EFFECT OF GAS FLARING ON THE RAINWATER QUALITY AND SOME OTHER ENVIRONMENTAL COMPONENTS OF ODAGWA IN RIVERS STATE, NIGERIA

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CERTIFICATION

This is to certify that this study on the "**EFFECT OF GAS FLARING ON THE RAINWATER QUALITY AND SOME OTHER ENVIRONMENTAL COMPONENTS OF ODAGWA IN RIVERS STATE, NIGERIA**" is an original work written by UZOMA HENRY CHIJIOKE (REG. NO. 20114774358) of the Department of Environmental Technology, School of Environmental Science.

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DEDICATION

This research work is dedicated to Prince Henry Uzoma (Jnr) and Late Princess Lydia Chinwendu Ekeh for the joy they created in my heart, also to brilliant Nigerians whom poverty denied access to tertiary education.

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To Dr. Mrs. S.M.O. Akhionbare my project supervisor, mentor and motivator, I must say thank you so much for your guidance, commitment and mentoring that resulted in this intellectual master piece.

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ABSTRACT

This study examines the effect of gas flaring on the rainwater quality and some other environmental components of Odagwa, a community hosting an SPDC flow station. Rainwater samples were collected at various distances from the flare point in ambient air, from various roofs and at various times during the rainy season. The direction of wind during the study period was predominantly south-west blowing towards the north-east direction. Samples were tested for Temperature, Turbidity, Colour, pH, Electrical Conductivity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Sodium, Magnesium, Calcium, Total Hardness (TH), Sulphate, Nitrate, Chloride, Aluminium, Iron, Zinc, Lead, Cadmium, Nickel and Manganese using standard methods. Tables, Bar charts, Line graphs, Percentile and Correlation were used to present and analyze the data. Results showed the following range of values: Temperature (30^oC-34^oC), Colour (12 – 18TCU) Turbidity (45-64 NTU), EC (16-20.5µS/cm), TDS (16-20mg/dm^3), pH (5.1 – 6.5), T S S (42 – 65mg/dm^3), Sodium (100-140mg/dm^3), Mg (0.1-0.18mg/dm^3), TH (50mg/dm^3) Sulphate (20-50mg/ dm^3), Nitrate (5-6mg/dm^3), Chloride (5.5-5.7mg/dm^3), Mn (0.05 – 0.3 mg/dm^3), Pb (0.04 – 0.08mg/dm^3), Cd (0.01– 0.24mg/dm^3) and Ni (0.001 – 0.05mg/dm^3) within 500m- 5000m distance from gas flare point. Results for intercepted rainwater samples collected from zinc, aluminium and asbestos roofs were; Turbidity (60 – 62 NTU), Colour (16-17units), pH (5.8 – 8), T S S (58 – 60 mg/dm^3), Mg (0.15-0.3 mg/dm^3), Sulphate (96 – 120mg/dm^3), Nitrate (40–60 mg/dm^3), Iron (0.04-0.05mg/dm^3) and Zn (0.05 – 10 mg/dm^3). A high negative correlation was recorded between distance from flare point and temperature in North, South, West and East directions (R^2=-0.88, - 0.92, - 0.89, - 0.877 respectively). Mean monthly pH of rainwater within Odagwa was 5.5-6.9 and its correlation with amount of rainfall was strong and positive (R^2=0.859). Generally results indicated that the rainwater and air quality of Odagwa are negatively impacted by gas flaring within the community. It was recommended that the use of rainwater in the community take into consideration necessary treatments.

KEYWORDS: Gas flaring, rainwater, quality and temperature.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Rain is a form of precipitation which forms a very important chain in the water cycle for water circulation on the planet earth.

In meteorology precipitation is any product of atmospheric condensation of water vapour that is deposited on the surface of the earth. It occurs when the atmosphere becomes saturated with water vapour and water condenses and falls out of the solution. The water vapour saturation occurs due to cooling and addition of moisture.

Rain according to meteorological consideration is water droplets that vary in size from 0.5mm to about 7mm, which are visible to the eyes (Anyadike and Obeta, 2012). We have three major types of rainfall, they include, convectional or convective storm, orographic or relief and frontal or cyclonic rain fall.

In the Niger Delta, there are large bodies of water and vegetation (tropical rainforest and mangrove swamp) that add moisture to the atmosphere. As a tropical region with other anthropogenic activities like oil exploitation, the ground level is usually heated up which makes the air to rise and get cooled as it ascends the altitude due to adiabatic lapse rate leading to saturation and rainfall. The type of rainfall experienced in the Niger Delta is majorly the convective storm which accounts for the heavy rains in the region. A closer look at the

Niger Delta rainfall and temperature data shows an increasing trend pointing to climate change traceable to Oil and Gas related activities.

The rain water is a natural source of water and in its pure state possesses the Physico-chemical and Biological characteristics of pure water (Akhionbare, 2009). At room temperature rainwater is a colourless, tasteless and odourless liquid. It boils at 100^0C (212^0F) and freezes at 0^0C (32^0F). It is a stable compound difficult to be broken by heating, when electrically conducting ions are present in water, current flows through water decomposing it into $H_2(g)$ and $O_2(g)$.

Rainwater, like other waters is a very good solvent especially for ionic or polar compounds hence the popular phrase "water a universal solvent". It is a good solvent for acids, bases, salts and a wide range of gases example CO_2, SO_2, NO_x, $NH_3(g)$.

The water molecule is made up of 2 atoms of Hydrogen and one atom of Oxygen bonded at an angle of 105^0 making it behave like a body having opposite charges called dipole. The chemical formula is simply H_2O but its behaviour is rather complex (Ellen *et al*, 2004).

Rainwater while falling through the atmosphere dissolves, dilutes and hydrolyses other pollutants in the space ranging from gases, particulates to vapours. This leads to the contamination of rain. Although this singular act may cleanse the atmosphere of pollutants yet the earth's natural and built environment, hydrosphere and lithosphere cannot be spared.

Depending on the activities going on in an area, rainwater can become turbid, coloured, acidic, alkaline, hardened, contaminated by trace elements, chlorides, sulphates, Nitrates, suspended solids, organic carbon, phosphates, Dissolved solids and carbonates.

The Niger Delta comprises the six states of the South-south Geopolitical Zone of Nigeria until in the recent past when Imo, Abia and Ondo States were added by the Olusegun Obasanjo Administration. The present day Niger Delta is made up of nine oil producing states of Nigeria, they include; Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers States.

Since the discovery of oil in commercial quantities at Oloibiri in the present day Bayelsa State by shell BP in 1956, Oil exploration and exploitation activities have been on the increase. Today, over 1,481 oil wells have been developed, producing from over 159 oil fields. There are more than 7000 km of pipelines and flowlines as well as over 275 flow stations operated by more than 13 oil companies (NNPC, 2001).

The Niger Delta environment have become the sink for over 1.8 billion cubic feet of associated gas flared on daily bases from over 123 flaring sites releasing over 45.8 billion kilowatt of heat (Amefiok *et al*, 2013).

Can the Niger Delta environment remain the same over forty years of incessant and ever increasing oil and gas exploitation? Closer study on Odagwa a community in Etche Local Government Area of Rivers State will go a long way in answering the above question.

Flaring of gas being typical fossil fuel combustion has notable products such as carbon dioxide (CO_2), Carbon Monoxide CO, Sulphur Dioxide SO_2, Nitrogen Oxides NO_X, Methane CH_4, Carbon Disulphate CS_2, Carbonyl Sulphide COS, Benzene, Toluene, Xylene, Benzo($\propto$)Pyrene, Hydrogen Sulphide H_2S, Metals like Arsenic, Chromium, cadmium, Nickel, Cobalt lead, Zinc, Iron, Dioxines and Particulate matter. The presence of these compounds in the atmosphere is of great environmental concern (Mokhatab *et al*, 2006).

1.2 Statement of the Problem

The particulates from the flare points could affect the turbidity, suspended solid and colour of rainwater. Gases like SO_2, NO_x, CO, CO_2 and CH_4 as well as sulphates, Nitrates and Carbonates could affect the pH, acidity and alkalinity, COD, Hardness, TOC and HCO_3 of rainwater. Introduction of trace elements into the rainwater cannot also be ruled out.

Obviously if the physico-chemical characteristics of rainwater are altered, there will be a strong indication that the physical environment of the area will also be affected.

As rain falls, it will have contact with vegetation, buildings, physical structures, soil, surface waters, ground waters, animals, human beings and in fact the bulk of the environment stands at risk of being polluted.

The qualitative and quantitative determination of the effect of gas flaring on the physico-chemical characteristics of rain water in Odagwa Community

and its corresponding impact on the physical environment of the area is therefore the thrust of this work.

1.3 Aim and Objectives

The aim of this research was to examine the effect of gas flaring on the rainwater quality and some other environmental components of Odagwa Community.

Objectives;

(1) To determine the Physico-chemical properties of rainwater at various distances from flare point.

(2) To determine any temporal variation in rainwater properties within 500m – 2000m from flare point.

(3) To determine the effect of acidified precipitation on various roofs within 500m – 2000m from flare point.

(4) To determine the effect of wind direction on ambient temperature around flare point at various distances in the month of June.

(5) To determine monthly pH variation of rainwater around flare area.

(6) To determine the experience of community dwellers on the effects of gas flaring on their livelihood and environment.

1.4 Justification of the Study

The Odagwa community is host to Nkali flow station. The station has operated for over 30 years and the community settlement is within 500m to

3000m radius from the flare point. Previously, associated gas in Odagwa was burnt through vertical flares of about 20m height; recently, the open pit method with pit diameter of about 10m and ceramic wall of about 3m height is being adopted. The products of gas combustion including the heat are now being released at ground level in the middle of the bush.

The community people complain of loss of biodiversity, leaking of roofs, heat, coloured rainwater with particles, peeling of paints and low crop yield. Their complaints could be traceable to over 30 years of gas flaring at the Nkali flow station. Associated gas as a fossil fuel, when burnt will release products that will compromise air quality and eventually become washed away by precipitation through dissolution of atmospheric pollutants in rainwater making the environment sink for pollutants in the atmosphere caused by gas flaring, the pollution potentials of gas flaring constituted the reason for this work.

1.5 Significance of the Study

Environmental studies are taking a centre stage around the globe. Man has in the past focused on exploitation of environmental resources but today global emphasis is on conservation and sustainability. Hence, the results from this study will;

* Guide policy makers in the oil and gas sector to have a second taught on gas flaring in the 21st century especially now that the Petroleum Industry Bill (PIB) is been considered in the National Assembly.

* Help the Odagwa community to know the quality of their rain water to inform its usage.
* Help the Odagwa community to know the level of impact on their physical environment which will also serve as a bargaining power for remediation measures.
* Appeal to the corporate conscience of the operators including Shell Petroleum Development Company (SPDC) to carry out their activities sustainably.
* Serve as a training manual for other researchers, consultants, activists, Non Governmental organizations (NGO's), Community Based Organizations (CBO's) and the International Community.
* Guide infrastructural developers on choice of materials of construction.
* Serve as analogue to studies in other gas flaring communities with similar geography and environmental conditions.
* Serve as reference material for future and related studies.
* Offer Odagwa Community Stakeholders opportunity to confirm their experiences about their environment.

1.6 Scope of the Study

The study was carried out in Odagwa community where Nkali flow station is located. Ulakwo and Obite communities will serve as the control locations.

Rainwater Samples will be collected in Odagwa between January to December directly from the ambient environment and from roofs (zinc, aluminium and asbestos). Composites of first flush and after first flush were made. Questionnaire instrument was used to get residents' experience on their environment.

Rainwater quality was assessed using the following parameters; pH, temperature, total suspended solid (TSS), total dissolved solid (TDS), electrical conductivity, total hardness (as CaCo3), colour, turbidity, calcium, magnesium, sodium, aluminum, sulphate, nitrate, chloride, cadmium, lead, manganese, nickel, zinc and iron.

Analytical Data will be presented using tables, bar chart, percentile, line graphs and correlation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Oil and Gas Exploitation in Nigeria

Nigeria, Africa's largest country has the oil and gas sector as her largest industry which generates over 70% of the nations GDP.

The British through Royal Dutch Shell discovered oil in the Niger Delta in the late 1950's. Before the discovery of oil, Nigeria's economic mainstay used to be Agriculture. Dr. John Isemede, the Director General of NACCIMA observed that the Nigerian Oil sector has caused substantial decline in Agricultural exports, which began in the mid 1960's and continued to date.

As at the year 2000, oil and gas exports accounted for more than 98% of export earnings and about 83% of Federal Government Revenue as well as generating over 70% of her GDP. It also provides 95% of Foreign exchange earnings and about 65% of FG budgetary revenue (Federal Ministry of Finance News Bulletin, 2000).

Nigeria's proven oil reserves are estimated by the US Energy Information Administration (USEIA, 2000) at between 16 and 22 Billion barrels (3.5×10^9 m^3). Nigeria Crude Oil Production averages 2.2mbpd and ranks sixth in world oil export and First in Africa. Production is expected to exceed this capacity but for OPEC regulations, disruptions by Niger Delta militants and oil theft.

According to the Federal Ministry of Petroleum Resources, Nigeria has a total of 159 oil fields and 1,481 oil wells in operation with the most productive

region as the coastal Niger Delta Basin having 78 of the 159 fields (FMPR, 2000).

Nigeria Petroleum is classified mostly as "Light and Sweet" as the oil is largely free from sulphur. Nigeria is the largest producer of sweet oil in OPEC and has her crude named after the oil terminals like; Bonny light, Qua Iboe, Escravos blend, Brass River, Forcados, Pennington and Anfan. The US is the largest importer of Nigeria's oil accounting for 40% of her export and about 10% of US oil imports (USEIA, 2000).

Nigeria's natural gas reserves are well over 187 trillion ft^3 (2,800km^3). The gas reserves are three times as substantial as crude oil reserves. The biggest natural gas initiative is the Nigeria Liquefied Natural Gas (NLNG) company operated jointly by the Federal Government and some major operators. It started operation in 1999. Shell Petroleum Development Company and Chevron Nigeria Limited are also developing gas utilization projects (NNPC, 2001). According to NNPC there is also West African Gas Pipeline expected on completion to transport natural gas to Benin Republic, Ghana, Togo and Cote d' Ivore.

Unfortunately, the majority of Nigeria gas is flared off and it is estimated that the country losses 18.2 million US Dollar daily from gas flaring (NNPC, 2001).

2.2 Associated and Non-Associated Gas

Associated Petroleum Gas (APG) also known as flare gas or associated gas, it is a form of natural gas which is commonly found associated with deposits of petroleum (Roland, 2010). Associated Gas is produced during crude oil production. (Mokhatab et al, 2006) stated that crude oil cannot be produced without associated gas which comes out of solution as pressure is reduced on the way to and on the surface. Associated gas serves as energy in driving crude production from the oil wells.

The associated gas is released as a waste product from the petroleum extraction industry, due to complexities in the management of the gas. It is simply burnt off in gas flares. The associated gas is composed of 81% Methane (CH_4), 5% Ethane (C_2H_6), 6% Propane (C_3H_8), 4% Butane (C_4H_{10}), 1% Nitrogen (N_2), > 0.15%CO_2. (Gazprom, 2010).

Apart from the Associated Gas that occurs in conventional oil fields, other sources of gas exists as non-associated gas occurring in conventional gas fields, unconventional gas (tar sands gas, coil bed methane, gas hydrates and deep gas).

According to Speight (1993), Non Associated gas sometimes called gas well gas is produced from geological formations that typically do not contain much, if any, higher boiling hydrocarbon (gas liquids) than methane. Non – Associated gas can sometimes contain non-hydrocarbon gases such as CO_2 and H_2S.

All over the world governments are mandating operators to stop flaring associated gas as citizens, civil society organizations and environmental activists are crying out that flaring constitutes environmental degradation and waste of non-renewable energy source. APG is flared in many countries where there are significant power shortages (BBC, 2011).

2.3 Gas Flaring Around the World

Flaring is performed as a routine part of various operations throughout the petroleum producing industry (AEUB, 1991). To Mokhatab *et al* (2006), flaring is used to consume waste gases (including hydrogen sulphide rich gases) in a safe and reliable manner through combustion in open flame.

According to AEUB (1991) flaring is employed; as a part of the completion and testing of natural gas wells, as a gas disposal method from the depressuring equipment, as an economical means of disposal especially when the well is producing small amounts of soluting gas and as an uncontrolled gas release during emergencies.

Gas flaring is a major contributor to air pollution making densely populated industrialized nations and cities like Tokyo in Japan, Mexico a pollution nerve centre. Air pollution capital of the world may be Brazil, a petrochemical centre no birds or insects remain, most trees are blackened and 40 of every 1000 babies are still born (Ministry of Environment, Japan, 2006).

Onosode (2003) listed some countries and the percentage of Associated Gas they flared; Nigeria 76%, Liberia 21%, Saudi Arabia 20%, Iran 19%, Mexico 5%, Britain 4.3%, Algeria 4%, USA 0.6%.

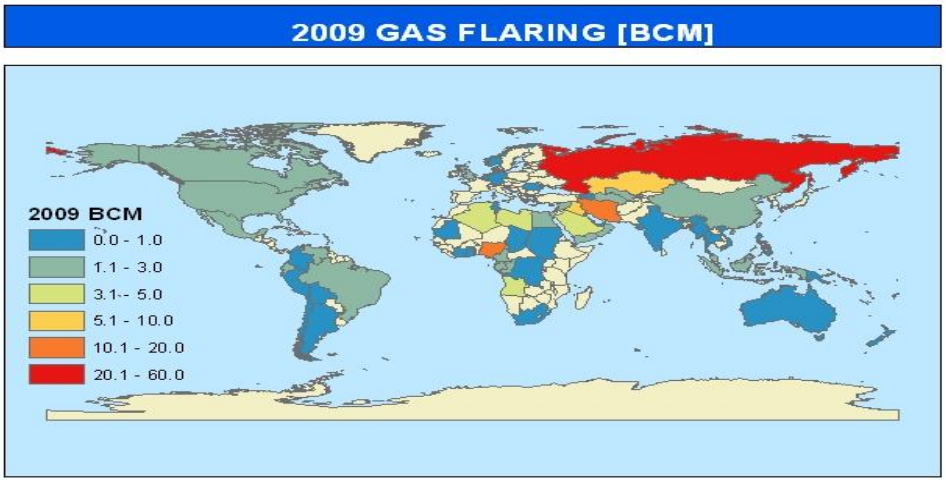


Fig 2.1; World gas flaring map

2.4 Gas Flaring in Nigeria

Since the struck of oil in commercial quantities at Oloibiri in the present day Bayelsa state, Associated Gas have been flared as a cheap disposal option till date. Flare emissions in Nigeria are the highest or perhaps second to the highest in the world (Olubayo, 2008).

Nigeria is the second largest offending country after Russia in terms of total volume of gas flared. In 2004, Nigeria's volume of gas flared was equivalent to one-sixth of total gas flared in the world. Between 1996 and 2006,

a period during which awareness of the negative impacts of gas flaring grew on the global climate, the global emission volume ranged between 150 – 170 billion cubic meters (BCM), Nigeria's share of the total volume was approximately 24.18BCM of gas while USA was 2.8 BCM (World Bank, 2007).

