorder, yet little has been done to show the effects of gas flaring on the pulmonary system of individuals living in this region.[12] Most studies done in relation to air pollution and lung function have focused on air pollution caused by automobiles, and the effect of using bio-mass fuel for cooking on the lungs.[16,7] Research conducted in Ile-Ife, Nigeria has demonstrated that the utilization of solid fuel for domestic cooking or heating is associated with an elevated risk of cough or phlegm and has a detrimental impact on mental quality of life.[17]

In other regions of the world, researchers have brought various pulmonary disorders in conjunction with refining of crude oil. A test carried out in adolescents in Sarroch and Burcei in Sardinia, Italy shows an increase in bronchial inflammation, in wheezing symptoms and a decrease in lung functions in children living in Sarroch, Sardinia, a petrochemical polluted commune as opposed to Burcei, Sardinia, a reference area.[18] In the above research the weekly levels of pollutants like sulphur dioxide, nitrogen dioxide and the carbon compound benzene were measured and these pollutants are components of gas flaring as well.[18,19]

Another study carried out by the Department of Physiology, College of Medicine, King Saud University, Riyadh, Saudi Arabia showed that petroleum refinery workers exposed to similar pollutants showed a decline in lung function when compared to a control group in Saudi Arabia.[20]

2.7. Research Question

Seeing the various health and environmental consequences of air pollution and having established that gas flaring is a major contributor to the air pollution crisis, especially in the Niger-Delta region, this project tries to answer the following questions:

1: How does gas flaring affect the pulmonary system of people living in the Niger-Delta?

2: How does distance to a flaring site affect the lung function of the inhabitants of the Niger-Delta region?

3. Materials and Methods

The aim of this project was to analyse the effect of air pollution caused by gas flaring on the lungs and how it affects lung function in people living in the Niger-Delta.

In order to achieve our aims, we applied for a permission to carry out lung function tests on individuals living in the Niger-Delta region of Nigeria. Our focus was streamlined to three communities in Rivers State, Nigeria and the approval contained the permission to use some primary health centres for our tests.

After securing the approval to use the primary health care centres in Aluu in Ikwerre Local Government Area (LGA), Eneka and Rumuodomaya in Obio/Apkor LGA several individuals were screened, and 179 subjects enrolled for the tests. These Local Government Areas are situated in Rivers State, in the Niger Delta of Nigeria. Manufacturing activities are presently very limited in Rivers State. However, there are also some considerable manufacturing activities taking place, all related to crude oil production and refining.[21]

3.1. Study design and conception

The concept of this study was framed in conjunction with Dr. Konrad Frank Ph.D., who also supervised this project. The materials (Hand spirometer, single-use mouthpiece, and single-use air-filter) were procured with financial support of the Boehringer Ingelheim Pharma GmbH & Co. KG. Azubuike Worlu was responsible for carrying out the test in Nigeria. This included the screening of subjects, collection of informed consent, survey using the ECRHS II questionnaire, as well as the spirometry test, and documentation of the results. The statistical analysis of the results took place in consultation with Dr. Hildegard Christ PhD of the Institute of Medical Statistics and Computational Biology of the University of Cologne.

This study used a descriptive cross-sectional design. Inferential statistical analysis was done, however with limited significance. Informed consent was obtained from the study participants, while the Rivers State Health Research Ethics Committee granted ethical approval with approval number: RSHMB/RSHREC/11.20/VOL8/074. In addition, this project was approved by the ethics committee of the University of Cologne.

3.2. Study population and recruiting of participants

The recruiting process took place in the months of February 2016 all through to April 2016. Subjects who visited health centres, mostly those who accompanied their sick relatives were randomly selected. 170 respondents consented to participate in the lung function tests. Subjects were adults of both sexes, male and female from 18 to 64 years old and have resided in their various locations, all in the Niger-Delta region for more than five years. 97 females and 73 males completed the tests. The minimum duration of residency in areas affected by gas flaring was placed at 5 years to ensure that individuals must have been duly exposed to the pollutants. Those enrolled to take part in the lung function tests were also screened to eliminate possible bias.

The screening process was needed to eliminate smokers and individuals with known pulmonary diseases, like asthma. In addition, individuals presenting further limiting factors like constant use of biomass fuel or firewood for cooking were excluded from the lung function tests. Visitors and individuals who are non-residents, or have not lived in the region for at least five years were likewise excluded. Subjects with possible occupational exposure to air pollutants were also excluded from the tests. Lung function tests were carried out using a hand spirometer: Vitalograph micro-Spirometer (63313 Vitalograph micro™), and the subjects were questioned using the short version of the ECRHS II questionnaire.

The ECRHS II questionnaire is part of a survey aimed at determining, amongst others, the incidence and prognosis of allergy, allergic disease (asthma, hay fever and eczema) and low lung function in adults.[22] This questionnaire has been widely used in several international surveys, and even translated into several languages. It was validated for use in Argentina, [23] and was used in several studies in Nigeria to evaluate respiratory problems.[24 25, 26] With the aid of the questionnaire the level of respiratory problems experienced by individuals enrolled in the tests could be quantified and objectivized. Questions number 8 and 9 of the questionnaire were left out due to redundancy, and question number 10 was already asked at another point of the screening process.

Below are questions posed and a positive answer resulted to scoring a point:

1. Have you had wheezing or whistling in your chest at any time in the last 12 months? IF 'NO' GO TO QUESTION 2, IF 'YES':
1.1. Have you been at all breathless when the wheezing noise was present?
1.2. Have you had this wheezing or whistling when you did not have a cold?
2. Have you woken up with a feeling of tightness in your chest at any time in the last 12 months?
3. Have you been woken by an attack of shortness of breath at any time in the last 12 months?
4. Have you been woken by an attack of coughing at any time in the last 12 months?
5. Have you had an attack of asthma in the last 12 months?
6. Are you currently taking any medicine (including inhalers, aerosols or tablets) for asthma?
7. Do you have any nasal allergies including hay fever? 27

The selected individuals underwent basic clinical examination and the vital parameters: blood pressure, pulse, temperature and respiratory frequency were also measured. On confirmation of normal vital signs, subjects were once again questioned about their medical history and their social history, and thereafter asked to perform spirometry with the aid of Vitalograph micro-Spirometer (63313 Vitalograph micro™).

The procedure for spirometry was adequately explained to the prospects, as a non-invasive test with no known serious side effect for participants. Each participant used a single disposable mouthpiece, and the accompanying air filter was changed regularly. Proper hygiene regulations were followed according to local standards. Informed consent was obtained according to local standards. Lung function tests were done according to the recommendations of the American Thoracic Society to meet the Acceptability Requirements for Adults and for Children.[28] The minimum quality category was grade B. Several tests were carried out, and the best three results, in some rare cases the best two results, were recorded.