Nigeria flares more natural gas associated with oil extraction than any other country with estimates suggesting that of the 3.5 BCF ($99Mm^3$) of associated gas (AG) produced annually 2.5 BCF ($71Mm^3$, or about 70%) is wasted via flaring. Though statistical data associated with gas flaring is unreliable but AG wasted during flaring is estimated to cost Nigeria US$ 2.5B annually (FoEI, 2013).

Companies operating in Nigeria prefer to exploit natural gas from the Non Associated deposits probably because it is costly to separate commercially viable AG from oil hence gas flaring becomes a better alternative to increase crude production.

Gas flaring is discouraged by the international community as it contributes to climate change, methane concentration in the Atmosphere, Global warming and CO_2 concentration.

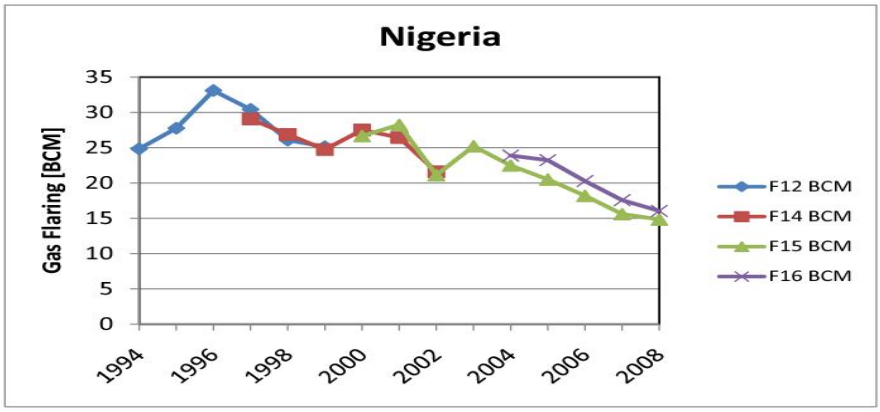


Fig 2.2; Volume of Gas Flared from 1994-2008

2.5 Types of Gas Flaring

Gazprom (2010) identified three basic types of flare systems namely Elevated flare, Ground flare and Smokeless flare.

Elevated Flare: In an elevated flare system, combustion reaction takes place at the top of the stack where the burner and igniter are located.

It requires less ground area, can be located within a process area or on the periphery of plant role site. With the elevated flare radiation effect and ground level concentration of pollutants can be maintained within allowable limit, piping cost tend to be lower due to smaller and shorter runs.

The problem with elevated flare systems is that the initial and operating cost are high, maintenance is difficult and tedious. The visibility of the flare is the most serious disadvantage and often times causes objection from local communities. The system also requires more steam to produce smokeless flare.

Ground Flare: In the ground flare system combustion takes place at or near ground level. There are two types of ground flare system. The type that uses water sprayers to disperse the combusting gases, the one that uses multi-jet burners.

Advantages of ground flare include:

- No Stack is required
- Simple to erect
- Maintenance is easy
- Flame is not visible for all to see
- Requires less steam to produce smokeless flame
- Lesser operating cost
- Relatively less noisy

The major disadvantages is that it must be well isolated from the main plant requiring considerable space, long pipe runs, concentrations of toxic gases are relatively high because of combustion taking place at ground level, requires high water consumption, the venturi type is usually very noisy.

Smokeless Flare: A flare is luminous when incandescent carbon particles are present in it when these particles cool, they form smoke. Smoke formation mainly occurs in fuel rich system when a low hydrogen atom concentration suppresses the smoke.

Prevention of smoke in flares according to is accomplished by;

* Distribution of waste gases through a number of smaller burners.
* Addition of steam where raw gas is preheated before entering the combustion zone.

Steam reacts with carbon particles to form CO, CO_2 and H_2 thereby removing C particles that could have formed smoke.

2.6 Products of Gas Flaring

Emissions resulting from the combustion of Associated Gas (AG) in an open uncontrolled manner will be a mix of smoke, precisely referred to as particulate matter. Combustion by products including Sulphur Dioxide (SO_2), Nitrogen Oxides (NO_x), Carcinogenic substances such as Benzo α Pyrene, Dioxin and unburnt fuel components such as Benzene, Toluene, Xylene and Hydrogen Sulphide (H_2S) (CPHA, 2000).

Gas flaring adds significant carbon emission to the atmosphere. Theoretically, associated gas combustion yields CO_2 and water when complete (Mokhatab *et al*, 2006). More over Manahan (2009) posited that flaring combustion is typically incomplete releasing substantial amount of soot and CO, Polycyclic Aromatic Hydrocarbons (PAH), small quantities of sulphur compounds like sulphur dioxide (SO_2), hydrogen sulphide (H_2S), carbon disulphide (CS_2), carbonyl sulphide (COS) and VOC's.

Flaring is a public and environmental concern, not only does it emit pollutants into the environment, it is a source of waste of invaluable energy

resources as well as source of noise, heat, odour and smoke that compromises the outdoor comport of residents (Mokhatab *et al*, 2006)

BBC documentary identified trace elements like Arsenic, Chromium, Cadmium, Nickel, Cobalt, Lead, Zinc, Mercury and Iron as possible products of gas flaring (bbc.co.uk, 2011).

Onosode (2003) pointed out lead, cadmium, Nickel and Mercury as heavy metals usually associated with Gas flaring and petroleum production.

What actually is in the waste gas been flared? Royles (2010) in his work concluded that the flared gas is composed of natural gas (Methane), Propane (LPG), Ethylene, Propylene, butadiene and butane to a tune of 95% and above.

2.7 Dilution and Dispersion Effects of Pollutants in the Atmosphere

Atmospheric conditions offer some removal mechanisms for pollutants emitted into the atmosphere. Akhionbare (2009) identified dispersion, gravitational settling, flocculation, absorption, rain out and adsorption as some of the removal mechanisms.

Dispersion is the process by which contaminants move through air spreading a plume over a large area, it could be vertical or and horizontal (Dara, 2006).

Vertical dispersion occurs as a function of adiabatic lapse rate which is the rate at which air cools as it rises in attitude. It is independent of ambient temperature hence the name adiabatic (Bhatia, 2009). The author showed that

the difference between ambient lapse rate and adiabatic lapse rate determines the stability of the air and the speed with which pollutants will disperse.

According to Narayanan (2009), when the ambient lapse rate equals the adiabatic lapse rate, the atmosphere experiences neutral stability. Super adiabatic condition prevails when ambient lapse rate is more than adiabatic lapse rate, the atmosphere experiences sub-adiabatic condition when ambient lapse rate is less than adiabatic lapse rate this leads to a special condition called temperature inversion.

Super adiabatic atmospheric conditions are unstable and favours dispersion while sub-adiabatic conditions trap pollutants at ground level due to poor dispersion. Bhatia (2009) hinted that super adiabatic conditions are characterized by looping plume like open burning on a sunny day, sub adiabatic has a fanning plume while neutral stability has a coning plume.

The Gausian model developed by Pasquil is the most commonly used model for the dispersion of gaseous air pollutants. According to Weiner and Mathews (2003), the Gausian model is based on the assumption that;

- The predominant force in pollution transport is the wind. Pollutants move predominantly downwind.
- The greatest concentration of pollutants is along the plume centre line.
- Molecules diffuse spontaneously from regions of higher concentration to regions of lower concentration.

- Pollutants are emitted continuously and the emission and dispersion process are steady state.

Precipitation according to Joseph (2003) constitutes an effective cleansing process of pollutants in the atmosphere in three ways;

(a) Washing out or scavenging of large particles by falling rain drops.

(b) Accumulation of small particles (condensation nuclei) in the formation of rain drops in cloud (rain out)

(c) Removal of gaseous pollutants by dissolution and absorption.

Bhatia (2009) suggested that dilution of particulates and gases can be accomplished by the use of tall stacks since pollutants discharged at tall stacks disperse easily and mixes well in the atmosphere. To him, a minimum stack height of 30m is ideal but theoretically effective stack height is given by $H = 74Q^{0.27}$ where Q is the particulate or gaseous emission rate in tones per hour which often gives stack height in excess of 400m, this is almost economically non feasible.

2.8 Flare Height, Ground Level Emission and Concentration of Pollutants

Ground level concentration of pollutants depends on; the effective stack height, topography of the area, physical and chemical characteristics of pollutants, meteorology of the area and removal mechanisms (Akhionbare, 2009).

All things being equal, the higher the effective stack height the better dispersion and other removal mechanisms will reduce pollutant concentration.

The topographic features of an area include both natural (valleys, oceans, rivers, lakes, foilages) and manmade (cities, buildings, bridges, roads, canals) elements distributed within the environment. These elements according to Joseph (2003) have some direct effect on pollutants in the atmosphere. Their prime significance is its effects on the meteorological elements.

Wind speed and direction gives an idea of initial dilution and downwind geometry. Atmospheric stability is associated with plume spread with turbulent motions in the atmosphere (obtained by vertical temperature gradient).

Humidity is associated with visibility, acid mist formation and concentration of particulates while surface temperature and precipitation offers possibility of wash out of pollutants.

For effective use of meteorological information, Dara (2006) observed that there is need to take on site meteorological data and compare them with those collected by a state agency. If they are comparable then it is advisable to use the data from state agency especially when their base station is located close to the site.

Regions with topography of tree cover are characterized by enhanced turbulence near the ground during moderate or strong winds resulting in lower concentrations for locations near sources and in fully covered regions blockage of elevated plumes results also in lower concentration at ground level (Bhatia,

2009). He went further to explain that in regions with bodies of water, there will be increased moisture in local atmosphere favouring fog formation at low lying spots and affecting SO_2 removal rate and other pollutants. For larger bodies of water, there will be formation of local circulation which can cause ground level fumigation of landward side of source.

According to Narayana (2009) ground level emission is associated with poor dispersion which is usually as a result of low wind speed, stable meteorological conditions arising from limited vertical air movement, large differences between day and night temperatures, trapping of cold air in valleys which results in stable conditions, fog and limited precipitation.

He further stated that air temperature near the ground surface in rural areas cools down rapidly causing inversion.

2.9 Acid Rain Formation

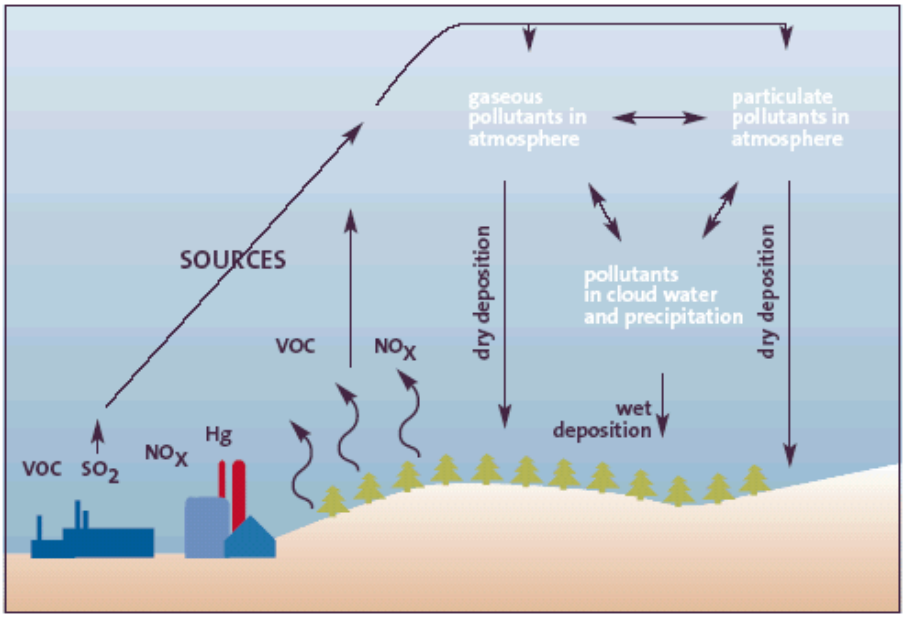


Fig 2.3: Formation of acid precipitation.

Acid rain is primarily formed as a result of emissions of SO_2 and NO_x which combine with atmospheric moisture to form sulphuric acid (H_2SO_4) and nitric acid (HNO_3) respectively (USEPA, 2011).

The United States Environmental Protection Agency confirmed that acid rain acidifies lakes and streams, damages vegetation, accelerates the decay and corrosion of building materials, paints and metallic structures.

Prior to falling to the earth, SO_2 and NO_x gases and their particulate matter derivatives, sulphates and nitrates contribute to visibility degradation and an oily hue is often observed on collected rainwater (USEPA, 2011).

The continued process of gas flaring has not only meant that a potential energy source and source of revenue has gone up in smoke but the USEIA (2011) identified gas flaring as a major contributor to air pollution and acid rain.

According to Noyes (2005), other acidifying gases that contribute to acid rain include; CO_2 and Chlorides. He stated that NO_x may be considered of less importance in acid rain formation from gas flaring since gas temperature do not usually exceed 1200^0F (650^0C) with the possibility of insignificant NO_X forming. Mokhatab *et al* (2006) on his part stated that, most significant conventional pollutant released by gas combustion are oxides of Nitrogen (NO_x) formed by heating around the point of combustion.

Akhionbare (2009) pointed out the chemical reaction for the formation of acid rain as

$O_3 \longrightarrow O_2 + O^*$

$O^* + H_2O \longrightarrow 2OH^-$

$OH^- + NO_2 \longrightarrow HNO_3$ (Nitric acid)

$OH^- + SO_2 \longrightarrow H_2SO_4$ (Sulphuric acid)

Precipitation in the form of rain, snow, ice or fog causes about half of the atmospheric acids formed to fall to the ground as acid rain while about half fall as dry particles and gases (Mokhatab *et al*, 2006). He also noted that wind can blow the acidic particles and compounds miles away from their source of formation before they are deposited and the deposited particles can as well be washed off by rain thus increasing the acidity of run offs.

According to Bhatia (2009), the reaction

$2SO_2 + 2H_2O + O_2 \longrightarrow 2H_2SO_4$

is catalyzed by metal salts such as iron and manganese. The sulphuric acid may also react with metal salts like NaCl and metal oxides like MgO, fe_2O_3, Z_nO, M_nO_2 or ammonia to produce sulphates.

$2NaCl + H2SO_4 \longrightarrow Na_2So_4 + 2HCl$

$MgO + H_2SO_4 \longrightarrow MgSO_4 + H_20$

$2NH_3 + H_2SO_4 \longrightarrow (NH_4)2SO_4$

Dara (2006) noted that with reactions of H_2SO_4 formed in acid rain, the acid droplets is being neutralized and solubility of SO_2 in droplets increases

thereby enhancing the Oxidation process. Both the acid droplet and sulphate particles are removed from the atmosphere by wet precipitation.

2.10 Smog Formation

The name smog is derived from smoke and fog. The major original reactants in an episode of photochemical smog are NO_x or SO_2 and unburned hydrocarbons commonly called VOC's (Volatile Organic compounds) Others include sunlight and oxygen. (Baird, 2005).

According to Colin and Michael (2005), the Smog formation follows the Chemical reaction;

$$\text{VOC's} + NO_x + O_2 + \text{Sunlight} \rightarrow O_3 + HNO_3 + HC$$

The mixture of Ozone, Nitric acid and hydrocarbon (SMOG) is of serious environmental concern especially in areas where removal mechanisms are difficult.

Bhatia (2009) noted that VOC's with double carbon bonds (C=C) are more reactive with free hydroxyl (OH^-) radicals than single bond VOC's like methane. Although methane is a major constituent of petroleum gas, it plays an important role in the stages of photochemical smog formation.

Photochemical Smog takes place during sunny days with low winds and low level of inversion. Dara (2006) observed that photochemical smog and the consequent formation of aerosols reduces visibility, causes irritation to the eyes and damage plants and rubber products. The free hydroxyl radical OH^+ present

in Smog can be a source of SO_2 Oxidation to sulphate. Dara (2006) also noted that SO_2 oxidation can as well take place in water droplets present in aerosol in the presence of NH_3 with oxides of Mn, Fe, Cu or Ni as Catalysts while particulate matter like soot can bring about catalytic oxidation of SO_2 by providing a heterogeneous contact phase.

Sulphur dioxide is an important pollutant in the formation of smog, acid rain and corrosion of metals and alloys.

Bhatia (2009) concluded that the condition for photochemical smog formation is air stagnation, abundant sunlight, high concentration of HC's and NO_x in the atmosphere which may be masked by smoke and SO_2. The reaction results in the production of secondary pollutants such as, Ozone, Aldehydes, Ketones and Peroxyacetyl Nitrates (PAN's).

2.11 Green House Gas emissions

The earth surface temperature is maintained at a habitable level by the action of atmospheric gases known as green house gases which helps to trap the sun's heat close to the earth's surface.

According to Fogg and sangster (2003), the main green house gases are water vapour, CO_2, CH_4, N_2O and several other manmade chemicals such as CFC's. Mokhatab *et al* (2006) was of the opinion that methane which is a major constituent of Associated and non- Associated gas can find itself into the atmosphere through venting or leakage from gas facilities.

Green house gases naturally regulate the earth's surface temperature but since the industrial revolution the Green house gas concentration have kept increasing beyond normal levels resulting in the trapping of more heat and adversely affecting the earth's climate.

The burning of fossil fuel is a major culprit as 99% of anthropogenically sourced CO_2 emissions are due to burning of fossil fuel (Mokhatab *et al*, 2006).

Gas flaring is implicated in the release of major Green house gases in the Niger Delta which poses a serious environmental challenge.

Akhionbare (2009) commented that total green house contribution of a particular molecule depends on infra-red absorption rate and atmospheric concentration of the molecule. She went further to state that the net effect of all factors is that H_2O is the most powerful green house gas followed by CO_2, CFC's, CH_4 and N_2O.

2.12 Impact of Gas flaring on Flora and Fauna

The SO_2 from gas flaring and its corresponding acid solution destroys plant tissues and produces chlorosis, a chronic leaf injury indicated by gradual yellowing of leaves as chlorophyll production is impeded. (Akhionbare, 2009).

Acid rain damages vegetation and wild life populations. Bhatia (2009) noted that air pollutants affect mainly the leaves of plants thereby damaging the leaf structure. The leaf is made of cuticle (waxy covering layer) designed to protect the inner tissue from excessive moisture loss and absorption of CO_2 and

O_2 with stomata for proper metabolism. Bhatia (2009) observed that these important organs of plants are adversely impacted by air pollutants leading to necrosis (dead areas on leaves), chlorosis (loss or reduction of chlorophyll), epinasty (downward curvature of leaves) due to higher rate of growth on upper surface and abscission (dropping of leaves). The ultimate effect is reduction in growth rate and eventual death of plant. Some pollutants deposited on leaves can poison animals when eaten. CO concentration creates no significant effects on plants but when it reaches 100-10,000 ppm it causes leaf drop, leaf cutting, reduction in leaf size, chlorophyll and premature aging (Bhatia, 2009).