Parameters measured were:
The Forced Expiratory Volume in one second (FEV1), Forced Vital capacity (FVC), Tiffeneau-Pinelli Index, and Peak Expiratory Flow, PEF. The definition and relevance of the parameters are as follow:

Peak expiratory flow (PEF)
The highest flow that can be achieved through a forced exhale without any delay, starting from a position of maximum lung inflation, is known as PEF.[29]

Forced expiratory volume in 1 second (FEV1)

The term FEV1 refers to the maximum amount of air a person can exhale in the first second of a forced expiration after taking a full breath. It is measured in liters.[29] It is crucial to take into account factors such as race, height, gender, and age when determining normal values. Since FEV1, just like other pulmonary function parameter varies with age, standing height, sex and ethnicity, test results need to be compared to predicted values, and lower and upper limits of normal (LLN and ULN, respectively) that are appropriate for the individual being tested.[30] It is recommended, however to use the latter (LLN) for such comparison.[31]

LLN

The lower limit of normal (LLN) for lung function parameters is equal to the fifth percentile of a healthy population for the said parameter. [32] It is the equivalent to the z-score of -1.645, so that 95% of a healthy population falls within the normal range.[28]

Vital capacity (VC):

The VC refers to the change in volume at the mouth from full inspiration to complete expiration and is measured in litres. There are two reliable ways to calculate the slow VC: the expiratory vital capacity (EVC), which measures the maximum volume of air exhaled from the point of maximal inhalation, and the inspiratory vital capacity (IVC), which measures the maximum volume of air inhaled from the point of maximal exhalation. These manoeuvres are generally unforced, with the exception of reaching reserve volume (RV) or total lung capacity (TLC), which require additional effort.[29]

In young people, IVC, EVC, and FVC have similar values, but among those with obstructive lung disease, their values differ in this order: IVC > EVC > FVC. The average healthy young adult can have a lung capacity of approximately 4.5-5 litres, depending on factors such as race, height, age, and gender.

FEV1/FVC (Tiffeneau-Pinelli index, relative FEV1)

This is the ratio of FEV1 to forced vital capacity (FVC) expressed as a percentage.

Forced expiratory flow rate at 75%, 50%, and 25% of vital capacity (FEF75%, FEF50%, FEF25%)

During forced expiration, the average airflow rates are measured and recorded when 75%, 50%, and 25% of the vital capacity remains in the lungs. These values are the forced expiratory flow at 75%, 50%, and 25% of vital capacity respectively.

The sum of the questionnaire was used to score respiratory problems the subjects faced and was recorded. The collected data was evaluated statistically with the aid of the statistical program SPSS. Subjects were placed in three groups according to the proximity of their homes to the gas flaring sites. Group 1 was made up of subjects living 1-3km away from a gas flaring site, group 2 had subjects living 3.5-11km away, and subjects placed in group 3 lived 12-30km away from gas flaring sites. The total number of subjects in Group 1 was 70, in Group 2, 60 and in Group 3, 40. It was difficult to find individuals living farther than 30km from gas flaring sites due to the density of gas flaring sites in the Niger-Delta region, amongst other reasons.

Three out of 179 results were invalid and nine others did not complete the procedure, and were not included in the final analysis.

4. Results

4.1. Preamble

The total number of subjects recruited was 179. The total number of subjects tested was 170. Nine subjects did not complete the tests. 97 females and 73 males completed the tests. Three out of 170 results were not considered in the overall statistical analysis due to the quality of the spirometry results. The subjects were distributed into three groups, according to the proximity of their residence to a gas-flaring site as shown below in Table 1. Each group had approximately the same number of men, with 24 men in Groups 1 and 2, and 25 men in Group 3 as shown below in Table 2. Group 1 had 70 subjects, Group 2, 60 and 40 subjects were in Group 3. Further differentiation according to occupation was not done, however subjects with possible occupational exposure to air pollutants were excluded from the tests. Group 1 had subjects living 1-3km away from gas flaring sites, Group 2 had subjects living 3.5-11km away, and subjects placed in Group 3 lived 12-30km away from a gas-flaring site. It was difficult to find individuals living farther than 30km from gas flaring sites due to the density of gas flaring sites in the Niger-Delta region, amongst other reasons.

Pulmonary function varies with age, standing height, sex and ethnicity.[30] According to the recommendation of the American Thoracic Society many spirometry parameters can be calculated, but most do not add clinical utility and should not be routinely reported. Only FVC, FEV1, and FEV1/FVC need be routinely reported.[28] These values are relevant for clinical examination and evaluation for a pulmonary obstruction or restriction, or a mixed disorder. [33]

Due to the above mention variation, pulmonary function test results need to be compared to predicted values, and lower and upper limits of normal (LLN and ULN, respectively) that are appropriate for the individual being tested.[30]

4.2. Descriptive analysis

The spirometry test revealed striking FEV1 values in all groups. The mean FEV1 in Group 1 was 1.94L in Group 2: 2.23L and 2.46L in Group 3 with a standard deviation of 0.51L, 0.64L, and 0.80L in groups 1, 2 and 3 respectively. FEV1 shows the maximum volume of air that can be forcefully expired within 1 second after maximal inspiration.[26] The average result shows a reduction in this value in subjects living closer to gas flaring sites, with worst results measured in Group 1 (subjects living at a distance from 1 to 3 km away from a gas flaring site). Comparing these results to the Global Lung Initiative (GLI) reference values for African Americans, the average FEV1 in Group 1, subjects living at a distance of up to 3km from a gas-flaring site, was 1.94L. This value is lower than the lower level of normal (LLN) for the population of that age, height, ethnicity, and sex. The LLN for males in Group 1 was 2.48L and 2.21L for women as shown in Table 4. This trend is seen in Group 2 as well. The average FEV1 in Group 2 was 2.23L, and the LLN for men was 2.50L. Women in Group 2 had an average FEV1 equal to the LLN, as shown below in Table 5. The average FEV1 value in Group 3 were normal for women, and slightly lower for men (See Table 6) when compared to the LLN.

Test result for FVC for Group 1 was 2.45L on the average. The average FVC in Group 2 was 2.78L and 3.04L in Group 3. These values were lower than the LLN for men and women in Group 1, and for men in Group 2 as shown below in Tables 4 and 5. The average FVC for women in Group 2 was normal, as well as for men and women in Group 3, as shown in Table 5 and Table 6 below.

The mean Tiffeneau-index (FEV1%/FVC%) was 72.79%, 76.53% and 77.9% with a standard deviation of 19.32%, 12.08%, 9.07% for groups 1, 2 and 3 respectively as shown below in Table 7. 14 Individuals in Group 1 had Tiffeneau-index values below 70%, 10 people in Group 2 fall under this category, as well as 7 subjects in Group 3. The overall Kruskal-Wallis test showed significant p-value of <0.05 with respect to the FEV1 results, and 0.603 with respect to the Tiffeneau-index as shown in Table 8 below.

4.3. Inferential analysis

Comparing the groups using the Mann-Whitney test Group 1 to 2 showed a significant p-value of <0.05 in respect to the FEV1% results as shown in Table 9 below. Comparing Group 2 to 3 showed a p-value of 0.001 (See Table 10), and <0.01 (See Table 11) comparing group 1 to 3, all with respect to the FEV1% results. In comparing Group 1 to 2 with respect to the Tiffeneau-index, the asymptotic significance value was 0.469. The comparison of Group 2 to 3 showed an asymptotic significance value of 0.719, and the comparison of Group 1 to 3 showed a value of 0.364, all with respect to the Tiffeneau-index results.

The results from the ECRHS questionnaire were recorded as binary data, with ‘0’ meaning a negative response to posed questions, and ‘1’ meaning a positive response to the question. The sum of the answers was used to score the amount of respiratory complaints of the subjects. The results show that individuals in Group 1 had more respiratory symptoms/complaints than the rest of the groups. The total number of reachable score is six. Having a score above three would indicate respiratory symptoms that could be classified as above moderate, or slightly severe. The mean number of respiratory complaints was 3.4 in Group 1, 2.92 in Group 2 and 2.48 in Group 3. The score reveals that individuals living in areas

1 to 3 km from gas flaring sites had more than three respiratory symptoms on the average and those living 3.5km and father indicated having less than 3 symptoms on the average.
The results of the tests show that the best spirometry values were measured in Group 3 with FEV1 at 99% and Tiffeneau-index at 97%, with the worst values in Group 1 with FEV1 at 30%.