CO combines with haemeglobin in animals to form complex compound called carboxy haemoglobin – Bhatia (2009) observed that CO concentration of over 400ppm will lead to infertility, premature births, spontaneous abortions, deformed offspring and death.

He went on to show that birds and other animals are sensitive to excessive CO_2 than humans. The effects of CO_2 are not orchestrated by CO_2 directly but by the absence of oxygen.

Hydrocarbons are injurious to plants, ethylene even at 1ppm concentration shows adverse effect on vegetation, acetylene and propylene at 50 – 500ppm are toxic to plants, inhibit plant growth as well as damage leaf tissues and death of flowering plants (Narayanan, 2009).

In his work Okereke (2006) showed that damage to crops are most severe during warm clear, still, humid weather when pressure is high. He stated that

exposure of crops to SO_2 and the by product, H_2SO_4 usually result in dry papery blotches that are generally white, tan or straw coloured and marginal or interveinal. On some species chlorosis and gradual bleaching of surrounding tissues occurs. Okereke (2006) pointed out that SO_2 can be severe at 50km or more from its source and in concentration of 0.5ppm (0.5mg/l) for four hours exposure time or 0.25ppm for 8 to 24 hours exposure time in which sensitive crops are damaged such as legumes, amaranthus, apple, barley, bean, sugar beet, carrot, cotton, oat, okra, orchard grass, pepper, lettuce, plantain, pumpkin, soya bean, spinach, straw-berry, sunflower, sweet pea, sweet corn, cucumber, hibiscus, onion and sorghum. He also observed NO_x and HNO_3 to have similar effects on majority of the above listed crops.

2.13 Impact of Gas Flaring on Buildings

Akpan (2003) observed in his study that an acidic rain of pH 5.4 measured in a sample from Eket showed a remarkable drop in chloride when compared to roof rainfall from 1,050 mg/l in direct rain water to 28.4mg/l in the roof rain water which he attributed to reaction between HCl in rain and zinc in roofing material. He also found a similar trend in sulphate concentration which he attributed to reaction between H_2SO_4 in rain and the protective ZnO layer of zinc plated iron roofs. These reactions he stated are responsible for accelerated corrosion of roofing materials in oil producing communities of Niger Delta.

He further posited that the main source of the acids in the rainwater at Eket is the Mobil Producing Gas flaring at nearby onshore and offshore locations. During the wet season flare gases are carried inland throughout Eket and the environs by the prevailing South-Westerly trade winds leading to persistent acid rain and infrastructural damages.

Sexton *et al* (2007) categorized impacts on buildings as weathering of the walls, changes in colour of roofing materials and walls, leakage of roof tops and cracks on walls.

While leaking roof is associated more with SO_2, colour changes in walls is correlated with NO_2 and weathering of walls with particulate matter (Nkwocha and Mbano, 2010.)

Potera (2009) reported that the older the building the more the impact. They went further to state that the mechanism of resistance of buildings to the pollutants may be altered by age, material used, length of exposure, seasonal variations, humidity, wind speed and other environmental stressors.

Aluminum roof less than 0.50mm thickness and galvanized iron sheets less than 0.18mm thickness will be more affected by corrosion and weathering. Asbestos based materials have shown stronger resistance to acid rain deterioration (Canadian Public Health Association, 2000). According to Essential Action (2001), asbestos based roofs contribute to health risks.

Sulphuric acid mist in the atmosphere causes deterioration of structural materials such as marble and limestone, buildings and sculptures, for acid reacts with them to form a powdery substance called gypsum (Narayanan, 2009).

2.14 Impact of Gas flaring on Paints and materials

At levels of 0.09-I ppm, SO_2 affects fabrics, leather and paint. SO_2 is readily absorbed by leather and causes it to disintegrate, paper is also discoloured by SO_2 making it brittle and fragile (Bhatia, 2009).

Oxides of Nitrogen (NO_x), causes fading in acetate, cotton and rayon fibres at levels of 0.6-2ppm over 2-3 months period according to Bhatia (2009). It has also been observed that particulate Nitrates attack and damage Nickel-Brass alloys in the presence of moisture while Hydrocarbon pollutants long chains of carbon atoms loosing tensile strength of polymers and paints.

Okereke (2006) pointed out that painted buildings and structures can quickly lose their aesthetic values due to air pollution arising from soot, dust, acid rain etc.

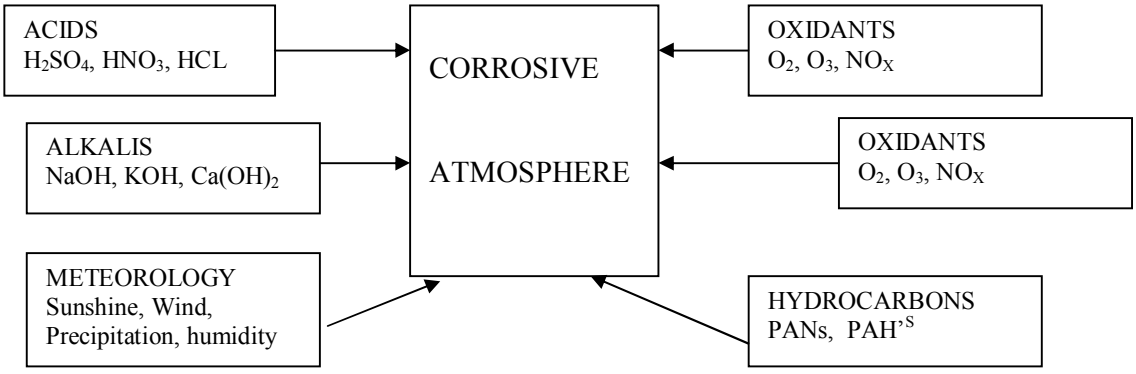


Fig 2.4 Corrosive Atmosphere due to Gas Flaring. Source: (Narayanan, 2009).

2.15 Impact of Gas flaring on Metallic Structures

Madden *et al* (2007) found out that the corrosive effects of acidic gases and particulates such as SO_2, NO_X, Sulphates and Nitrates are observed on metallic structures and equipment.

Nkwocha (2010) pointed out that the corrosion occurs more during months of scanty rain say December to April than May to July and September. The acidic gases and particulate matter combine with precipitation to form acidic solutions of pH of about 4.9 and less thereby acting as a corrosive agent exerting high oxidative stress on the metallic surfaces (Bhatia, 2009, Lawton, 1997 and Jones, 1996).

The acidic solution formed according to Akhionbare (2009) accelerates the corrosion of iron, steel and zinc, deterioration and fading is produced in fabrics such as cotton, nylon, rayon, leather and paper. Wood and plastics are also affected.

Particulates through their own corrosiveness or in the presence of SO_2 and moisture can accelerate the corrosion of steel, copper, zinc and other metals (Bhatia, 2009). He went further to explain that the most notorious pollutant responsible for metallic corrosion is SO_2. It has been reported that corrosion of hard metals such as steel begins at annual mean concentration of 0.02 ppm ($52\mu g/m^3$).

Okereke (2006) concluded that acid rain causes corrosion of roofing zinc sheets, other metal structures and concrete.

2.16 Impact of Gas flaring on Soil Properties and Crop yield

Polluted water acutely affects soil fertility by killing bacteria and soil micro-organisms, enhances alkalinity or acidity of the soil affecting plant metabolism with an ultimate disturbance of the whole ecosystem (Bhatia, 2009).

Soil is the upper thin layer covering the uncemented or weakly cemented particles formed over land over a period of time. It primarily consists of mineral particles with void spaces containing water and or air which make it capable of supporting life (Garg, S. and Garg, R, 2009).

The soil is polluted when municipal and industrial wastes are dumped over it, insecticides are sprayed, fertilizers are applied or acidic rain falls over it. The toxic or alkaline or acidic pollutants may find entry into the soil layers thereby polluting the soil. He went further to explain that soil impacts may be noticed in changes in colour, texture, composition, structure, availability of important nutrients like Fe, Mn, Zn, Co, abundance of less needed nutrients like Cu, Ni, Pb, Cr, Cd.

Garg, S. and Garg, R (2009) explained that air pollutants like SO_2, NO_X, Sulphates, Nitrates may fall down on land either as dust, droplets or with precipitation as rain or snow producing acids like H_2SO_4 and HNO_3 called acid rain, which leads to soil acidification.

Acidified soils have low pH value which accelerates mobilization of Aluminum and heavy metals like Cd, Pb, Zn, Cr, Cu, As, etc from the metals

present in the soil. The mobilized Al and heavy metals may find their way to the surface or underground water through leaching, run off, percolation and infiltration Garg and Garg , 2009).

He observed that acidification of soil and its associated leaching of nutrients in conjunction with other factors such as ozone pollution, acid deposition, ammonium uptake etc. have been found to be causing a great damage to trees in forested areas, crops and other important plants. This he pointed out show in the form of discolouration, crown defoliation, deformed branch structures and deaths.

Although soils have in built ability to buffer acid called buffering capacity which is the amount of acid that needs to be added to raise the soil pH by one unit. Soils with considerable alkalinity have higher buffering capacity (Bhatia 2009).

Okereke (2006) in his work identified crop damage to be caused by toxic gaseous pollutants such as SO_2, Floride, Chloride, Ozone and Ethylene emissions. He stated that the above substances form chemical compounds that interfere with either crop water uptake or soil nutrient levels or even damage plant cells. He went further to explain that the effects of pollution on plants can be mottled foliage, burning at leaf tips, twig die back, stunted growth, premature leaf drop, delayed maturity, abortion, reduced crop yield and quality.

2.17 Impact of Gas flaring on Ground Water and Surface Water

Human activities are constantly adding industrial, domestic and agricultural waste to ground water reservoirs. Excessive mineralization of ground water degrades its quality producing objectionable tastes, odour and hardness. Although the soil mantle through which water passes acts as an adsorbent retaining a large part of colloidal and soluble ions with its cation exchange capacity yet ground water is not completely free from chronic pollution.

According to Bhatia (2009) Rainfall pattern, Depth of water table, distance from source of contamination, soil properties and infiltration are factors which affect the extent of groundwater pollution.

Air born pollutants can be deposited on land or water through wet or dry deposition. These pollutants can fall directly on water or washed into water bodies via run off. Parts of the pollutants from the atmosphere end up in streams, rivers, oceans, lakes, estuaries, creeks and aquifers where they affect the water quality.

Narayanan (2009) discovered that the presence of secondary porosity and fractures within the rock mass over the aquifers can lead to the movement of ground pollutants through the ground water.

Acidified water in the range of pH 1-3.5 damages plant leaves, vegetation and kills aquatic animals, at pH 3.5-4.5, fishes die and most aquatic organisms

suffer fatality, at pH 4.5-5.5 bigger aquatic organisms like the Salmon experiences fecundity while at pH 5.5-6.0 nutrients are leached from the soil (Narayanan, 2009).

Akhionbare, (2009) pointed out that precipitation is a viable source of materials that exerts a profound influence on the composition of many surface waters and ground waters.

Surface water comes in direct contact with pollutants through atmospheric precipitation, precipitation run off and leaching. Bhatia (2009) stated that urban centres will have more polluted surface waters than the rural areas due to atmospheric contamination with CO_2, CO, SO_2, NH_3, NO_X, H_2S, smoke, vehicular emission, waste water and solid waste dumps. He found out that in polluted surface waters ions like Na^+, K^+, $Mg^{2+,}$ SO_4^{2-}, $H_2PO^-_4$ and $H_4P_2O_7^{2-}$ interact to form a variety of complex compounds thereby influencing the water quality.

Garg, S. and Garg, R (2009) stated that the ionic forms of aluminum and heavy metals from soil by acid rain can find its way to surface waters proving very toxic for fresh water organisms including fish.

The groundwater usually has more dissolved Ca^{2+} and Mg^{2+} due to decreased pH caused by acidification. Akhionbare (2009) observed that CO_2 in the atmosphere mixes with precipitation to form a weak acid

$$CO_2 + H_2O \rightarrow H_2CO_3$$

which infiltrates through the soil dissolving $CaCO_3$ and $MgCO_3$ which are ordinarily less soluble in water.

Amadi (2010) attributed the changes in physicochemical characteristics of water to industrialization and pointed out Oil and Gas activities as a major culprit in the Niger Delta. He listed Pb, Mn, Cu, Fe, As, Zn, NO_3, pH, PO_4, Mg, K, Ca, Cl, Na and H_2O as properties that are affected.

2.18 Impact of Gas flaring on Local and Global Climate

In the immediate locality of gas flaring there is usually thermal pollution which alters the temperature of the vicinity; particles are released into the atmosphere which serves as condensation nuclei for rain formation. Together with temperature variations and variations in local wind the particles lead to more precipitation which can cause flooding, erosion, landslides and washing away of nutrients for shallow rooted food crops.

Narayanan (2009) observed that atmospheric haze being the condition of reduced visibility can be caused by air pollutants in the form of particulates (aerosols) or gases (SO_X, NO_X, CO_X) in combination with the secondary pollutants in the atmosphere. In spite of the haze being felt in the immediate locality, Narayanan (2009) said that the ultimate effect of these atmospheric pollutants is global.

Gas flaring can be a precursor to global environmental challenges like, Global warming, Green House Gas emission, Ozone layer depletion, acid rain,

smog, variation in solar radiation, rise in sea levels and flooding while in the immediate environment, air quality degradation leading to changes in meteorological conditions and environmental pollution is experienced (Gerret, 2007).

2.19 Impact of Gas flaring on Rainwater Quality

Ejeleonu *et al* (2011) discovered from a study carried out in the Niger Delta that rainwater in gas flaring communities are relatively acidic, contain acidic radicals and are rich in both micro nutrients and heavy metals. They pointed out that the pH of water samples increase from the flare point to a neutral value some 5000m or more from the flare point.

At the instant of formation, precipitation is very pure because it has its origin in a massive solar distillation process called the hydrologic cycle (Akhionbare, 2009).

However, as rain falls a scrubbing or scavenging mechanism sets-in in the atmosphere leading to rain out or wash out. This mechanism helps to clean the atmosphere of pollutants and in turn make the rainwater susceptible to pollution.

Rain picks up particles such as dust, ash and aerosols. Some of the particulates serve as condensation nuclei for rain formation. Rain also dissolves atmospheric gases like O_2, N_2, CO_2, SO_2, NO, NO_2 with the oxides of Nitrogen and sulphur primarily responsible for acid rain (Akhionbare, 2009).

Some of the physicochemical parameters of rainwater affected by gas flaring include; pH, conductivity, K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_2^-, PO_4^{3-} SO_4^{2-}, HCO_3^-, Zn^2+, Pb^2+, V^{3+}, Ni^2+ and Fe^{2+} (Ejeleonu *et al*, 2011).

Rainfall is slightly acidic due to the action of CO_2 producing a pH of 5-6. Aririatu (2006) pointed out TSS, Hardness, Cd, Cu, As, as important parameters to be considered in rainwater quality assessment with respect to gas flaring.

2.20 Sustainable Gas Flaring

The efficiency of a flare is a measure of how effective that flare is in converting all of the carbon in the fuel to CO_2. Studies have indicated that flares have highly variable efficiencies on the order of 62-99% (Mokhatab *et al*, 2006).

Gas flares are usually operated in uncontrolled conditions. The tips of the flare can be exposed to wind, humidity and temperature variations that reduce efficiency and increase variability. Narayanan (2009) listed other factors like composition of waste gas stream entering the flare, improper flaring practices and incomplete combustion as factors affecting the efficiency of gas flares.

Mokhatab *et al* (2006), suggested that the operation flare review will give the operators opportunities to examine the flexibility in the operation to enhance the flare system performance to achieve improved efficiency in terms of environmental, economic and safety goals.

Miles (2001a) examined how a flare system can be designed safely to meet the challenge of reducing emissions to the environment as well as reducing the cost of operating the overall flare system.

Staged flares with the benefit of variable orifice solutions probably offer one of the best all round solution. More so the combination of the flare system and flare gas recovery will have economic and environmental benefit. (Miles, 2001b).

2.21 Alternative Technologies to Gas Flaring

Recent reviews show that, Associated Gas Reinjection, Gas transportation, Gas to liquid, Domestic and industrial Gas utilization could serve as alternatives to gas flaring (SDN, 2010).

Mokhatab *et al* (2006) suggested incineration as a more efficient method to dispose of waste gases, though he pointed out factors such as cost and technological complexities as difficulties to the use of incinerators.

Other alternatives include conserving the waste gas for processing at natural gas facilities, ensuring that flare systems are properly designed, constructed and maintained through guidelines, codes of practice or regulation and flare gas recovery (zero flare option) (Miles, 2001). He noted that for flare recovery to be implemented there will be a precondition that the gas recovered must be utilized. If H_2S is present in the gas, it is usually sweetened by absorption of the H_2S in amine solution while the H_2S is flared releasing SO_2

into the atmosphere. Instead of this old approach, Noyes (2005) suggested that the H_2S could be used as feed stock for other useful processes like the production of elemental sulphur, sulphuric acid etc.

Operators can as well reduce the impacts of flaring at gas processing / disposal facilities by minimizing the total volume of gas they flare at the plant and by reducing the frequency and duration of upset flaring events (Mokhatab *et al*, 2006).

2.22 Pollution Prevention

Pollution prevention is the reduction or elimination of pollutants to the environment. Pollutants such as hazardous and non hazardous wastes and regulated and unregulated chemicals from all sources may be discharged as air emissions, waste water or solid waste. All of these wastes are treated except air emissions, which is difficult to capture and constitutes the largest source of untreated waste in the environment.

The limits of pollutants emitted into the atmosphere, land and water are defined by various pieces of legislations enforced by agencies like Federal Ministry of Environment, NESREA, DPR, USEPA and WHO.

According to pollution prevention act of the USA, Congress established a national policy that;

- Pollution should be prevented or reduced at source whenever feasible.

- Pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible.
- Pollution that can neither be prevented nor recycled should be treated in an environmentally safe manner whenever feasible.
- Disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner (USEPA and GRI, 1996).

Pollution prevention is an economically advantageous, strategically wise way for companies to protect the environment while protecting themselves from liability, legal infractions, and unnecessary costs. (Mokhatab *et al*, 2006). Speight (1996) said that pollution prevention programs often yields returns on investment.

2.23 Gas Utilization and the Future of Gas flaring in Nigeria

Power Generation: Nigeria has electricity need of over 35,000mw to drive her economy; sadly the country is still grappling with average of 4000mw power generation for her over 167 million inhabitants (NERC, 2013).

Natural gas is a major source of fuel for electricity generation through the use of cogeneration, gas turbines and steam turbines. It can as well be combined with renewable energy sources like wind or solar and for alimenting peak load, power stations function in tandem with hydroelectric plants. Most arid peaking power plants and some off grid, engine generators use natural gas

and high efficiencies can be achieved through combining gas turbine with steam turbines in combined cycle mode.

Most importantly, natural gas burns more clearly than other fossil fuels and produces less CO_2 per unit of energy released about 30% less CO_2 than petrol (Speight, 1993).