Distance [km]					
		Frequency	Percentages	Valid percentages	Cummulatve percentages
Valid	Group 1 (1 – 3 km)	70	41.2	41.2	41.2
	Group 2 (3.5 – 11 km)	60	35.3	35.3	76.5
	Group 3 (12 – 30 km)	40	23.5	23.5	100.0
	Total	170	100.0	100.0	

Table 1: Distribution of subjects into groups according to distance from flaring site.

Gender					
		Frequency	Percentages	Valid percentages	Cummulatve percentages
Valid	Female	97	57.1	57.1	57.1
	Male	73	42.9	42.9	100.0
	Total	170	100.0	100.0	

Table 2: Distribution of subjects according to gender.

Distance [km] * Gender Cross table					
			Gender		Total
			Female	Male	
Distance [km]	1 - 3	Total	46	24	70
		% in Distance [km]	65.7%	34.3%	100.0%
	3.5 - 11	Total	36	24	60
		% in Distance [km]	60.0%	40.0%	100.0%
	12 - 30	Total	15	25	40
		% in Distance [km]	37.5%	62.5%	100.0%
Total		Total	97	73	170
		% in Distance [km]	57.1%	42.9%	100.0%

Table 3: Distribution of gender of recruited subjects within each individual group.

Description:

Table 1 shows the distribution of recruited subjects in various groups, namely Group 1, Group 2, and Group 3 according to the distance in Kilometer (km) of the residence of the subject from the location of a gas-flaring site. The table also shows the percentage of the number of the subjects in each group in relation to the overall number of recruited subjects, i.e. Percentages.

Table 2 shows the distribution of recruited subjects according to gender. The table also shows the percentage of the number of female and male subjects in each group in relation to the overall number of recruited subjects, i.e Percentages.

Table 3 shows the gender distribution of recruited subjects inside the various groups. It also shows the number, as well as percentage of females and males in each group. This distribution shows that the number of males in each group is relatively constant.

Group 1

	Average Height (cm)	Average Age (years)	Average FVC (in L)	Average FEV_1 (in L)	LLN FEV_1 (in L)	LLN FVC (in L)
Male	164.86	31.54	2.45	1.94	2.481	3.010
Female	164.86	31.54	2.45	1.94	2.213	2.625

Table 4: Lung function values for group 1 with comparative LLN values according to GLI reference value for African Americans.

Group 2

	Average Height (cm)	Average Age (years)	Average FVC (in L)	Average FEV_1 (in L)	LLN FEV_1 (in L)	LLN FVC (in L)
Male	165.53	31.48	2.78	2.23	2.502	3.036
Female	165.53	31.48	2.78	2.23	2.230	2.646

Table 5: Lung function values for group 2 with comparative LLN values according to GLI reference value for African Americans.

Group 3

	Average Height (cm)	Average Age (years)	Average FVC (in L)	Average FEV_1 (in L)	LLN FEV_1 (in L)	LLN FVC (in L)
Male	164.80	30.05	3.04	2.46	2.504	3.025
Female	164.80	30.05	3.04	2.46	2.226	2.626

Table 6: Lung function values for group 3 with comparative LLN values according to the GLI reference value for African Americans.

Description:

Tables 4, 5, and **6** show Lung function values with comparative LLN (Lower Limit of Normal) values according to the GLI reference value for African Americans.

Group/Distance	Sum of Score	Vital Capacity %	FEV_1 %	Tiffeneau Index %
1/1-3km	3.4	64.45	59.55	72.79
2/3.5-11km	2.9	69.20	67.15	76.53
3/12-30km	2.5	79.18	74.33	77.90

Table 7: Average spirometry values according to groups.

Statistics for a, and b.				
	FEV_1	$FEV_{1\,\%}$	TIFF. INDEX FEV_1/FVC	VC%
Chi-Square	19.209	41.110	1.011	39.238
Df	2	2	2	2
Asymptotic Significance	0.000	0.000	0.603	0.000
a: Kruskal-Wallis-Test b: Group variables: Distance (km)				

Table 8: Kruskal-Wallis-Test: Test in all Groups

Description:

Table 7 shows the average spirometry values (Vital capacity percentage (VC %), Forced Expiratory Volume in one second FEV_1 percentage (FEV1 %), and Tiffeneau-Index (FEV1%/FVC %), as well as the average sum of scores for Groups 1, 2 and 3.

Table 8 shows an inferential statistical analysis (Kruskal-Wallis-Test) of spirometric values (FEV_1, FEV_1%, Tiffeneau-Index (FEV1%/FVC %), and VC %) in all groups.

	FEV_1	FEV_1 %	TIFF. INDEX FEV_1/FVC	VC%
Mann-Whitney-U	1408.000	1165.500	1945.000	1436.000
Wilcoxon-W	3686.000	3443.500	4430.000	3714.000
Z	-2.907	-4.081	-0.724	-2.774
Asymptotic Significance (double-sided)	0.004	0.000	0.469	0.006
a: Group variable: Distance (km)				

Table 9: Mann-Whitney-U-Test: Distance [km] 1 – 3 to 3.5 – 11
(Group 1 to Group 2)

	FEV_1	FEV_1 %	TIFF. INDEX FEV_1/FVC	VC%
Mann-Whitney-U	1003.000	744.000	1149.000	600.000
Wilcoxon-W	2833.000	2574.000	2979.000	2430.000
Z	-1.386	-3.211	-0.359	-4.226
Asymptotic Significance (double-sided)	0.166	0.001	0.719	0.000
a: Group variable: Distance (km)				

Table 10: Mann-Whitney-U-Test: Distance [km] 3.5 – 11 to 12 – 30
(Group 2 to Group 3)

	FEV_1	FEV_1 %	TIFF. INDEX FEV_1/FVC	VC%
Mann-Whitney-U	679.500	422.500	1254.000	415.500
Wilcoxon-W	295.500	2700.500	3739.000	2693.500
Z	-4.253	-5.911	-0.908	-5.956
Asymptotic Significance (double-sided)	0.000	0.000	0.364	0.000
a: Group variable: Distance (km)				

Table 11: Mann-Whitney-U-Test: Distance [km] 1 – 3 to 12 – 30
(Group 1 to Group 3)

Description: Tables 9, 10, and 11 show group by group inferential statistical analysis (Mann-Whitney-U-Test) of spirometric values (FEV_1, FEV_1%, Tiffeneau-Index (FEV1%/FVC %), and VC %)

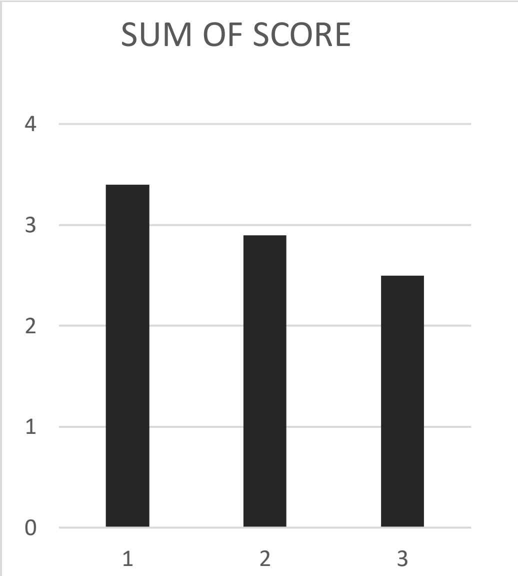

Diagram 3: Sum of Score in Groups.