Domestic Use: Natural gas dispensed from a simple stove top can generate heat in excess of 2000^0F (1093^0C) making it a powerful domestic cooking and heating fuel. In developed countries, it is supplied to homes via pipe networks where it is used for various purposes. For areas without pipelines, the compressed natural gas (CNG) and Liquefied Petroleum Gas (LPG) are used. (Mokhatab *et al*, 2006).

Transportation: Natural gas is an alternative cleaner fuel to other fossil fuels for automobiles. The world has about 16.4 million natural gas powered vehicles at the end of 2012. This figure is led by Pakistan, Iran, Argentina, Brazil, India and China in descending order (Mokhatab *et al*, 2006)

Fertilizer Production: Natural gas is a major feed stock for the production of ammonia through the Haber Process for use in fertilizer production (Wikipedia, 2010).

Aviation: Russian aircraft manufacturer TUPOLEV is currently running a development program to produce LNG and Hydrogen powered aircrafts. It claims that at current market prices an LNG powered air craft would cost 5,000 roubles ($218/£112) less to operate per ton, roughly equivalent to 60% with

considerable reduction in CO, HC's, CO_2, NO_X emissions and offer higher engine efficiency.

Hydrogen: Natural gas can be used to produce hydrogen using the hydrogen reformer method. Hydrogen has many applications, for instance, it is the primary feed stock for the chemical industry, a hydrogenating agent, important in oil refining and a source of fuel for hydrogen powered automobiles

Chemical Manufacturing: Natural gas is a feed stock in the manufacture of fabrics, glass, steel, plastics, paints and so many petrochemical products.

Industrial Application: Industries are the worst hit in energy cuts. Natural gas can be used for industrial heating, cooling, electricity, transport and process feed stock.

The future of Nigeria is in the sustainable process industry sector which natural gas will be a major enhancer why waste this valuable resource?

2.23 Environmental Management Programmes

Targeted at Reducing Gas Flaring

The Associated and Non Associated gas is a collection of pollutant chemicals in the form of Inorganic gases like, SO_2, NO_X, CO, CO_2, H_2S or organic gases like HC's. The rate of release or concentration in the exhaust air stream in parts per million or comparable units along with the type of gaseous emission greatly influences the applicable control technology (Mokhatab *et al,* 2006).

Recommended protocols must take place as a prelude to the cleanup of emissions and mitigating future releases. Necessary actions for cleanup of gas emissions include;

- Identification of emission
- Identification of the emission sources
- Estimation of the emission rate
- Atmospheric dispersion, transformation and depletion mechanisms.
- Emission control methods
- Air quality evaluation methods
- Local, regional and global impacts
- Regulations (USEPA, 2005).

In the USA Programs such as the EPA, natural gas STAR program and the API STEP programme are put in place to ensure a sustainable environment from oil and gas exploitation.

2.24 Environmental Management Systems

Organizations are getting more concerned with achieving and demonstrating sound environmental performance by controlling the impact of their activities, product and services on the environment taking into consideration their environmental policy and objectives.

It was for this purpose that the ISO14001 standard has been developed to provide organizations with the elements of an effective environmental

management system which can be integrated with other management requirement to help organizations achieve environmental and economic goals. The overall aim of EMS according to Mokhatab *et al* (2006), is to support environmental protection and prevention of pollution in balance with socio-economic needs.

Organizations especially Oil and Gas operators in Nigeria should review and continually improve their environmental management system to achieve overall improvement in environmental performance (DPR, 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

Odagwa the study site and Ulakwo as well as Obite the control sites are communities in Etche Local Government Area of Rivers State. Ulakwo community is about 5km from Odagwa while Obite is about 25km from Odagwa. Etche L.G.A. is located at North-Eastern part of Rivers State, Nigeria. It lies within latitude $4^0$45'N to $5^0$17'N and longitude $6^0$55' E to $7^0$17'E and covers about 641.28km^2 of land area (Nwankwoala and Nworgu, 2009).

The Federal Survey Department map (fig 3.1) show that Etche lies within the coordinates $06^0$05'E to $07^0$14'E and $05^0$08'N to $04^0$45'N.

3.1.2 Political Economy

Etche is one of the 24 Local Government Areas of Rivers State. It has a population of 295,200 people (NPC, 2006). It has 19 electoral wards including Akwa/Odagwa, Ulakwo and Obite. The L. G. A. has five clans and about 35 communities. Odagwa, Ulakwo and Akwa belong to the Ulakwo / Umuselem clan while Obite belong to the Mba clan.

Etche has its L.G.A. headquarters at Okehi. It is bounded in the North by Imo State, East by Imo River and Omuma L.G.As, South by Obiakpo and Oyibo L.G.As and West by Ikwerre L.G.A.

Agriculture is the economic mainstay practiced as farming, fishing, lumbering and hunting. Other economic activities include petty trading, sand mining, transportation, agro-processing, construction and educational activities.

Oil and Gas exploration and exploitation have been going on in Etche since the inception of oil exploitation in Nigeria dating back to 1958. Plates 1 and 2 illustrates oil and gas exploitation experience in Odagwa.

3.1.3 Vegetation

The area is characterized by the tropical rain forest vegetation (Nworgu, 2001). The Popular trees in the area include Iroko, Obeche and Mahogany. Plant species are scattered, heterogeneous and exist in different heights. The vegetation supports tree crops (citrus, rubber, cocoa, oil palm), arable crops and vegetables.

3.1.4 Drainage and Topography

The area has gently rolling topography below 200m above sea level, it belongs to the Niger Delta Coastal Plain and classified as low land.

The Etche area is drained by the Otammiri, Ogochie and Imo Rivers. These rivers flow South wards to join the Niger and subsequently the Atlantic Ocean.

3.1.5 Geology and Soil

The area is characterized by sedimentary rock formation and the alluvian deposits comprising of tertiary and quaternary marine or continental deposits.

Extensive petroleum deposits mask the underlying geological structure (Nworgu 2001). The soil type prevalent in the area can be classified as coarse, loamy, highly weathered, less water logged, moderately acidic and low soluble salt content.

3.1.6 Weather and Climate

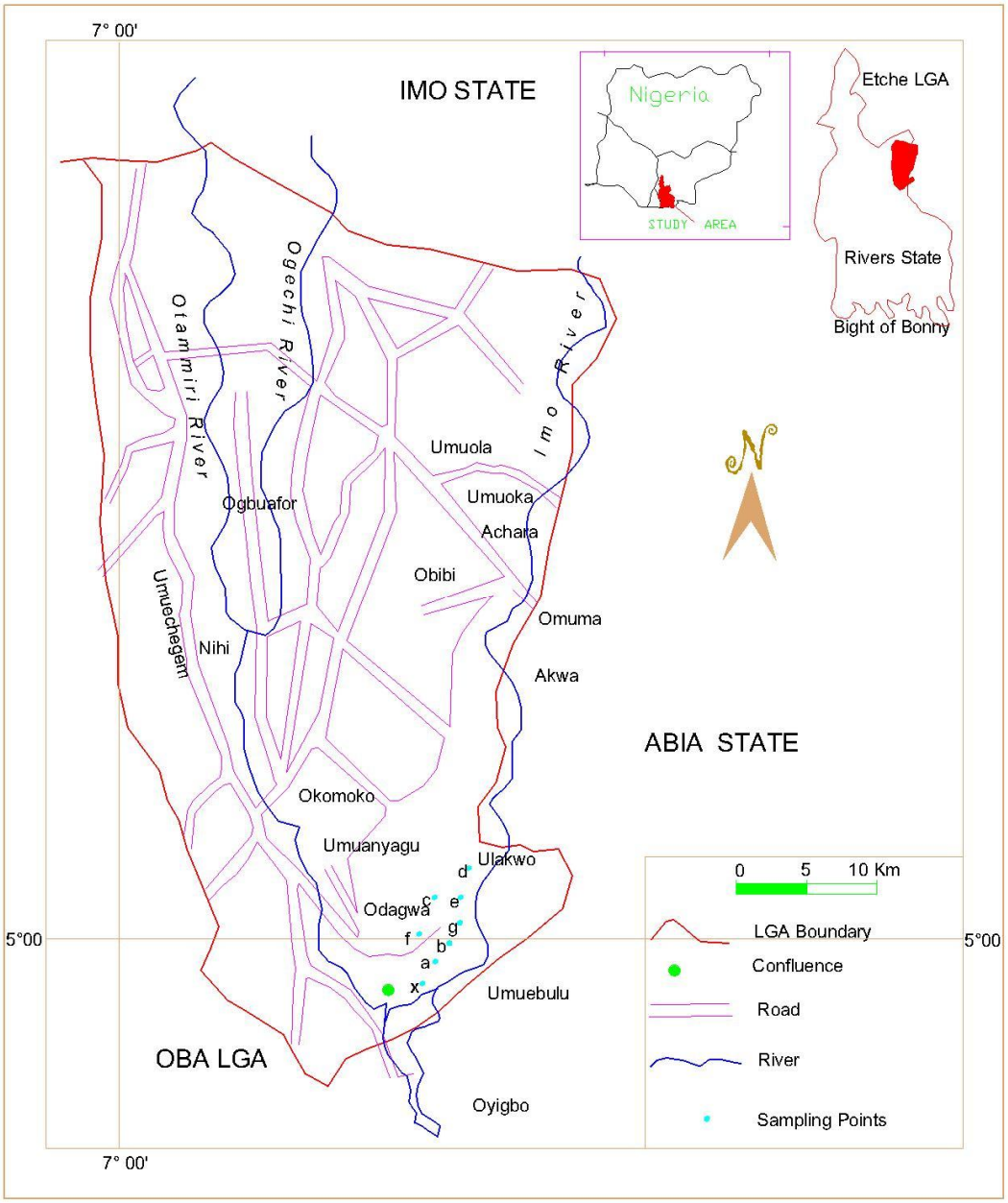
The weather and climate of the area is characteristic of the tropical equatorial climate. Amount of rainfall in the area is between 2000mm to 4000mm annually with two peaks in June / July and September (Nwankwoala and Nworgu, 2009). It has two major seasons, the long rainy season (March to July) and the long dry season (November to February) as well as two minor seasons the short rainy season (September to October) and short dry season (August).

Humidity of the area ranges from 40% in dry season to 90% in rainy season. It has two distinct air masses, the tropical continental and tropical marine.

Mean monthly wind speed is between 22.77 to 66.12 Knots, wind direction is dominated by the South Westerly wind throughout the year.

Mean monthly minimum temperature is 21.1^0C to 24^0C while mean maximum monthly temperature is between 29.3^0C and 34.2^0C (NIMET, 2013).

3.1.7 Maps and Pictures



SOURCE: FED SURVEY MAPS, RIVERS STATE.

FIG 3.1; MAP OF ETCHE LGA SHOWING THE SAMPLING POINTS

Plate 1; The Nkali Flow Station flare point 500m from sampling point a

Plate 2; The Nkali Flow Station Facility Gate 40m from flare point

3.1.8 Geographical Coordinates

Table 3.1 below shows the geographic coordinates of sampling points in Odagwa and the control site at Ulakwo using Garmin Global Positioning System, model etrexH.

3.2.0 Research Design

The research combined experimental and descriptive survey designs. The experimental design was used to collect data on physicochemical characteristics of rainwater and field data while the descriptive survey design was used to collect secondary data on meteorological elements and primary data from questionnaire instrument.

3.2.1 Instrumentation

The close ended questionnaire was administered with the provision of a likert 4 point scale to aid rating.

Table 3.1; Geographical coordinates of sampling points

Sampling Points	Northing	Easting	Elevation(ft)
Flare Area X	04°59.720’	07 ° 11.490’	54.12
A	04°59.560’	07 ° 11.165’	82.71
B	04°59.280’	07 ° 10.695’	98.56
C	05 ° 05.162’	07 ° 07.415’	131.43
D	05 ° 06.290’	07 ° 06.316’	98.85
E	05 ° 04.380’	07 ° 07.623’	97.62
F	05 ° 04.192’	07 ° 07.455’	97.31
G	05 ° 04.161’	07 ° 07.172’	97.56
H	05 ° 04.462’	07 ° 05.115’	96.78

3.2.2 Validation of the Instrument

The Questionnaire Instrument was validated by presenting it to my project supervisor to cross check to ensure that it actually measured what it was supposed to measure.

3.3.0 Data Collection

3.3.1 Sampling

The objective of sampling is to collect a portion of material small enough in volume to be analyzed insitu, transported conveniently and handled in the laboratory while still accurately representing the material being sampled.

3.3.2 Sampling Plan

The sampling of rainwater for this work commenced with the plan to use 4 sampling points in July, 3 sampling points in November, 1 sampling point in March, July and November as well as for January through December, totaling 8 sampling points.

It was planned that plastic buckets, stand, plastic bottles and appropriate preservative will be used.

The analytes was planned to include: Temperature, electrical conductivity, turbidity, colour, total suspended solids, total dissolved solids, pH, sodium, magnesium, calcium hardness, nitrate, sulphate, chloride, iron, manganese, lead, cadmium, nickel, zinc and aluminum.

The analytical methods planned to be used included: instruments, tetrimetric method, argentometric method, evaporation method, flame photometry, ultra violet spectro photometer and atomic absorption spectro photometer (AAS).

3.3.3 Preparation for sampling

Provision for sampling bottle, buckets, preservatives, labels, markers, pens, record pads, storage ice packs, buffers and distilled water were made before embarking on sampling field work. A list of insitu measurements and analysis was also made to include; pH, turbidity, colour, electrical conductivity and temperature.

3.3.4 Sampling locations

Eight sampling points were chosen randomly within the strategic study location and control of 500m to 5000m from gas flare point.

The points were designated as A, B, C, D, E, F, G, H, as shown on the map (fig 3.1), points A, B, C, D are 500m, 1000m, 2000m and 5000m from the gas flare point and were chosen to show variations in rainwater quality parameters with respect to distance from flare point. Point D served as control location.

Points E,F,G were randomly chosen within 500m to 2000m from flare point to show effects on various roofs.

The community secondary school Odagwa lying within 500m to 2000m from flare points was also chosen as sampling point H to collect samples from January to December for pH variation. In temporal variation March, July and November samples was used to represent early, mid and late rainy periods respectively.

3.3.5 Sampling Method

Plastic buckets sterilized by rinsing with tap water, chromic acid, 1:1 Nitric acid and finally with distilled water was used to collect rainwater samples on a stand of about 1.5m to avoid splash water contamination according to Ejeleonu *et al* (2011).

Samples were divided into two parts for heavy metal analysis and the other part for other parameters. Composite samples of first flush and after first flush were made at various sampling locations according to Ubuo (2012). The frequency of sampling was monthly in the year 2013. The roofs sampled were 0-5 years old according to method used by Akpan (2003) within 500m – 2000m from gas flare point and at the control location in Obite.

The month March was chosen to show variations with distance from flare point, November for effect on roofs while March, July and November was used for temporal variations and January to December was for pH variation.

3.3.6 Sample storage and preservation

The samples collected were stored in 2 litre plastic bottles properly rinsed and labeled. The samples for calcium, magnesium, sodium, chloride, sulphate, nitrate, hardness, TSS and TDS were preserved at temperature of 4^0c using the Rubbermaid model FG2A0904MODBL-5 QUART Personal ice chest cooler for a maximum holding time of 24 hours.

The samples for heavy metal analysis were preserved by adding 2ml conc. HNO_3I^{-1} solution to the sampling bottle before storing the sample to ensure that all composites were well preserved.

3.3.7 Meteorological Data

Data on monthly weather conditions for a year was extracted from secondary data spanning over ten years from Nigeria Meteorological Agency (NIMET, 2013). Temperature, wind speed and wind directions of sampling points was obtained using the centigrade thermometer, merlin digital anemometer-brass model and hand held digital compass- model 21E. The measurements were taken at a height of 1.5m and at 40m apart from gas flare point in the north, south, east and west directions according to method used by Oseji (2010).

3.3.8 Residents Experience

Data on the residents' experience of Odagwa environment was obtained using the likert 4 point scale close ended questionnaire instrument. It was administered to 100 people in Odagwa community with minimum of Senior School certificate.

3.4.0 Laboratory Analysis Methods

Analytical methods used were according to APHA (2012), standard methods water manual.

3.4.1 Temperature

The centigrade thermometer measuring 0^0C to 100^0C with mercury as thermometer liquid was used to obtain the temperature of the water sample by putting it into the sample and enough time allowed for equilibration. Temperature measurements were taken insitu.

3.4.2 Turbidity

The turbidity of water samples was measured insitu using the Hach portable turbidometer, model 2100Qis. The intensity of light scattered by the sample was compared with the intensity of light scattered by the standard reference suspension (Formazine), under the same condition. It was measured in nephelometric units (NTU).

3.4.3 Colour

Colour is measured in Hazen Units based on the platinum – cobalt (Pt/Co) Scale and measurement was obtained insitu using the Lovibond system 2000+ (comparator & disc) colorimeter, model L0142000-G with standard disc.

3.4.4 Total Suspended Solids (TSS)

The Evaporation Method was used for obtaining the measurements of TSS of 100ml sample. The sample was filtered using a glass fibre filter disc and transferred to previously ignited and weighed evaporating dishes. The difference in weight gave the value of the TSS in mg TSS per dm^3 of sample.

3.4.5 Electrical Conductivity

The Hach Electrical Conductivity meter, model HQ40D was used insitu to measure the electrical conductivity of water samples. The unit of measurement is (μS/cm) and it gave a measure of the ability of aqueous solution to carry an electric current. It was based on the principle that conductance G varies as A/L

G = KA/L where K =conductivity.

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3.4.6 Total Dissolved Solids (TDS)

The TDS is the portion of solids that passes through a filter paper of 2.0μm or smaller pore size. It was measured using the evaporation method at temperature of $180^0 \pm 2^0$C. Filtered sample was evaporated and dried in weighed dishes at 180^0C to constant weight. 30 minutes interval was allowed for dishes to cool before weighing was carried out. The increase in weights over empty dishes represented the TDS content. The unit of measure is mg/dm^3

3.4.7 p H

The pH is measured using the electrometric method with a pH meter and electrodes. The meter was calibrated potentiometrically with electrode system using standard borax buffer and neutral solution (blank) to give a pH of 4 and 7.

After calibration, the probe was rinsed with deionized water and immersed in a 50ml sample adjusted to temperature of 25^0C and the pH was

read off. The pH measurement was taken insitu using the Hach portable metre model HQ40D.

3.4.8 Determination of Alkali Earth Metals using Flame Photometry

The flame photometric method was used to determine the concentration of sodium, magnesium and calcium (Skoog *et al*, 2000). Calcium stock solution was prepared by mixing 0.252g of dry primary standard calcium carbonate ($100g/dm^3$) in a 6MHCl.

Magnesium stock solution was prepared from 0.101g of dry magnesium oxide ($40g/dm^3$) dissolved in 6MHCl and diluted with de ionized water to $1000dm^3$

Sodium chloride stock was also prepared from 0.510g ($58g/dm^3$) dissolved in water and diluted to $200dm^3$.

Unknown samples of the 3 analytes were prepared. The sample was mixed with fuel and oxidant before it flowed into the flame whose temperature is between 2300 and 3400k. The exited particles emit energy in the form of radiation with a characteristic wavelength which is measured by the photo detector.

3.4.9 Determination of Total Hardness as $CaCO_3$

A $50dm^3$ sample was pipette into a $250dm^3$ volumetric flask and a few drops of HCl acid was added to it to decompose any hydrogen carbonates, which would interfere with the result. The solution was boiled to remove CO_2. It

was cooled to 50^{o}C and 2dm^{3}of buffer solution was titrated using EDTA standard titrant. The total hardness was calculated using the relation;

$$\text{Hardness/EDTA (mg } CaCO_3) = \frac{\text{vol of EDTA} \times F \times 1000 \times 0.1 \times 17.8}{\text{Vol of sample}(dm^3)}$$

Where $F = \frac{\text{mass of } CaCO_3 \text{(mg)}}{\text{Vol of EDTA } (dm^3)}$

3.4.10 Nitrate (NO^{-}_{3})

The ultraviolet spectrophotometric method was used to get the measure of Nitrate concentration Deshpande (2008). The sample was filtered and 1ml of 1NHCL per 50ml of sample was added. The absorbance or transmittance was read off at 220nm and 275nm. Zero absorbance or 100% transmittance was set using distilled water. The concentration of NO^{-}_{3} in mg per dm^{3} of sample was obtained.

3.4.11 Chloride (Cl^{-})

The Argentometric method was used to obtain the concentration of chloride (Cl^{-}) in mg per dm^{3} of sample. Chloride was determined in a slightly alkaline solution by titration with standard silver nitrate using potassium chromate as an indicator.

Silver Chloride is quantitatively precipitated before red silver chromate is formed.

$$\text{Chloride (Mg/L)} = \frac{(A-B) \times N \times 35.45 \times 1000}{\text{Ml of Sample}}$$

Where: A = Ml $AgNO_3$ required for sample

B = Ml $AgNO_3$ required for blank

N = Normality of $AgNO_3$ used (0.1M$AgNo_3$).

3.4.12 Sulphate (SO_4^{2-})

Ultraviolet spectrophotometer was used to determine the sulphate concentration (Deshpande, 2008). Sulphate ion was precipitated as $BaSO_4$ (Barium Sulphate) in acidic medium by the addition of 0.1MHCl to 0.1M$BaCl_2$ (Barium Chloride). The light absorption by the precipitated suspension was measured by Spectrophotometer at wavelength of 420nm.

$$mg/dm^3\ (SO^{2-}_4) = \frac{MgSO^{2-}_4 \times 1000}{\text{volume of sample}}$$

3.4.13 Determination of Metals Using AAS

Atomic Absorption Spectroscopy (AAS) was used to determine the presence and concentration of metals including Zinc (Zn), Lead (Pb), Nickel (Ni), Manganese (Mn), Iron (Fe) and Aluminum (Al) in water samples.

AAS describes a situation in which Electro-Magnetic Radiation (EMR) is absorbed by atoms and measured. All atoms can absorb EMR and the wavelength at which it is absorbed is exclusive for a particular element.

Metals in their elemental form absorb ultra-violet light when they are excited by heat. Each of the metals have a specific wavelength that will be absorbed. Example,

Zinc	=	535nm
Manganese	=	525nm
Nickel	=	445nm

3.5.1 Geographical measurements

Wind Speed and Direction

During sampling the wind speed and direction was determined using the merlin digital anemometer, brass model and hand held digital compass, model 21E.

Geographical Coordinates;

The geographical coordinates and elevations was obtained by a Garmin GPS (global positioning system), model Etrex

3.6.0 Data Presentation and Analysis

Tables; Results were tabulated for better organization and presentation.

Bar Charts; Bar charts were drawn to show variations with: distance from flare point, types of roof, period of rainfall and monthly pH variation.

Line Graphs; Line graph was used to present the variation of distance with temperature in four directions from flare point.

Correlation; Correlation analysis was made between; rainwater properties at various distances from gas flare point, distance from flare point and temperature in four directions as well as between pH of rainwater and amount of rainfall.

Percentile; The percentile analysis was used to analyze the response of residents.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Variation of Physicochemical Properties of Unintercepted Rainwater at Various Distances from the Flare Point.

The results of the study are presented in Table 4.1

Table 4.1; Variation of Physico Chemical Properties of Rainwater at Various Distances from Gas Flare Point.

S/N	PARAMETER	UNITS	500M	1000M	2000M	CONTROL (ULAKWO) 5000M
1.	Temperature	OC	34	32	32	30
2.	Turbidity	NTU	60	64	62	45
3.	Colour	TCU	16	18	15	12
4.	Electrical Conductivity	µS/cm	20.5	18.5	17.0	16.0
5.	PH	-	5.1	5.4	5.8	6.5
6.	Total Suspended Solids (TSS)	mg/dm^3	65	60	58	42
7.	Total Dissolved Solids (TDS)	mg/ dm^3	20	18	16.8	16.0
8.	Manganese	mg/ dm^3	0.2	0.3	0.3	0.05
9.	Sodium	mg/ dm^3	100	120	140	140
10.	Magnesium	mg/ dm^3	0.1	0.15	0.18	0.15
11.	Calcium	mg/ dm^3	1.3	1.28	1.25	1.05
12.	Sulphate	mg/ dm^3	20	50	50	20
13.	Nitrate	mg/ dm^3	5	6	8	5
14.	Chloride	mg/ dm^3	5.5	5.7	5.6	5.7
15.	Total Hardness as CaCO3	mg/ dm^3	50	50	50	50
16.	Lead	mg/ dm^3	0.08	0.06	0.058	0.04
17.	Cadmium	mg/ dm^3	0.2	0.24	0.15	0.01
18.	Nickel	mg/ dm^3	0.01	0.05	0.02	0.001
19.	Zinc	mg/ dm^3	0.05	0.04	0.06	0.06
20.	Iron	mg/ dm^3	0.06	0.05	0.04	0.05

SOURCE: FIELD WORK

The variations are represented in Figures 4.1 to 4.6

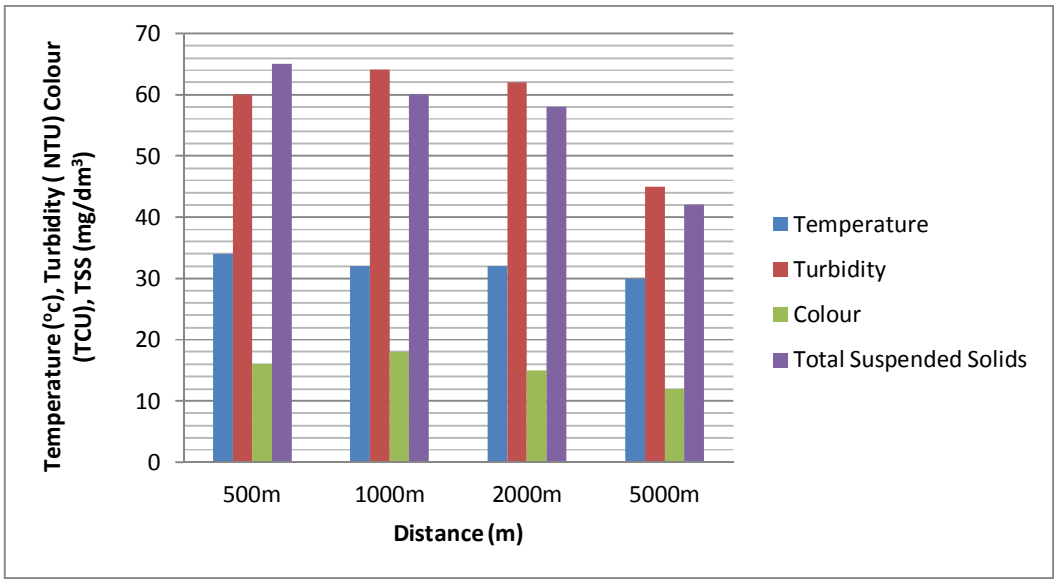

Fig 4.1; Variation of Temperature, Turbidity, Colour and TSS with Distance from Flare Point.

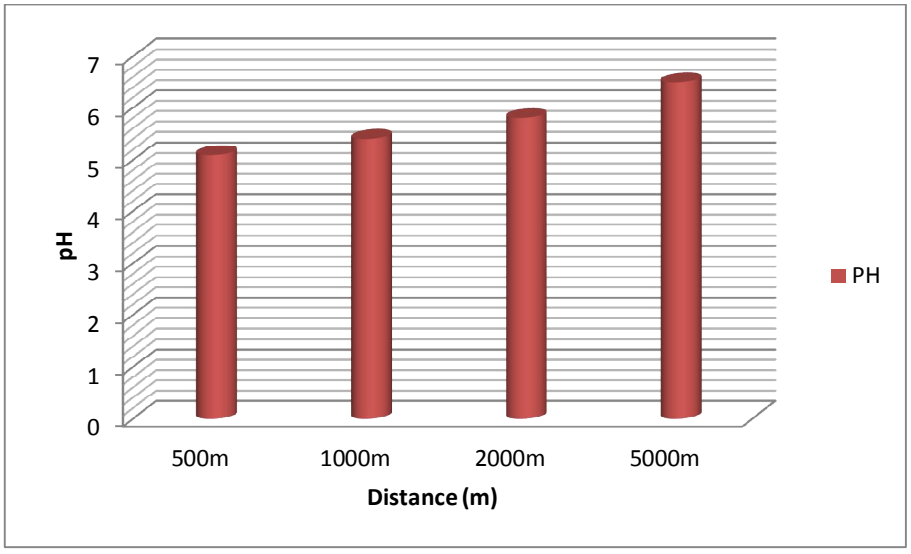

Fig 4.2a; Variation of Rainwater pH with Distance from Flare point.

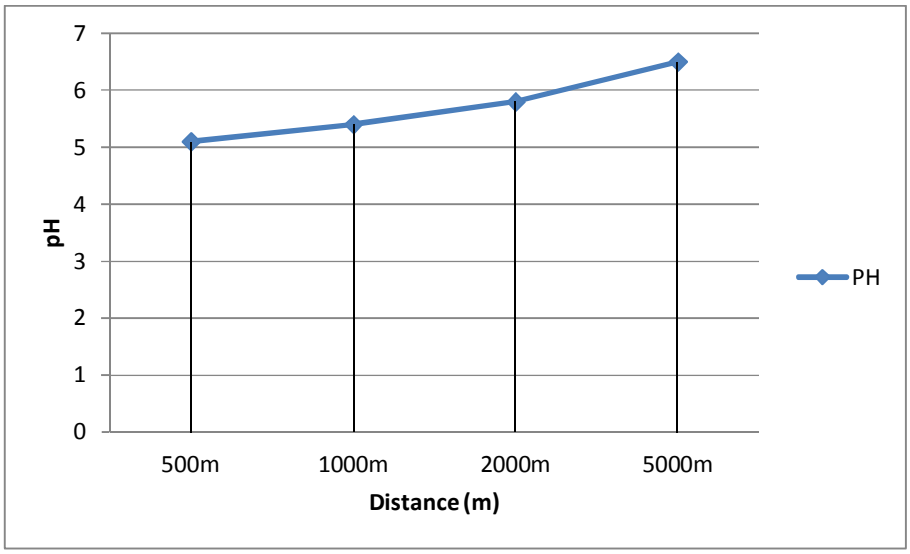

Fig 4.2b; Variation of Rainwater pH with Distance from Flare point.

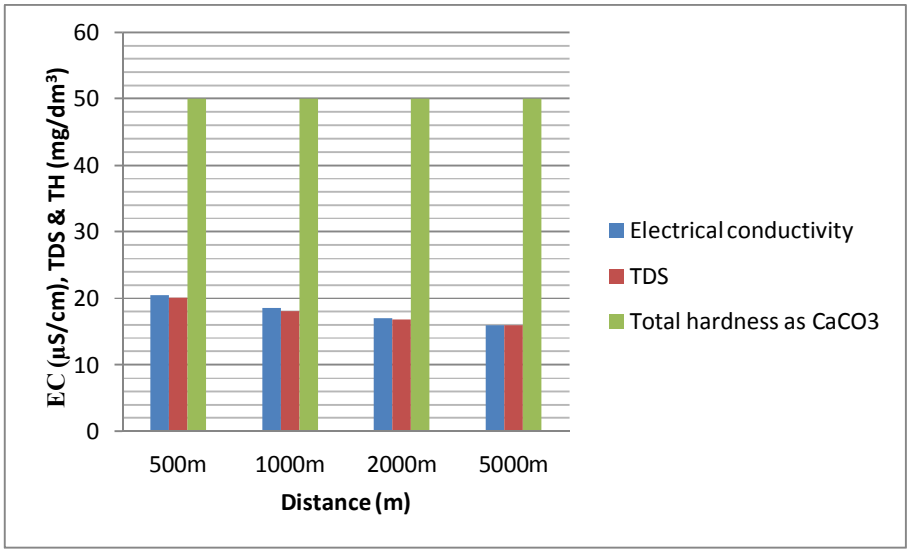

Fig 4.3; Variation of EC, TDS and TH with Distance from flare point.

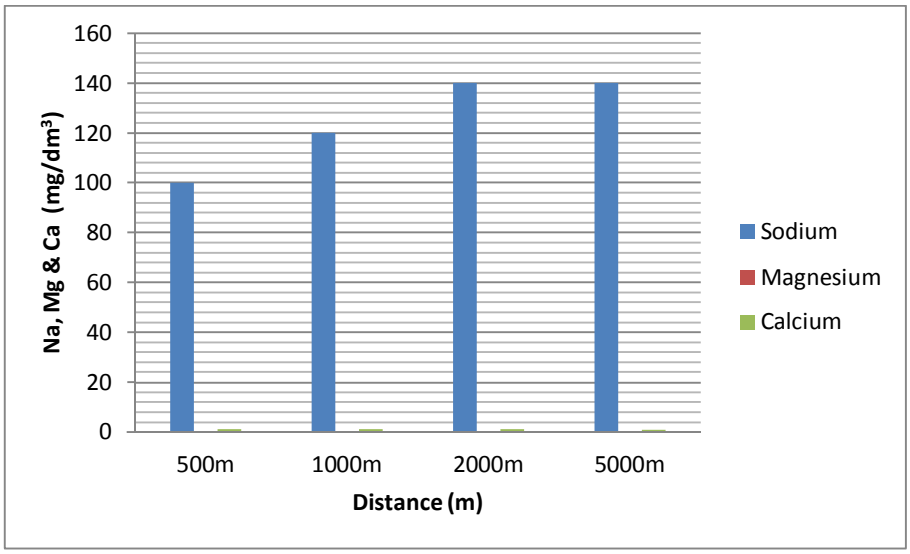

Fig 4.4a; Variations of Sodium, Magnesium and Calcium with Distance from flare point.

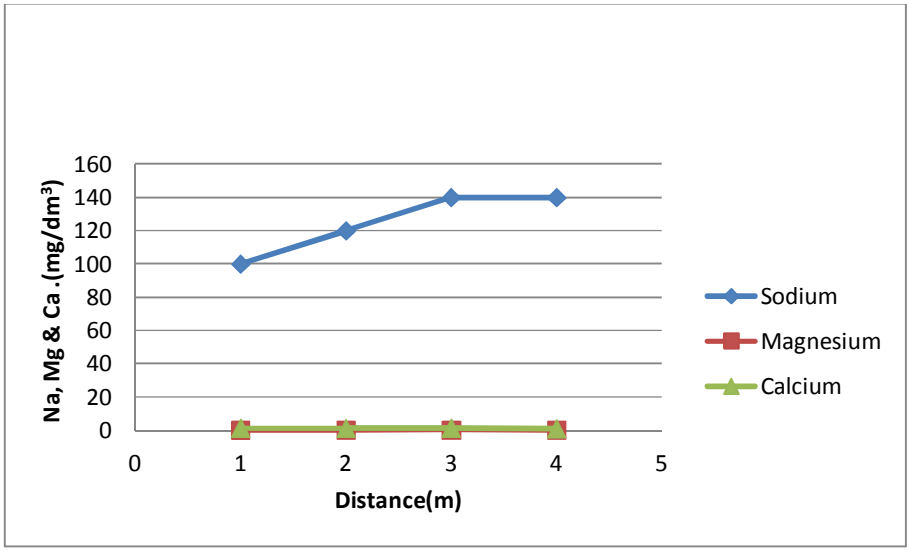

Fig 4.4b; Variation of Sodium, Magnesium and Calcium with Distance from Gas Flare Point.

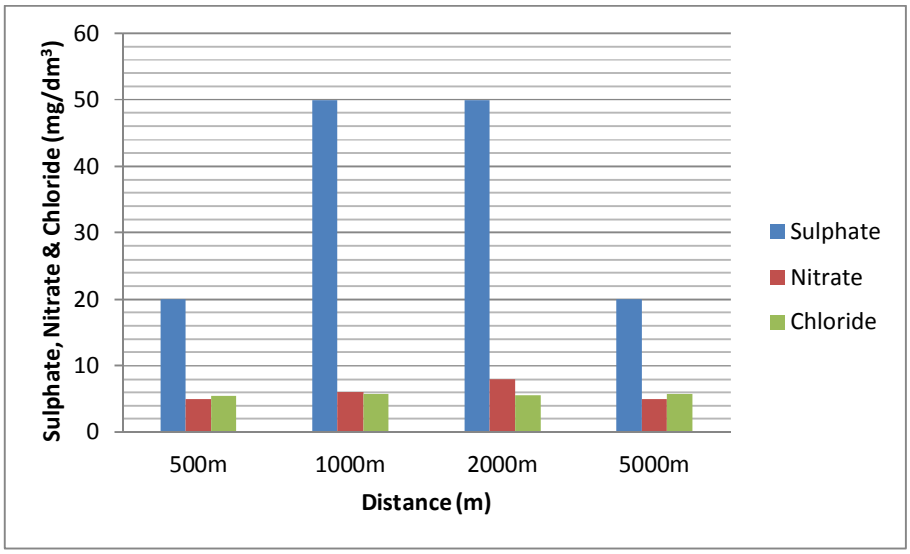

Fig 4.5a; Variation of Sulphate, Nitrate and Chloride with Distance from Flare Point.