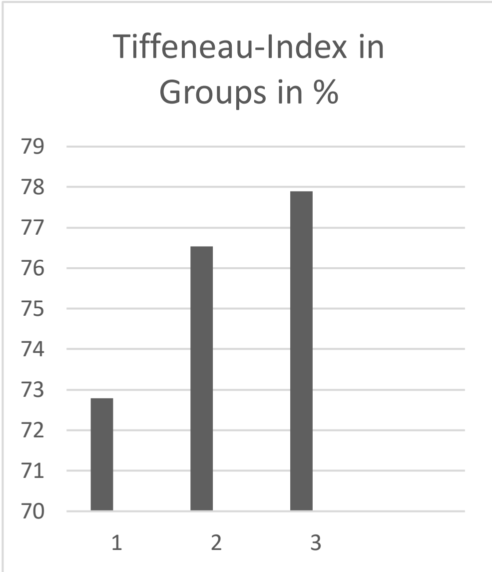

Diagram 4: Tiffeneau-Index in Groups**.**

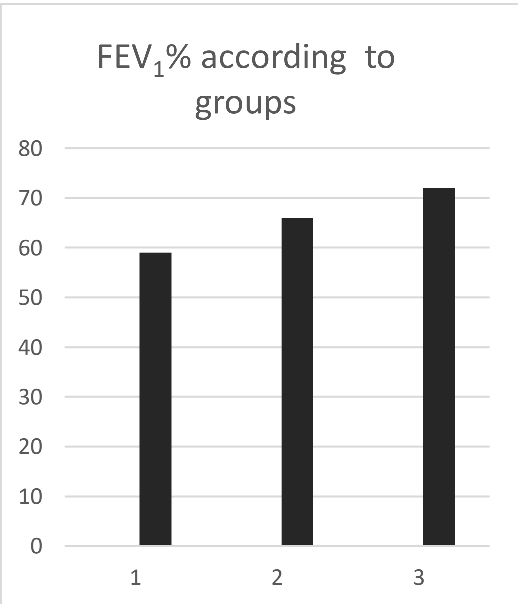

Diagram 5: Average FEV_1 in Groups.

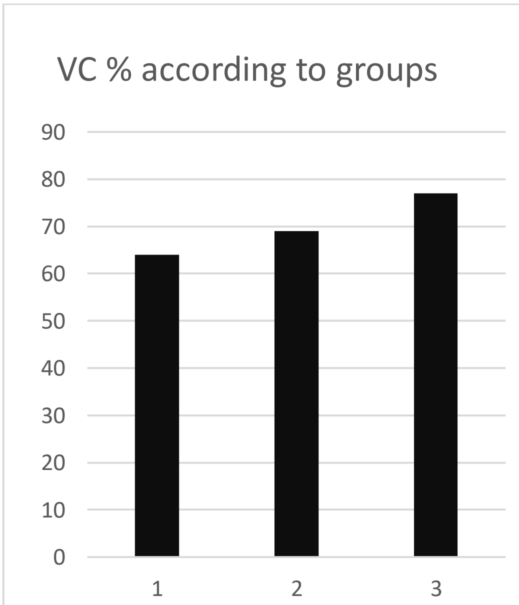

Diagram 6: VC values in Groups.

Description:

Diagram 3 shows the average of the sum of scores in each group (Groups 1, 2 and 3). The score was developed using the European Community Respiratory Health Survey questionnaire II (ECHRS II). The highest number reachable is a score of six. The ECRHS II questionnaire evaluates the incidence of respiratory complaints by the subjects.

Diagram 4 shows the Tiffeneau-Index (FEV1%/FVC%) in Groups 1, 2 and 3 in percentage.

Diagram 5 shows the FEV_1 percentage in Groups 1, 2 and 3.

Diagram 6 shows the Vital capacity values in Groups 1, 2 and 3 in percentage.

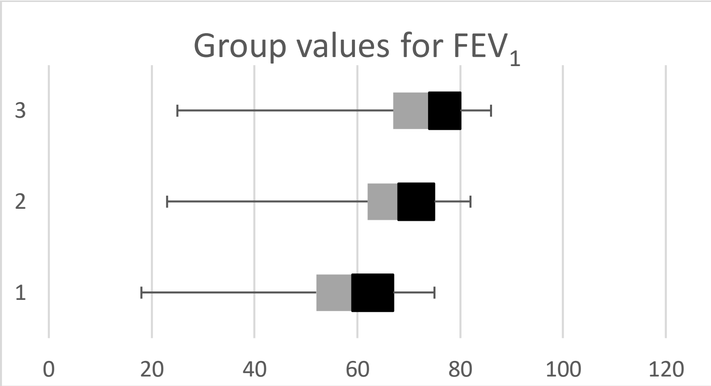

Diagram 7: FEV_1 in groups in Box and Whisker plot

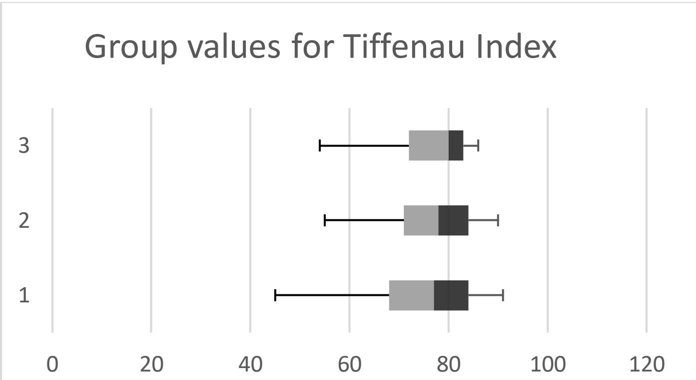

Diagram 8: Tiffeneau Index in groups in Box and Whisker plot

Description:

Diagram 7 shows the boxplot for the FEV_1 percentage in Groups 1, 2 and 3. This box plot shows the median, the minimum and maximum, as well as the 25^{th} and 75^{th} percentile of the FEV_1 percentage in the various groups.

Diagram 8 shows the boxplot for the Tiffeneau-Index (FEV1%/FVC%) in Groups 1, 2 and 3. This box plot shows the median, the minimum and maximum, as well as the 25^{th} and 75^{th} percentile of the Tiffeneau-Index (FEV1%/FVC%) in the various groups.

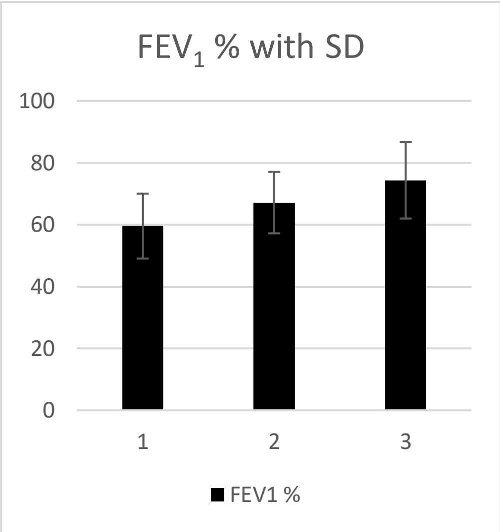

Diagram 9: FEV_1 with Standard-deviation

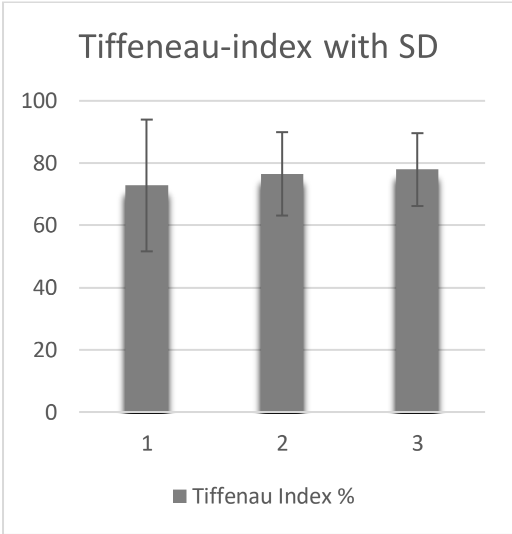

Diagram 10: Tiffeneau-Index with standard deviation

Description:

Diagram 9 shows the FEV_1 percentage and standard deviation integrated as whiskers for Groups 1, 2 and 3.