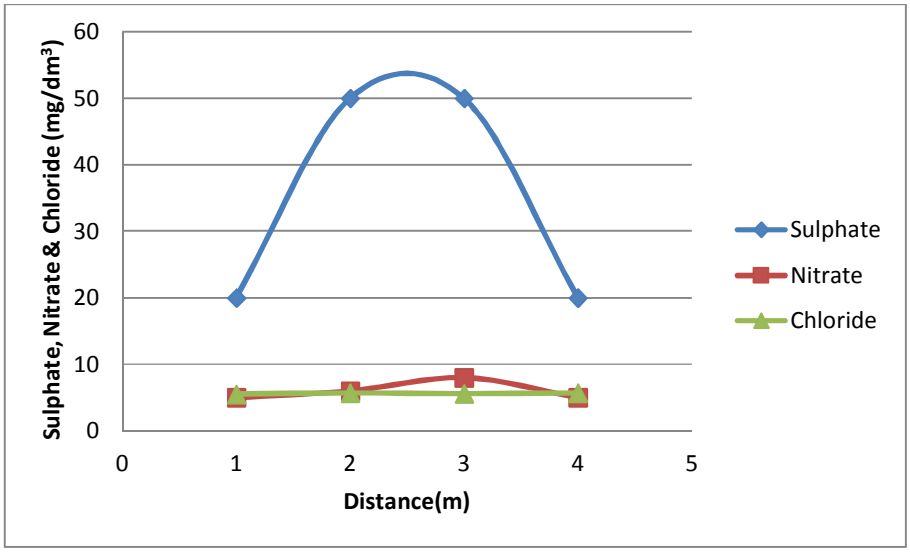

Fig 4.5b; Variation of Sulphate, Nitrate and Chloride with Distance from flare point.

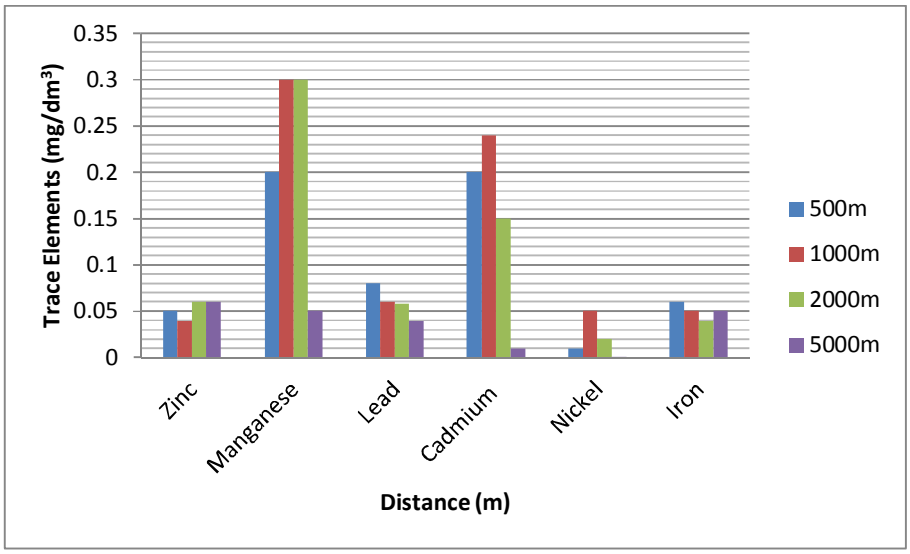

Fig 4.6; Variation of Heavy metals with Distance from flare point.

The results show that physical properties decreased with increase in distance from flare point. (Temperature 30°C-34°C, Turbidity 45-64NTU, Colour 12-18Pt/Co units and TSS 42-65mg/dm^3). pH increased with increased distance from the flare point (pH 5.1-6.5). Electrical Conductivity and TDS decreased slightly but were low while Total Hardness remained constant (EC 16-20.5µS/cm, TDS 16-20mg/dm^3, TH 50mg/dm^3). Alkali earth metals increased with distance from flare point but magnesium and calcium were low (Sodium 100-140mg/dm^3, magnesium 0.1-0.18mg/dm^3, calcium 1.05-1.3mg/dm^3) the nutrients increased, peaked and then decreased with distance from flare point (Sulphate 20-50mg/dm^3, Nitrate 5-8mg/dm^3, Chloride 5.5-5.7mg/dm^3). For the heavy metals, lead decreased with distance, zinc and iron decreased and increased while manganese, cadmium and nickel increased and then decreased with increase in distance from the flare point (Lead 0.04-0.08mg/dm^3, Zinc 0.04-0.06mg/dm^3, Iron 0.04-0.06mg/dm^3, manganese 0.05-0.3mg/dm^3, Cadmium 0.01-0.24mg/dm^3 and Nickel 0.001-0.05mg/dm^3). From correlation analysis; temperature had high correlation with turbidity, colour, electrical conductivity, pH, TSS, TDS, Mn, Na, Mg, Ca, Cl, Pb, Cd and Fe. The

correlation between temperature and SO_4, NO_3, Ni, and Zinc was low. Turbidity recorded high correlation with colour, EC, pH, TSS,TDS, Mn, Ca, SO_4, NO_3, Pb, Cd,Ni and Zinc while the correlation with Na, Mg, Cl and Fe was low. There was high correlation between colour and EC, pH, TSS, TDS, Mn, Na, Ca, SO_4, Pb, Cd, Ni and Zn while correlation between colour and Mg, NO_3, Cl and Fe was low. Electrical Conductivity had high correlation with pH,TSS,TDS,Na, Mg, Ca, Pb, Cd, Zn and Fe with low correlation with Mn, SO_4, NO_3 and Ni. pH recorded high correlation with TSS,TDS, Mn, Na, Ca, Cl, Pb, Cd and Zn with low correlation between pH and SO_4, NO_3, Cl, Ni and Fe. TSS recorded high correlation with TDS, Mn, Na, Ca, Cl, Pb, Cd, Zn and Fe. Correlation between TSS and Mg, So_4, No_3, Ni and Fe were low.(See appendix I).

The correlation analysis revealed strong relationships between parameters at distances 500m to 5000m from the gas flare point (appendix I).

4.1.2 Variation of Physicochemical properties of Rainwater Intercepted by Various Roofs.

The results are presented in Table 4.2

Table 4.2; Variation of Physicochemical Properties of Rainwater Intercepted by Various Roofs.

			STUDY LOCATION (ODAGWA)			CONTROL LOCATION (OBITE)		
S/N	PARAMETER	UNITS	G.I.Rs	Al.Rs	As.Rs	G.I.Rc	Al.Rc	As.Rc
1.	Turbidity	NTU	60	62	60	3	2	4
2.	Colour	TCU	16	16	17	6	5	10
3.	PH		8	5.8	6	6.9	6.8	6.9
4.	Total Suspended Solids (TSS)	mg/dm^3	61	58	60	32	28	30
5.	Total Dissolved Solids (TDS)	mg/dm^3	30	25	30	28	23	26
6.	Magnesium	mg/dm^3	0.15	0.17	0.3	0.05	0.05	0.1
7.	Sulphate	mg/dm^3	100	96	120	52	45	54
8.	Nitrate	mg/dm^3	40	42	60	20	25	28
9.	Chloride	mg/dm^3	50	45	45	14	12	15
10.	Iron	mg/dm^3	0.4	0.05	0.04	0.05	0.02	0.01
11.	Zinc	mg/dm^3	10	0.05	0.05	1.5	0.04	0.04
12.	Aluminum	mg/dm^3	0.00	0.1	0.00	0.00	0.01	0.00

SOURCE: FIELD WORK

G.I.R = GALVANIZED IRON ROOF. Al.R = ALUMINIUM ROOF. As.R = ASBESTOS ROOF

S - represent study location. c – represent control location.

The variations are represented in Figures 4.7 to 4.12

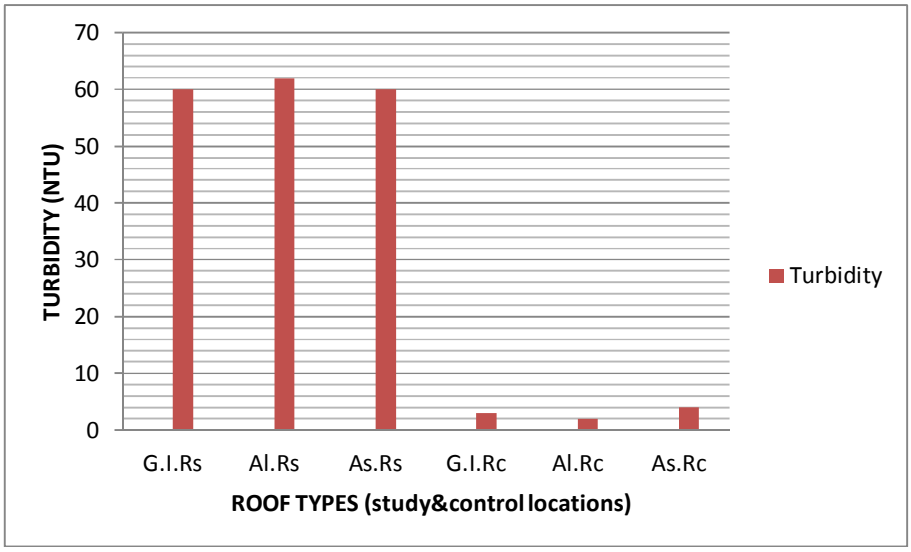

Fig 4.7; Variation of Rainwater Turbidity from roofs in study and control locations.

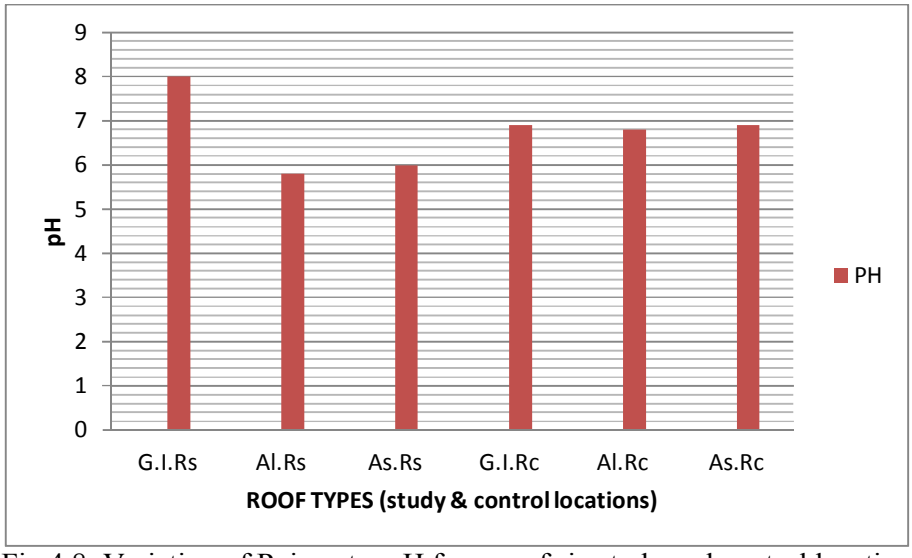

Fig 4.8; Variation of Rainwater pH from roofs in study and control locations.

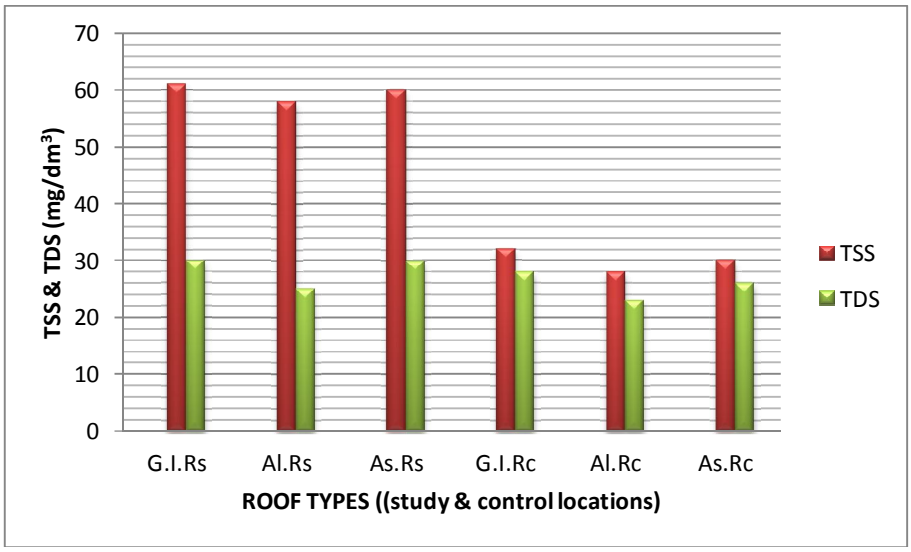

Fig 4.9; Variation of Rainwater TSS and TDS from roofs in study and control locations.

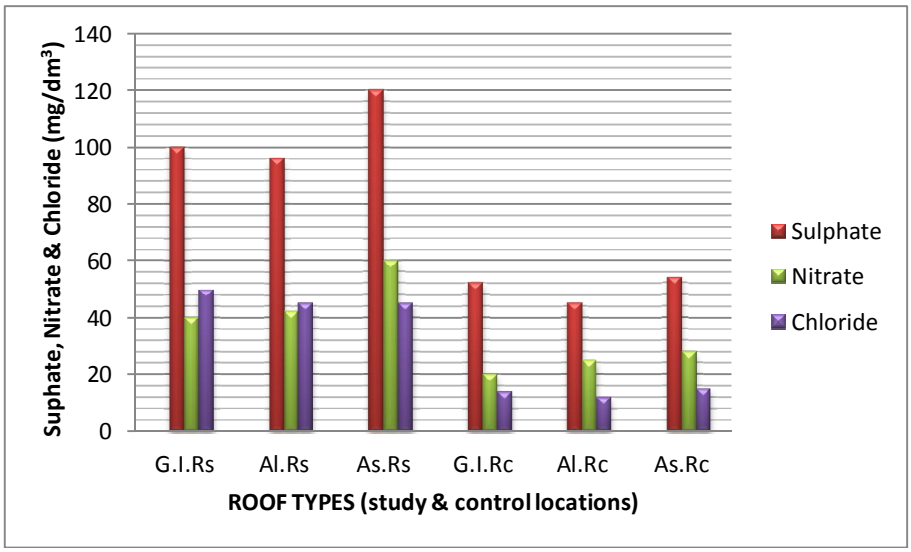

Fig 4.10; Variation of Rainwater sulphate, Nitrate and Chloride in study & control locations.

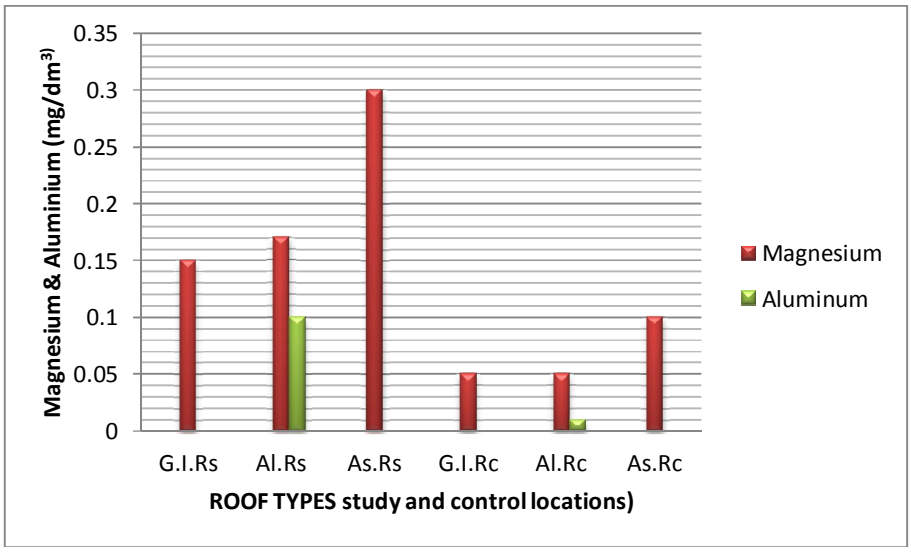

Fig 4.11; Variation of Rainwater Magnesium and Aluminum in study & control locations.

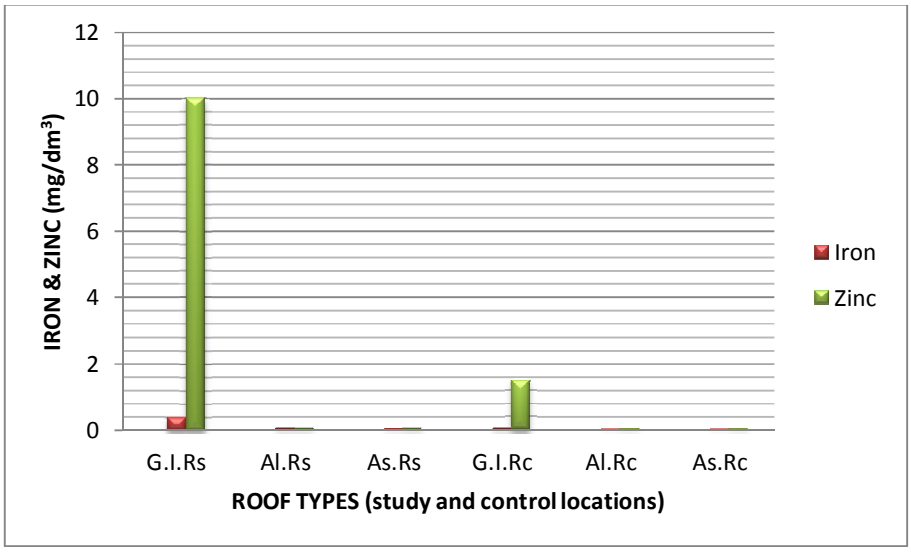

Fig 4.12; Variation of Rainwater Iron and Zinc in study & control locations

The results show that, rainwater turbidity was highest with Aluminium roof and colour was highest in galvanized iron roof (Turbidity 60-62NTU, Colour 16-17 TCU, TSS 58-61mg/dm^3).

pH was highest with zinc roof and lowest with Aluminium roof (pH5.8-8). Sulphate and nitrate was highest with asbestos roof and lowest in Aluminium while chloride was highest in zinc roofs.

(Sulphate 96-120mg/dm^3, Nitrate 40-60mg/dm^3, Chloride 45-50mg/dm^3). Zinc and Iron recorded highest values in galvanized Iron Roof (zinc 0.05-10mg/dm^3, iron 0.04-0.4mg/dm^3). Magnesium was highest in Asbestos roof while Aluminium was found only in aluminium roofs. (Magnesium 0.15-0.3, Aluminium 0.00-0.1mg/dm^3)

4.1.3 Temporal Variation of Physicochemical properties of Rain Water.

The results are presented in Table 4.3

Table 4.3; Temporal Variation of Physicochemical Properties of Rainwater.

S/N	PARAMETER	UNITS		March (FR)	JULY (MR)	NOV. (LR)
1.	Temperature	^{O}C		32	28	30
2.	Turbidity	NTU		63	30	55
3.	Colour	TCU		16.5	5	14
4.	Electrical Conductivity	µS/cm		18	12	15
5.	PH	-		5.6	6.8	6
6.	Total Suspended Solids (TSS)	mg/dm^3		59	45	50
7.	Total Dissolved Solids (TDS)	mg/ dm^3		17	8	12
8.	Manganese	mg/ dm^3		0.3	0.2	0.25
9.	Sodium	mg/ dm^3		130	100	110
10.	Magnesium	mg/ dm^3		0.17	0.15	0.17
11.	Calcium	mg/ dm^3		1.27	1.00	1.20
12.	Sulphate	mg/ dm^3		50	30	50
13.	Nitrate	mg/ dm^3		7	5	8
14.	Chloride	mg/ dm^3		5.65	5	6
15.	Total Hardness	mg/ dm^3		50	45	48
16.	Lead	mg/ dm^3		0.06	0.04	0.05
17.	Cadmium	mg/ dm^3		0.12	0.1	0.1
18.	Nickel	mg/ dm^3		0.04	0.02	0.03
19.	Zinc	mg/ dm^3		0.05	0.05	0.04
20.	Iron	mg/ dm^3		0.05	0.05	0.06

SOURCE: FIELD WORK

The variations are represented in Figures 4.13 to 4.18

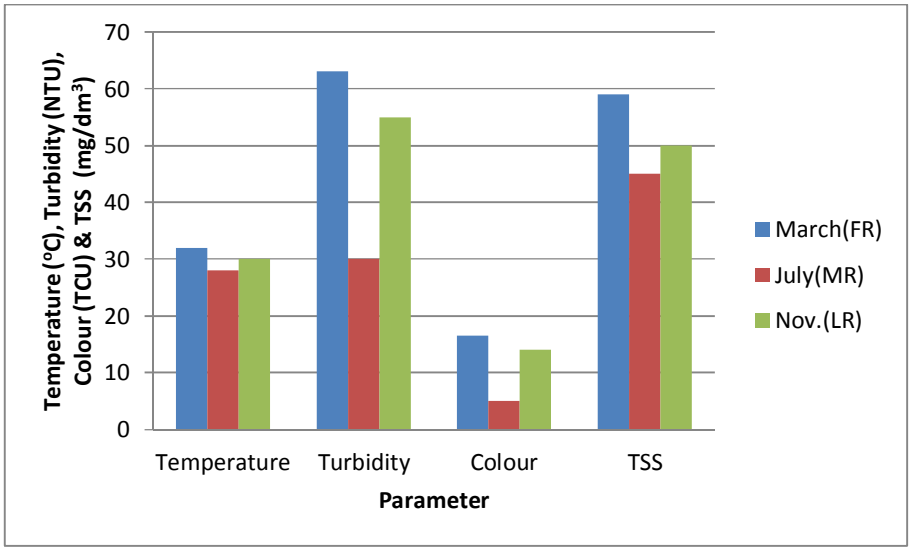

Fig 4.13; Temporal Variations of Temperature, Turbidity, Colour and TSS.

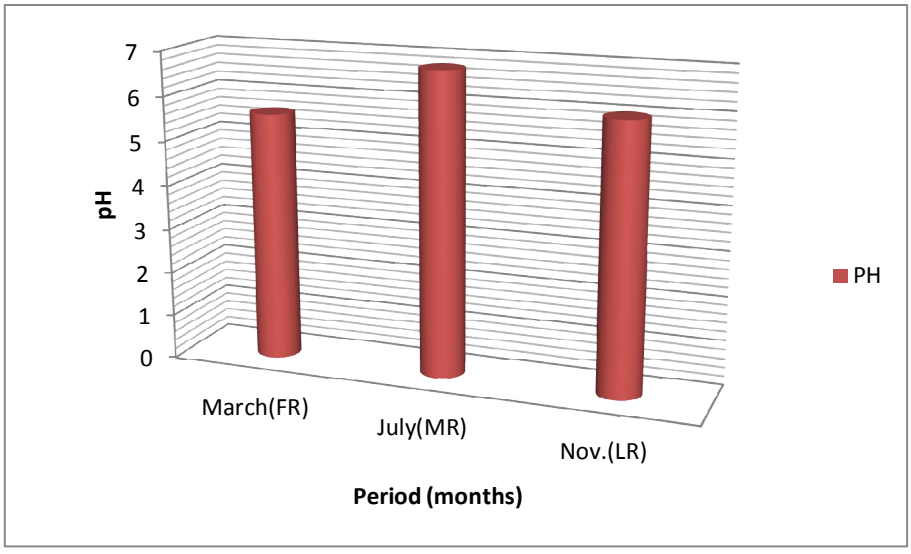

Fig 4.14; Temporal Variation of Rainwater pH

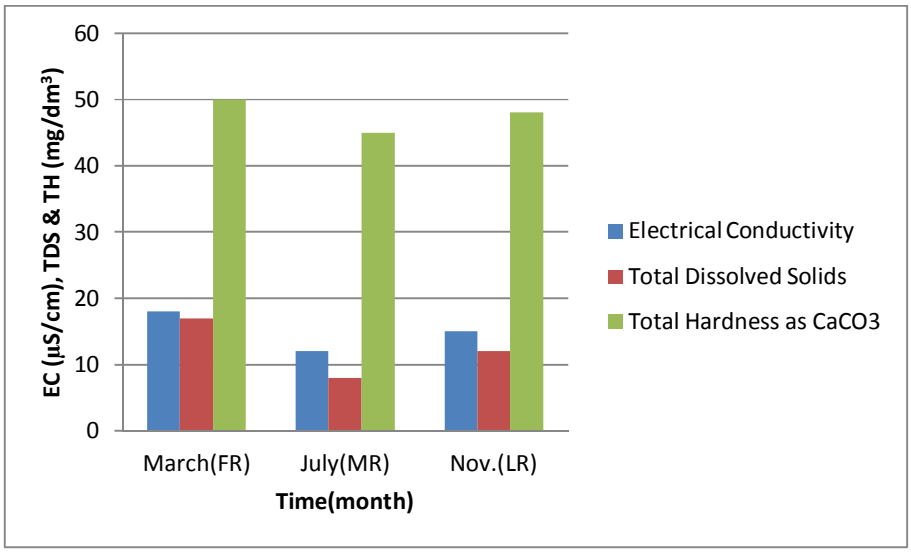

Fig 4.15; Temporal Variation of EC, TDS and TH.

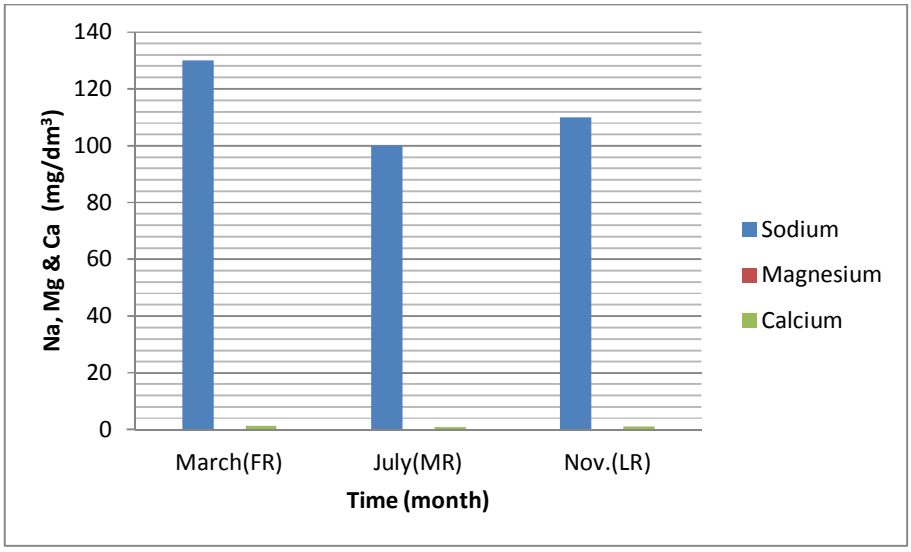

Fig 4.16a; Temporal Variation of Sodium, Magnesium and Calcium.

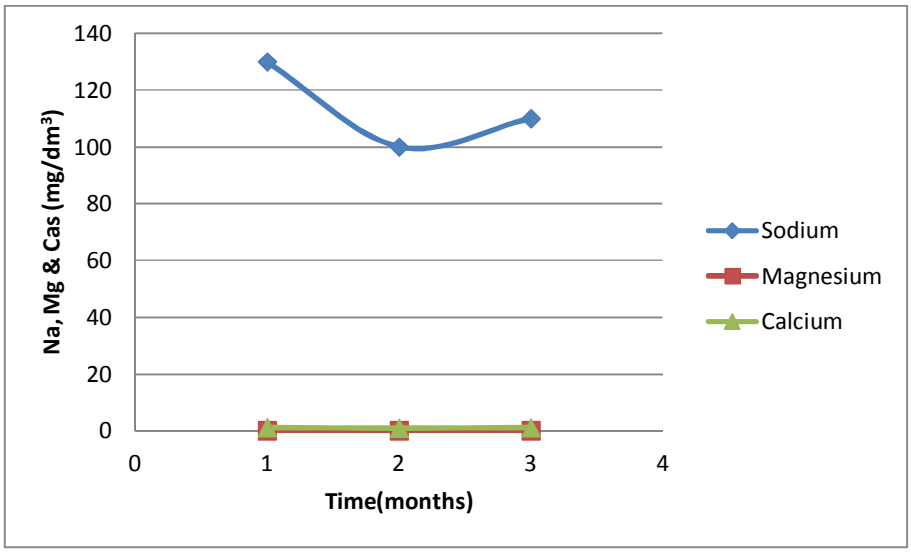

Fig 4.16b; Temporal Variation of Sodium, Magnesium and Calcium.

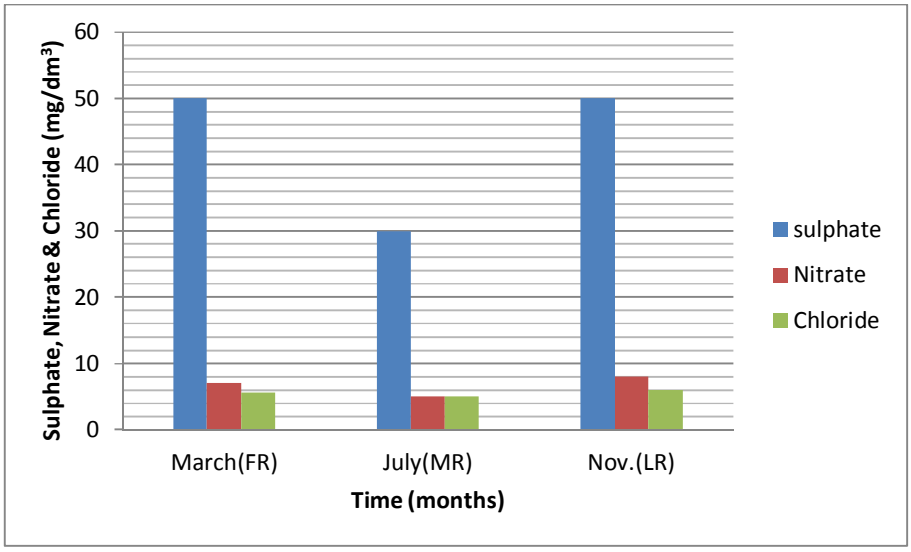

Fig 4.17a; Temporal Variation of Sulphate, Nitrate and Chloride.

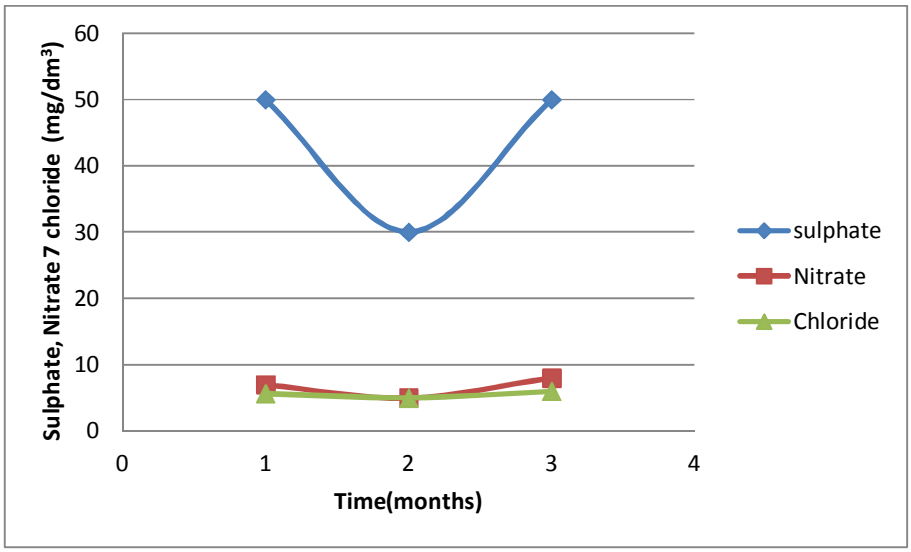

Fig 4.17b; Temporal Variation of Sulphate, Nitrate and Chloride

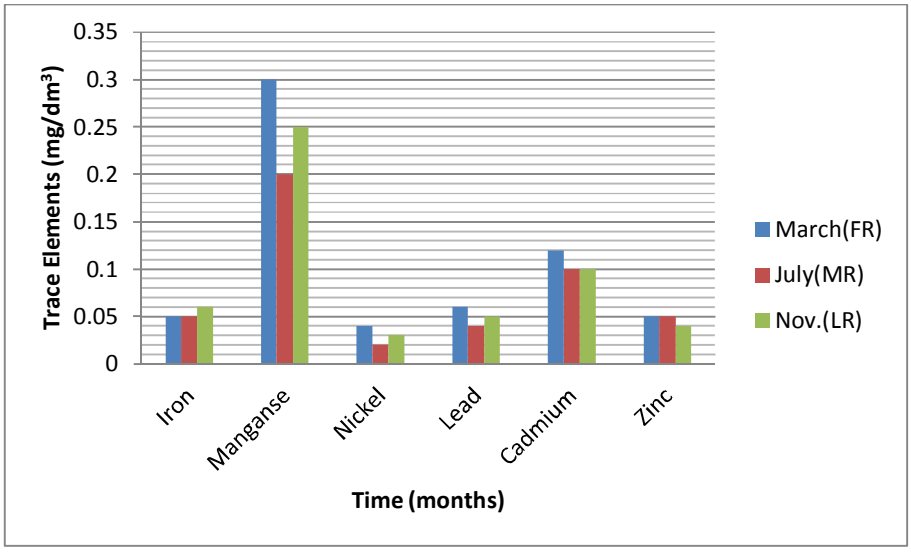

Fig 4.18; Temporal Variation of Heavy metals in Rainwater.

The results show that the physical properties decreased and increased from first rain through mid rain to last rain. (Temperature 28-32^{o}C, Turbidity 30-63NTU. Colour 5-16.5Pt/Co unit, TSS 45-59mg/dm^3). pH increased and then decreased (pH 5.6- 6.8). The EC, TDS, TH, alkali earth metals, nutrients and some heavy metals decreased reaching minimum in July then increased. (EC 12-18μS/cm, TDS 8-17mg/dm^3, TH 45-50mg/dm^3, Sodium 100-130mg/dm^3, Magnesium 0.15-0.17mg/dm^3, Calcium 1.00-1.27mg/dm^3, Sulphate 30-50mg/dm^3, Nitrate 5-8mg/dm^3, Chloride 5-6mg/dm^3, Manganese 0.2-0.03mg/dm^3, Nickel 0.02-0.04mg/dm^3 and Lead 0.04-0.06mg/dm^3). The heavy metals cadmium and zinc decreased from first rain to last rain while iron increased from a constant value in first and mid rain to a higher value in last rain (Cadmium 0.1-0.12mg/dm^3, Zinc 0.04-0.05mg/dm^3, Iron 0.05-0.06mg/dm^3).

4.1.4 Variation of Ambient Temperature with Distance from Flare Point.

The results are presented in Table 4.4

Table 4.4; Variation of Ambient Temperature with Distance from Gas Flare Point.

S/N	PARAMETER (M)		TEMPERATURE (^{0}C)			
			NORTH	SOUTH	WEST	EAST
1.	40	D1	50.1	45.1	42.2	52.2
2.	80	D2	47.3	40.2	42.1	49.3
3.	120	D3	43.1	38.2	40.6	43.1
4.	160	D4	39.4	38.1	38.2	41.2
5.	200	D5	31.2	31.3	31.2	31.1
6.	240	D6	30.6	30.1	30.2	31.1
7.	280	D7	30.4	28.8	30.1	32.2
8.	320	D8	30.1	28.6	30.1	32.1
9.	360	D9	31.1	29.1	30.1	32.1
10.	400	D10	31.1	28.5	30.1	30.8

SOURCE: FIELD WORK

The variations are represented in Figures 4.19 to 4.24

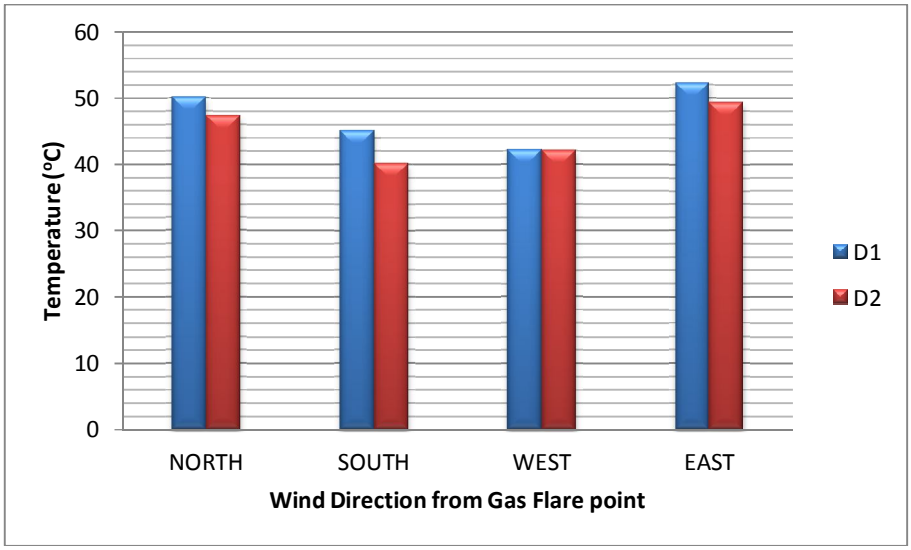

Fig 4.19; Temperature variation with wind direction at D1 and D2.

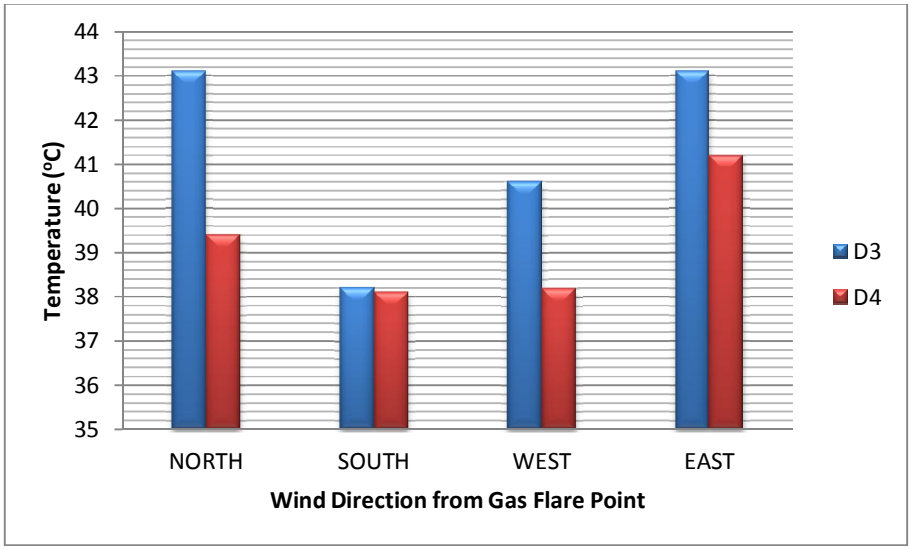

Fig 20; Temperature variation with wind direction at D3 and D4.