Diagram 10 shows the Tiffeneau-Index (FEV1%/FVC%) and standard deviation integrated as whiskers for Groups 1, 2 and 3.

7

Auto ID : MP0796521032016104507 Vitalograph® 29-03-2016 19:20:01

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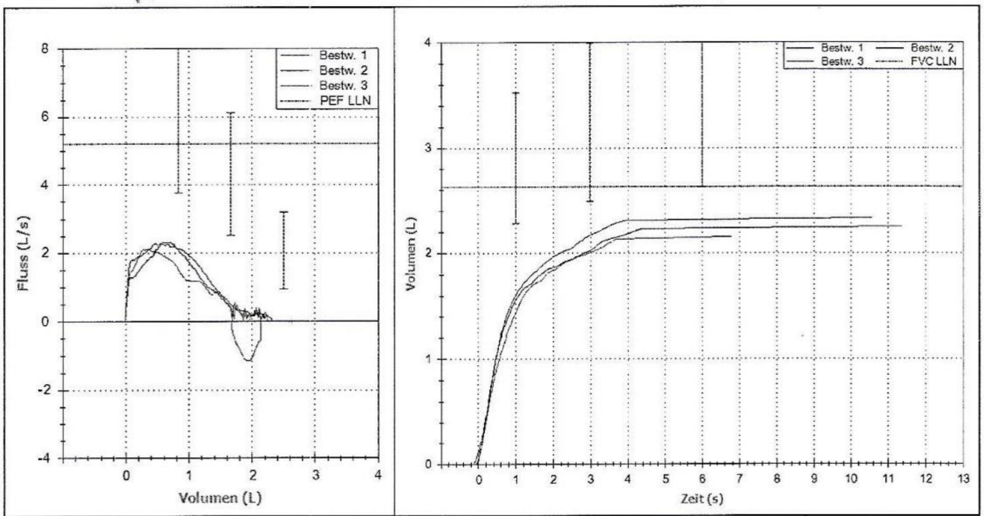
♀ 28 157 cm

21-03-2016 10:45:07

6 EGKS (1.00)

24-11-2015 16:07:11



BTPS	Norm	Bestw. 1*	Bestw. 2	Bestw. 3	% Norm.
hh:mm:ss		10:49:56	10:49:08	10:47:52	
VC (L)	**3.31**	2.16	2.16	2.16	**65**
FVC (L)	**3.34**	2.33	2.25	2.15	**70**
FEV1 (L)	**2.90**	1.61	1.56	1.45	**56**
FEV1/VK	**0.84**	0.69	0.69	0.67	**82**
PEF (L/min)	**401**	136	139	127	**35**
FEF25-75 (L/s)	**3.93**	1.08	0.96	1.06	**27**
FEF25 (L/s)	**5.96**	2.23	2.27	1.99	**37**
FEF50 (L/s)	**4.31**	1.61	1.44	1.18	**37**

FVC-Repr. (L) (%)	FEV1-Repr. (L) (%)	FET (s)	Vext (L)	Plateau	Keine Artefakte < 1s
0.08 (4%)	0.05 (3%)	10.57	0.06	✓	✓

Computer-Interpretationen sind unverbindlich.
Interpretation der Testsitzung: Leichte Restriktion.

Signatur: ______________________ **Datum:** ______________

Vitalograph Reports: 65033 V2.00.0124
Seite 1 von 1

Vitalograph micro

63703 V1.02 ID : MP07965
63700 V1.01.0047

Diagram 11: Example of spirometry result from group 1 (Living 1-3.5 Km from flaring site).

Auto ID : MP0796523032016121409 | Vitalograph | 29-03-2016 18:50:21

MP07965_20160323121134

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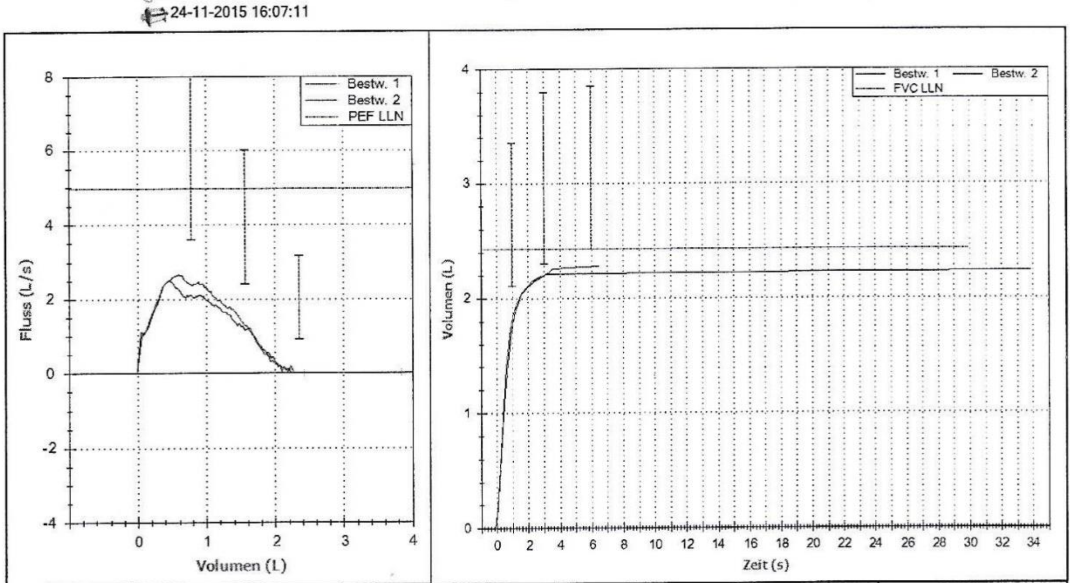
2 | EGKS (1.00)

24-11-2015 16:07:11



BTPS	Norm	Bestw. 1*	Bestw. 2	Bestw. 3	% Norm.
hh:mm:ss		12:14:09	12:15:40		
VC (L)	3.10	2.25	2.25		73
FVC (L)	3.14	2.28	2.23		73
FEV1 (L)	2.73	1.83	1.76		67
FEV1/VK	0.84	0.80	0.78		95
PEF (L/min)	386	159	149		41
FEF25-75 (L/s)	3.90	1.78	1.64		46
FEF25 (L/s)	5.82	2.63	2.29		45
FEF50 (L/s)	4.21	2.02	1.81		48

FVC-Repr. (L) (%)	FEV1-Repr. (L) (%)	FET (s)	Vext (L)	Plateau	Keine Artefakte < 1s
0.05 (2%)	0.07 (4%)	6.49	0.13	✓	✓

Computer-Interpretationen sind unverbindlich.
Interpretation der Testsitzung: Leichte Restriktion.

Signatur: ______________________ **Datum:** ______________

Vitalograph Reports: 65033 V2.00.0124
Seite 1 von 1

Vitalograph micro

63703 V1.02 ID : MP07965
63700 V1.01.0047

Diagram 12: Example of spirometry result from group 2 (Living 3.5-11 Km from flaring site).

113

Auto ID : MP0796530032016115237 Vitalograph® 06-04-2016 01:51:20

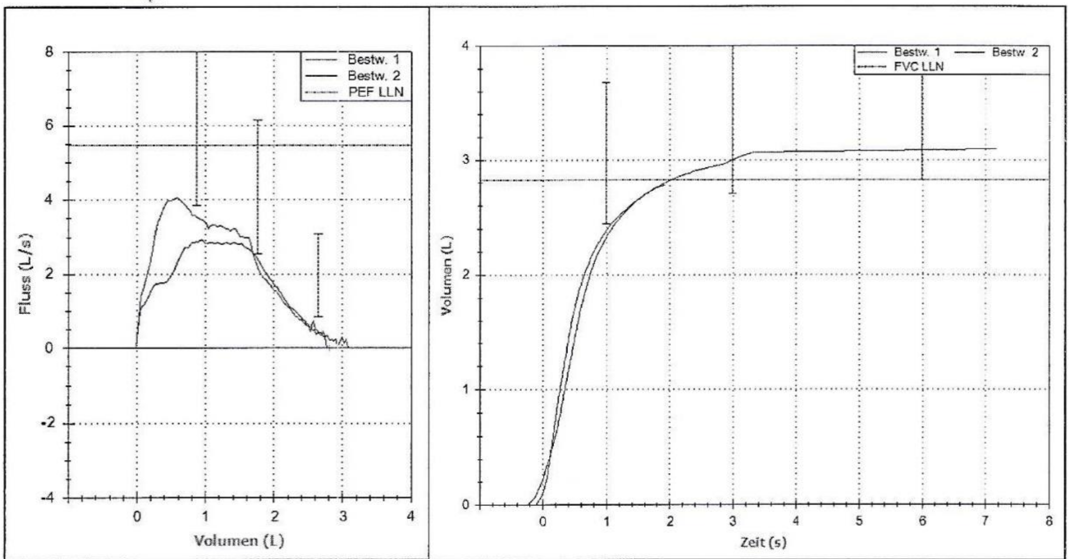
MP07965 20160330114855

♀ 36 166 cm

30-03-2016 11:52:37

2 EGKS (1.00)

24-11-2015 16:07:11



	BTPS	Norm	Bestw. 1*	Bestw. 2	Bestw. 3	% Norm.
hh:mm:ss			11:53:18	11:52:37		
VC (L)		**3.52**	3.25	3.25		**92**
FVC (L)		**3.53**	3.09	2.78		**88**
FEV1 (L)		**3.06**	2.39	2.33		**78**
FEV1/VK		**0.82**	0.74	0.72		**90**
PEF (L/min)		**416**	243	176		**58**
FEF25-75 (L/s)		**3.77**	2.09	2.47		**55**
FEF25 (L/s)		**6.05**	3.71	2.70		**61**
FEF50 (L/s)		**4.33**	3.01	2.83		**70**

FVC-Repr. (L) (%)	FEV1-Repr. (L) (%)	FET (s)	Vext (L)	Plateau	Keine Artefakte < 1s
0.31 (10%)	0.06 (3%)	7.16	0.13	✔	✔

Computer-Interpretationen sind unverbindlich.
Interpretation der Testsitzung: Atemfunktion im Normalbereich.

Signatur: ______________________ **Datum:** ______________

Vitalograph Reports: 65033 V2.00.0124
Seite 1 von 1

Vitalograph micro

63703 V1.02 ID : MP07965
63700 V1.01.0047

Diagram 13: Example of spirometry result from group 3 (Living 11-30 Km from flaring site).

5. Discussion

Air pollution poses a major risk to the entire well-being of an individual and leads to an increase in cardio-vascular as well as respiratory disorders, which in-turn increases the risk of mortality. A case-crossover study carried out in the United States of America shows that even short-term exposures to pollutants like $PM_{2.5}$ (Particulate matter 2.5) and warm-season ozone were significantly associated with increased risk of mortality in older adults.[34] $PM_{2.5}$ refers to tiny particles or droplets in the air that are two and a half microns or less in width. These particles primarily stem from the emissions of vehicles such as cars, trucks, buses, and construction equipment, as well as from other fuel-burning activities like wood, heating oil, or coal. Additionally, natural sources like forest and grass fires also contribute to these particles. [35]

It is worth noting that a study conducted in Iran has revealed that PM_{10} exposure is responsible for a significant percentage of annual deaths. Specifically, this exposure accounts for 44.3% of total annual deaths caused by cardiovascular diseases and 9.55% of those caused by respiratory diseases.[36] This study took into consideration the total number of deaths associated with the exposure to $PM_{10.}$ Another study conducted in the US utilized a nationally representative sample. The findings unequivocally demonstrated that the association between $PM_{2.5}$ and heart disease mortality was remarkably similar to previous estimates and was consistently elevated across the board. Significantly, the study identified no discernible differences in the associations among non-Hispanic black and Hispanic adults compared to non-Hispanic white adults. [37] In other words, Hispanic adults, black adults and white adults are exposed to a similar increased risk of mortality when exposed to air pollution.

5.1. Niger-Delta in a Nutshell

In view of the health risks associated with air pollution, this study looks into the respiratory problems people living in the Niger-Delta region of Nigeria face because of air pollution caused by gas flaring. Nigeria is a country of about 200 million people, located in West Africa and the Niger-Delta Region is located in the Southern part of the country. Over 40 million people live in this region of Nigeria and the population density is about 600/square kilometre. This region also hosts about 220 gas flaring sites, amounting to one gas-flaring site per 318 square kilometres.

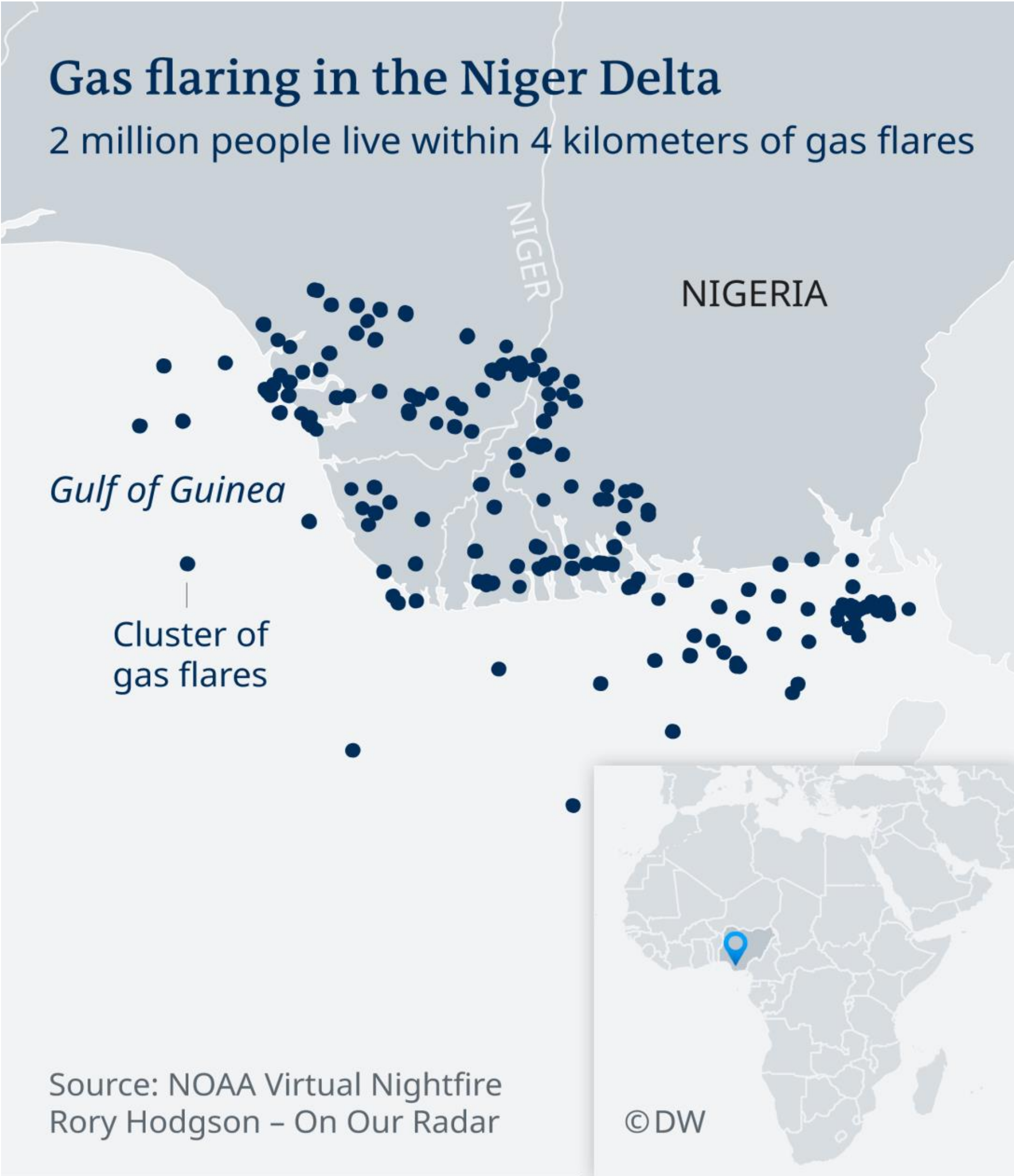


Diagram 14: Map of a section of the Niger-Delta showing gas flaring sites .[14]

The climate in the Niger-delta is tropical, such as found in most countries along the equator, with long months of rainfall and high humidity levels, a typical tropical monsoon climate. Wind velocity is relatively low compared to that found in the northern part of the country, and average monthly wind velocity of about 2-3m/s has been recorded by researchers in the coastal region of Nigeria.[38]

5.2. Climate as a major factor for pollutant concentration

Although various factors come together to determine the concentration of particulate matter or pollutant in a region, researchers have found that wind speed/velocity, humidity as well as wind direction play an important role in air pollution. Higher wind velocity, for example leads to a lower concentration of polluted air, since the air is easily and widely dispersed.

To buttress this point, some researchers in India looked at how meteorological factors affected the concentration of pollutants. These Researchers built two stations, a monitoring station to serve as the source station from where air pollutants are emitted, and a dilution station situated 6 to 7 km far towards North from the source station. The results of their tests showed that as wind speed and temperature increase the dispersion of the pollutant increase. This led to a large difference in air pollutants concentrations between the source station and dilution station. Out of the three meteorological parameters used (wind speed, wind direction, and temperature) wind speed is found to affect the dispersion of pollutants the most.[39]

The European Environment Agency (EEA) states that air pollutants can spread through various means, and not only by air. Other means of dispersion of air pollutants may also include water, food, soil, and living organisms. The way pollutants spread depends on the type of pollutant and the emission source. Environmental conditions also play a significant role in determining the rate and pattern of dispersion. Several factors affect pollution dispersal in the air, including meteorological conditions such as wind speed, wind direction, and atmospheric stability, emission height (ground level or high-level sources), local and regional geographical features, and the emission source (fixed point or diffuse sources like cars and solvents) [40]

These geographic factors contribute in keeping the climate in the Niger Delta relatively constant, especially as the wind moves slowly allowing polluted air to be suffered most likely in the region where it is generated. These factors make the Niger-Delta region unique in view of air pollution and its health effects, as opposed to Alberta in Canada with a monthly wind speed of about 5m/s or Dhahran with a wind speed of about 3m/s and totally different meteorology as the Niger-delta.

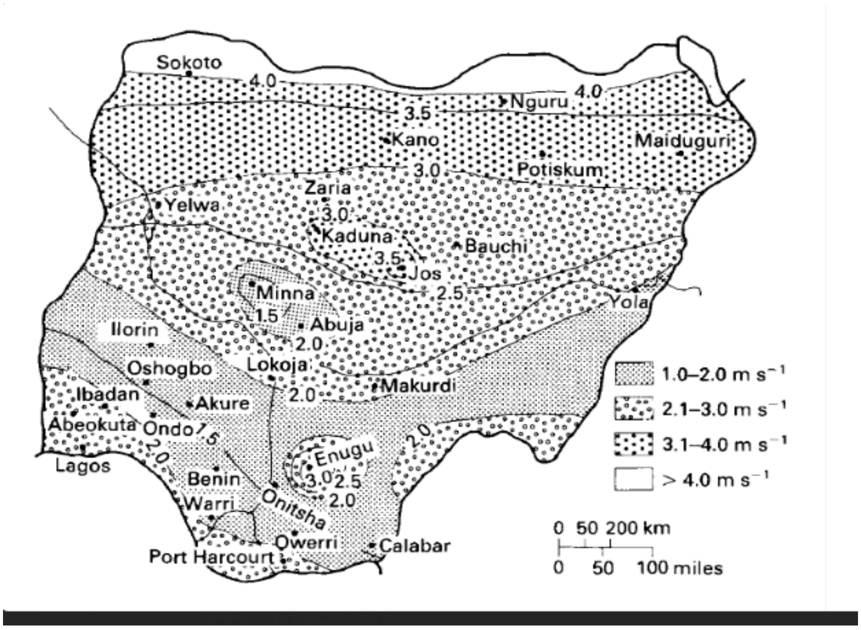


Diagram 15: Nigeria annual average wind speeds distribution[41]

5.3. Further Discourse

The Niger-Delta region is bordered by the Atlantic Ocean to the South and is rich in crude oil and gas deposits. Exploration of these natural resources have been taking place for over half a century and this has given rise to the environmental and health issues suffered by the millions living in this region. One of the major problems caused by oil exploration is gas flaring. It is a common practice by oil exploring firms to flare associated gas, which is gas found with crude oil during the drilling process. Most companies would have facilities to store this gas in order to minimize the amount being flared, yet others due to lack of such facilities end up flaring the entire amount of gas found while drilling. This has caused a steady rise in the level of pollutants like particulate matter and other dangerous compounds found in the air.

Several studies have been done with regard to the health concerns crude oil exploration poses to the inhabitants of oil exploring communities. One of such studies linked gas flaring as a risk factor to developing hypertension, a non-communicable cardio-vascular disease.[12] Our study however focuses on the respiratory problems caused by gas flaring and intends to establish a relationship between air pollution caused by gas flaring and lung function.
To achieve this aim, we started by comparing the lung function of individuals living close to gas flaring sites with those living afar off.

We carried out lung function test on 170 individuals selected from three Niger-Delta communities and grouped the subjects according to the proximity of their homes to a gas flaring site. The subjects were also screened to get the desired population and the whole process and methods of the test is documented in the sub-section ‘Methods.’ Due to the density of gas flaring sites in this region, it was difficult to obtain subjects that lived farther than a perimeter of 30km from such sites.

The population in view ranges from sub-urban to urban and air pollution is a wide spread menace as expected in such areas. Apart from gases released into the atmosphere from automobile engines, there has been an increase in illegal crude oil refining activities in the region covered by this test. This too contributes immensely to the problem of air pollution. What this means is that an average individual from this region would be expected to develop a respiratory problem sooner or later depending on the duration of habitation in this region.

5.4. Addressing the research question

The results show that people living closer to gas flaring sites had reduced lung function as shown in the FEV_1 values, and more respiratory complaints like wheezing and coughing as recorded in the score obtained from the questionnaire (See Table 7 above). We eliminated possible bias by excluding smokers and individuals with previous history of respiratory illnesses, like asthma and people with a history of using bio mass fuel in cooking, like firewood. Subjects with possible occupational exposure to air pollutants were also excluded from the tests.

Individuals with healthy lungs have FEV_1 values above the LLN for their age, height, sex and ethnicity. This applies also to FVC as well, which is an indicator for a restrictive lung disease. When these values (FEV_1 and FVC) are compared with each other a ratio (Tiffeneau-Index) is generated which confirms the absence or presence of an obstructive lung problem.[33] The ERS/ATS technical standard on interpretive strategies for routine lung function tests recommends an analysis of the Tiffeneau-Index first. Once this ratio is below the LLN, and the FVC is normal (>LLN), then we can confirm a clinical obstruction. It is noteworthy that the ERS/ATS Guideline for COPD classifies a clinical obstruction by a Tiffeneau-Index of <0.7.[42]

Going by the results of the tests 14 Individuals in Group 1 had Tiffeneau-index values below 70. 10 people in Group 2 fall under this category, and 7 subjects in group 3. The collated score from the questionnaire shows a reduction of pulmonary problem experienced by the subjects as one moves or lives farther from gas flaring sites. Subjects in Group 1, those living in a perimeter of up to 3km from gas flaring sites recorded an average of more than 3 respiratory complaints, subjects living 3.5 to 11km away from flaring sites had about 3 symptoms of breathing discomfort and those farther away about 2-3 symptoms.

These results, even in such a small-scale experiment answer our research questions: a) How does gas flaring affect the pulmonary system of people living in the Niger-Delta? b) How does distance to a flaring site affect the lung function of the inhabitants of the Niger-Delta region? Gas flaring has negative effects on the pulmonary system of those living close to gas flaring sites as seen above. Living close to a gas-flaring site worsens lung function parameters, like FEV_1 and FVC, and increases pulmonary problems with symptoms like, wheezing and coughing as stated above.

5.5. Limitations

Despite these remarkable findings, some limitations were inevitable due to the resources at hand while carrying out this research. Real time particulate matter levels in test locations was not measured. This would have provided a more accurate variable in the overall evaluation of pulmonary test results. It would have also given an overview of real-time amount of noxious gas the subjects were exposed to. The study conducted in the gas flaring community of Igrwuta in 2009 revealed alarming findings. The concentration of particles during the rainy season was found to range from 0.4 ± 0.4μg/m3 in June to 25 ± 5.4μg/m3 in May across all flaring sites. What is even more concerning is that the levels of particulates exceeded regulatory limits for TSP, PM10, and PM7 at all sites, particularly during December and January.[9] This poses a great risk to the health and wellbeing of the community, and immediate action must be taken to address this issue.

At the time of conducting this study there was no robust health database with sufficient data to represent majority of the study population. This study uses a cross sectional design, which is prone to several biases, like recall bias.[43] Some subjects had difficulty in accurately reporting pulmonary symptoms. Some subjects denied having any breathing problems in the last twelve months, only to claim to do so when the same question was posed in a different manner. In some cases, after denying having any breathing problems some subjects indicated to have breathing problems by giving a positive answer to subsequent questions inquiring the presence of a breathing discomfort. Some subjects also denied having asthma, only to affirm the use of an anti-asthmatic drug.

The recruiting process involved a screening process for eligible subjects to eliminate smokers, and other variables that may increase the probability of subjects having poor lung function values, like asthma in the subject's medical history. This pre-selection, which may be a strength for this study, could also lead to selection bias. Although average age, number of men, and height in the groups were similar, the number of subjects do not completely cover the range of the population of the study area. Pregnant women, children, as well as the elderly (66 years and above) were not recruited for this study. This implies that this project did not examine the hazards that pregnant women and their unborn babies are exposed to due to gas flaring. Young children too were not covered in this project; even though it is estimated by the World Bank that air pollution of this manner would lead to an increase in child mortality.[10] The ratio of women to men was 3:1 in Group 1, 3:2 in Group 2, and 1:3 in Group 3. This too poses a limiting factor in interpreting the results.

Finally, the test results should be interpreted with caution. The results show the plausibility of a negative relationship between gas flaring and lung function, but cannot be used to prove that the exposure to air pollution caused by gas flaring leads to a pulmonary disease. Several studies in this regard have proven the futility of trying to establish such claims.[44]

6. Summary

Gas flaring among other man made and industrial activities is a major source of air pollution in the Niger-Delta. These flaring activities which have existed over 50 years have adversely affected the environment and has caused a rise in health problems suffered by individuals living in this region. The unique geographical factors in this region makes it difficult for polluted air to disperse swiftly leading to a situation, where the effects of polluted air are felt by those living in the region where the problem originates. Health problems like cardiovascular diseases have been recorded in the past and this project looked into the respiratory problems faced by individuals as a result of living close to a gas-flaring site.

To achieve this aim, 179 individuals were recruited, 170 participants were carefully examined, as previously pulmonary sick people, smokers and people using biomass fuel for cooking were excluded. Subjects with possible occupational exposure to air pollutants were excluded from the tests. The recruited individuals answered a questionnaire to assess the respiratory problems they experienced and underwent lung function test using a hand spirometer. The subjects were grouped into 3 groups as follows: People living within a perimeter of 1-3km in Group 1, 3.5-11km in Group 2 and 11-30km in Group 3.

The results show an increase in respiratory symptoms as one lives closer to a gas-flaring site. All individuals in the test had lived a considerable number of years (five years) in this region and the average result shows a reduction in lung function in all groups. However, Group 1, which was made up of people living very close to a gas flaring site within a perimeter of up to 3km showed to have more respiratory problems, like coughing, wheezing, shortness of breath and a more reduced lung function as shown by lung function tests.
The values measured among others were the FEV_1, the FVC, and the Tiffeneau-Index.

The tests show poorer average FVC value in relation to the proximity of the residence to a gas-flaring site. The average FEV_1 values follow similar pattern. Although the average Tiffeneau-Index in all groups was normal 14 individuals in group 1, 10 in group 2 and 7 in group 3 had values lower than the expected normal values (LLN).

This goes in line with our initial concern that living close to a gas-flaring site would lead to more respiratory problems and poorer lung function. Stricter regulations would be needed to prevent air pollution caused by gas flaring from further escalation, and we recommend that flaring sites be moved farther away from residential areas. The best solution, however, would be the building of gas storage facilities and infrastructure, as well as the proper use of explored gas for energy production.

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8. Appendix

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