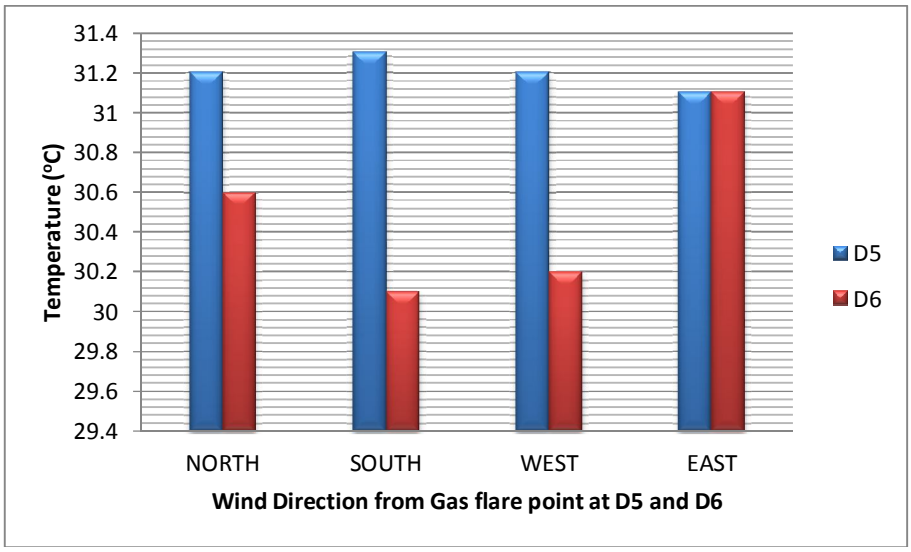

Fig 4.21; Temperature variation with wind direction at D5 and D6.

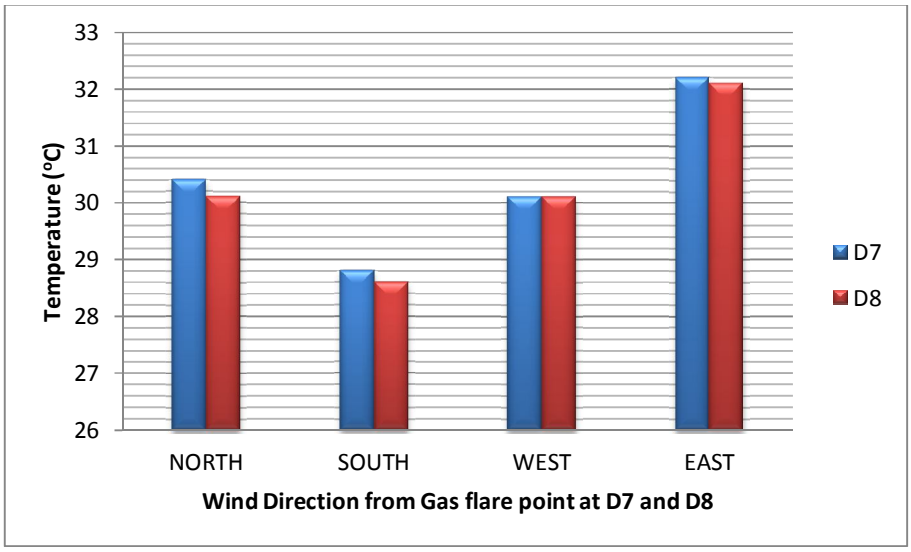

Fig 4.22; Temperature variation with wind direction at D5 and D6.

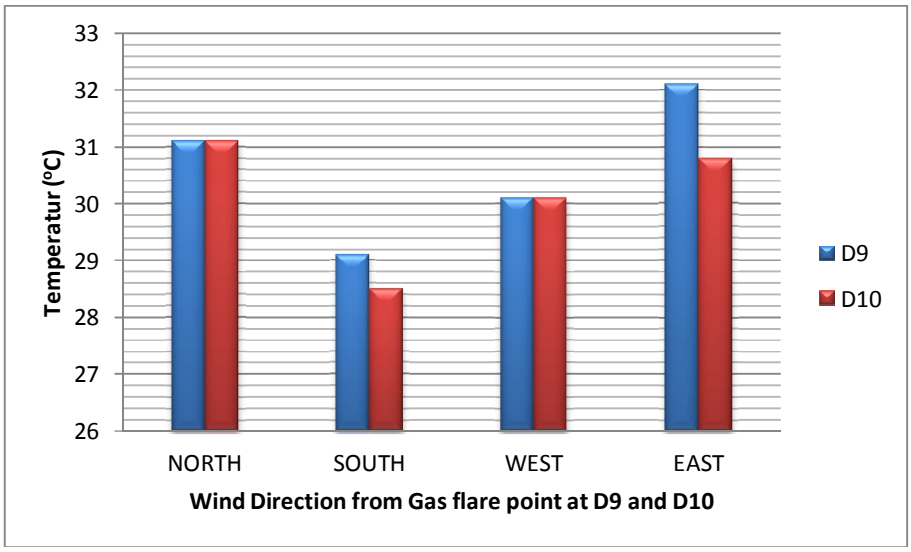

Fig 4.23; Temperature variation with wind direction at D9 and D10

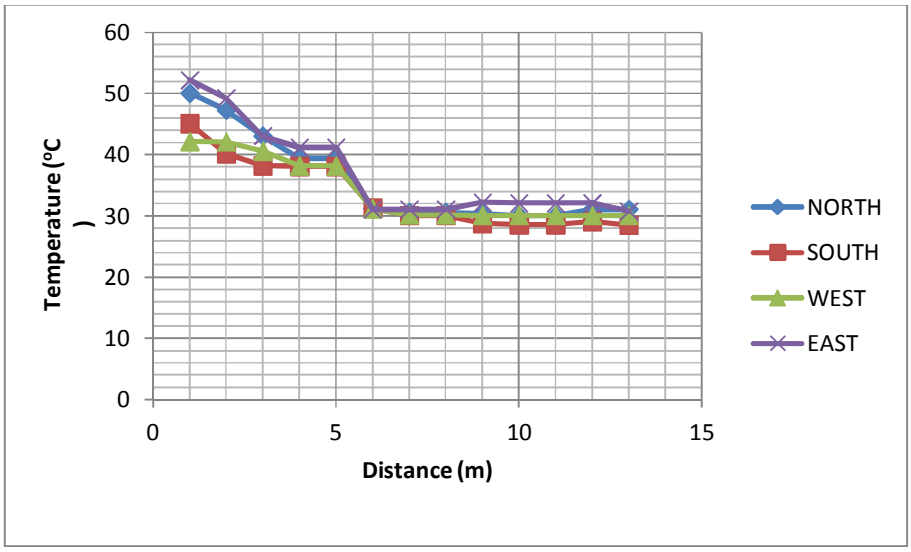

Fig 4.24; Variation of temperature with distance in various directions

The results of temperature variation in the ambient environment show that ambient temperature was above mean temperature of the area within the first 200m from gas flare point in the north , south, east and west directions. Temperature in the east direction was highest followed by north with west as lowest. Generally the temperature decreased with increase in distance from the flare point.

At D1; 40m (40.2-52.2^{o}C), D2; 80m (40.2-49.3 ^{o}C), D3; 120m (38.2-43.1 ^{o}C), D4; 160m (38.2-41.2 ^{o}C), D5; 200m (31.1-31.3 ^{o}C), D6; 240m (30.1-31.1 ^{o}C), D7; 280m (28.8-32.2 ^{o}C), D8; 320m (28.6-32.1 ^{o}C), D9; 360m (29.1-32.1 ^{o}C) and D10; 400m (28.5-31.1 ^{o}C).

A high negative correlation was obtained between distance from gas flare point and temperature in North, South, West and East directions (R^2=-0.88, - 0.92, - 0.89, - 0.877 respectively) (appendix II).

4.1.5 Monthly Variation of Rain water pH, Amount of Rainfall and Wind Speed.

The results are presented in Table 4.5

Table 4.5 Monthly Variation of Rainwater pH, Amount of Rainfall and Wind Speed.

S/N	MONTH	PH	RAINFALL		TEMPERATURE		WIND	
			AMOUNT(MM)	FREQ.	MIN (0^0C)	MAX (0^0C)	SPEED (Knots)	DIRECTION
1.	JANUARY	5.5	23.4	2	21.1	34.2	66.12	SW
2.	FEBRUARY	5.6	10.4	9	22.9	32.6	56.80	SW
3.	MARCH	5.6	92.7	6	24	34.6	50.96	SW
4.	APRIL	5.9	244.7	14	23.6	32.9	50.32	SW
5.	MAY	6.5	194.9	9	23.1	32.4	43.24	S
6.	JUNE	6.8	317.8	16	22.8	30.2	40.33	SW
7.	JULY	6.8	313.0	22	23.0	29.3	42.18	SW
8.	AUGUST	6.7	248.6	19	22.6	29.9	54.89	W
9.	SEPTEMBER	6.9	409.4	22	22.9	29.5	33.67	SW
10.	OCTOBER	6	207.6	18	22.2	30.4	31.79	W
11.	NOVEMBER	6	79.0	5	23.2	31.7	22.77	SW
12.	DECEMBER	5.8	0.00	0	21.7	32.7	35.29	N

SOURCE: FIELD WORK.

The variations are represented in Figures 4.25 to 4.27

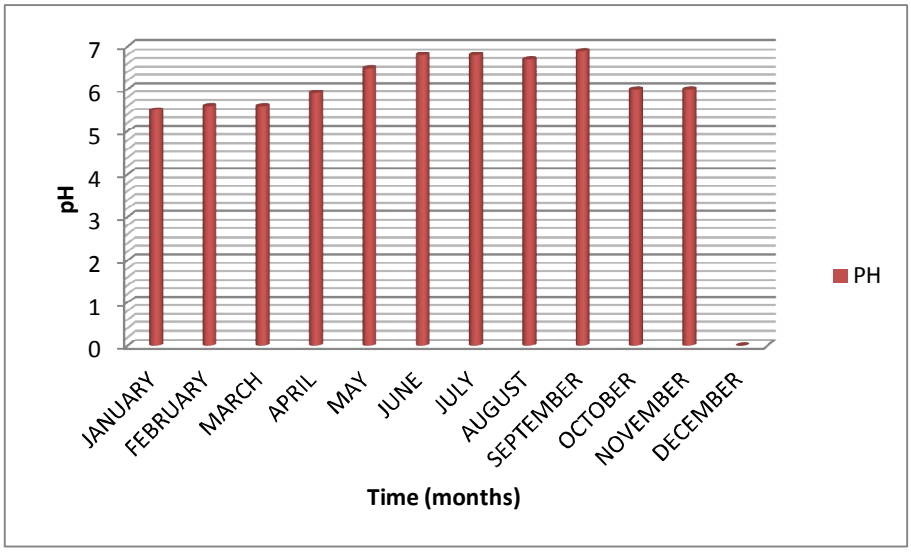

Fig 4.25; Monthly Variation of Rainwater pH.

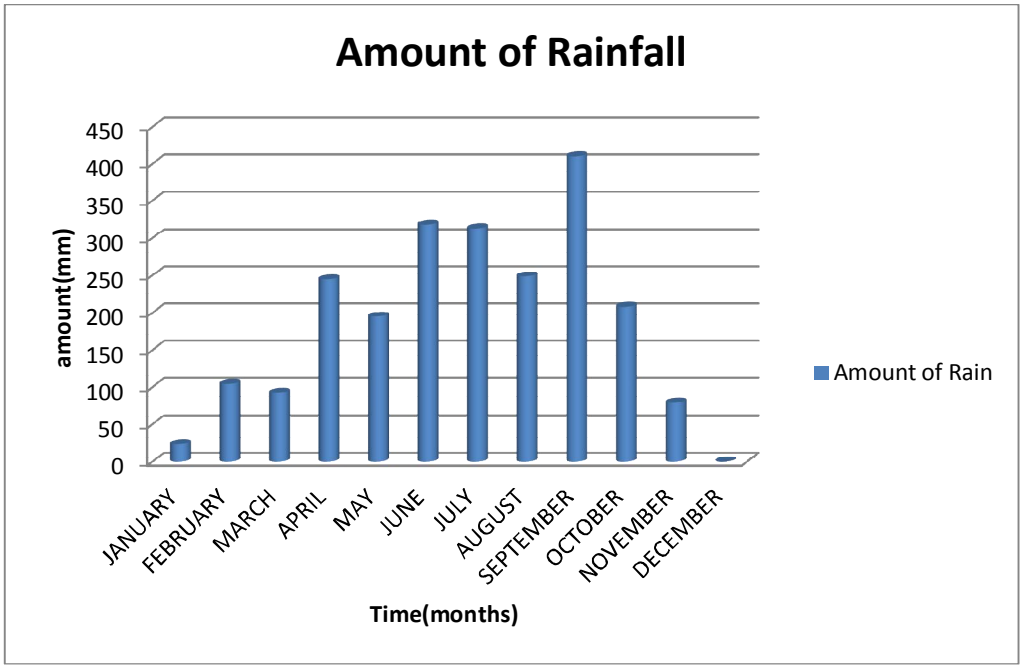

Fig 4.26; Monthly Variation of Amount of Rainfall.

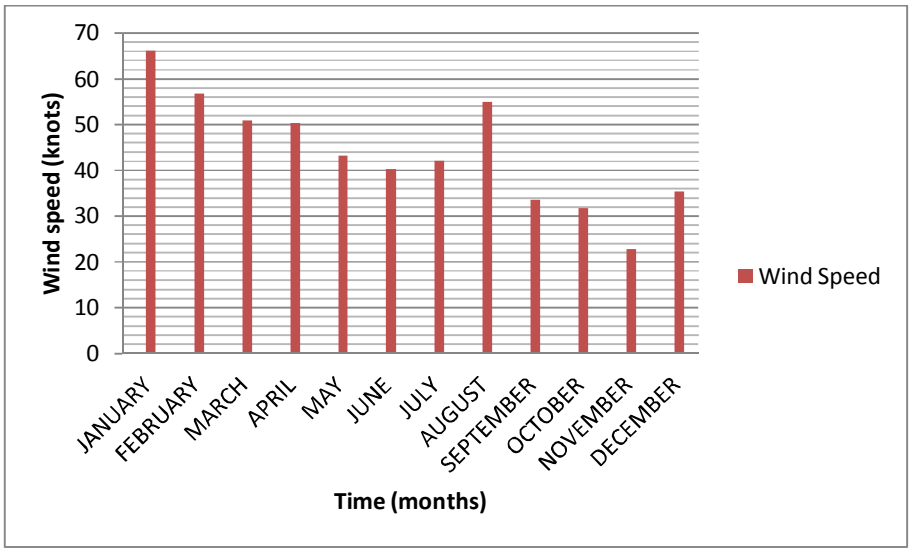

Fig 4.27; Monthly Variation of Wind speed.

Results show that rainwater pH increased from January and peaked in September and then decreased. Similar trend was noticed in the amount of rainfall while the wind speed had a continuous undulating trend. pH (5.5-6.9), Amount of Rainfall (23.4-409.4mm) Wind Speed (22.77-66.12 knots). The south westerly trade wind dominated throughout the year. Monthly pH of rainwater within Odagwa was 5.5-6.9 and its correlation with amount of rainfall was strong and positive (R^2=0.859) (appendix II).

4.1.6 Perception Of Odagwa Community Dwellers on Gas Flaring.

The result of the responses of residents to the questionnaire on the state of Odagwa environment is presented in Table 4.6

Table 4.6; Experience of Community Dwellers on the Effect of Gas Flaring.

Population=100, sample=60

S/N	EFFECT OF GAS FLARING	Strongly Agree		Agree		Disagree	
		SA	%SA	A	%A	D	%D
1.	Gas flaring as major pollution source	55	92	5	8	-	-
2.	Coloured Rainwater	32	53	20	33	8	4
3.	Corrosion of roofs and fading of materials	40	67	16	27	4	6
4.	Decline in wild animal specie	30	50	20	33	10	17
5.	Decline in Plant specie	28	47	22	36	10	17
6.	Poor Crop yield	50	83	10	17	-	-
7.	Heavy Rains and Flooding	45	75	15	25	-	-
8.	Rainwater as major source of Domestic Water supply	60	100	-	-	-	-
9.	Excessive Heat in the Community	40	67	15	25	5	8
10.	Rainwater mainly harvested by zinc roofs	50	83	10	17	-	-

SOURCE: FIELD WORK

Gas flaring was identified by 92% of the residents as the major source of environmental pollution in the area. 53% strongly agree that the rainwater is coloured, 67% strongly agree that roofs corrode easily while 50% and 47% strongly agree that there is a decline in animal and plant species. 83% confirmed poor crop yield, 75% strongly agree that there is heavy rain and flooding in Odagwa. 100% of the residents strongly agree that rain water is a major source of domestic water supply. 67% and 83% strongly agree that the

Community experiences much heat and that rainwater is mainly harvested from zinc roofs respectively.

The residents of Odagwa are of the view that gas flaring is a major contributor to the environmental pollution of the area.

4.2.0 Discussion

4.2.1 Variation of Rainwater Quality at Various Distances from Gas Flare Point

Results showed that rainwater quality parameters recorded an increased level within 2000m from gas flare point. The rainwater temperature, colour, turbidity, pH, total suspended Solids (TSS), Manganese, Lead, Cadmium and Nickel were high (Table 4.1, Fig 4.1- 4.6). The high values are due to dissolution and deposition of pollutants in the Rainwater. .

Ejelonu *et al* (2011) found out that in Utorogu gas flaring Community the rainwater within 1500m radius had pH less than 6.5. It was similar to results obtained by Ubuoh (2012) in Akwa Ibom communities experiencing gas flaring. In his study Akpan (2003) discovered that rainwater in gas flaring communities of Eket in Akwa Ibom State has high values of colour, turbidity, lead, nickel and TSS. Akhionbare (2009) confirmed that at the instant of formation, rainwater is pure but gets contaminated as it dissolves pollutant gases in the atmosphere.

The rainwater in Odagwa has pH levels from 5.1 to 5.8 within 2000m from the gas flaring point, Avwiri and Ebeniro(1995) concluded in their study

that it can lead to corrosion of metals, fading of paints, fabrics and other materials, acidification of surface, groundwater and soil as well as destabilization of aquatic ecosystem. Okereke (2006) added that soil acidity and accumulation of heavy metals such as lead can cause poor crop yield and poisoning of living organisms. The high temperature can deplete dissolved oxygen in the rainwater and nearby surface waters such as Imo, Otamiri and Ogochie rivers. The high TSS, turbidity and colour will make the rainwater lose its aesthetics and acceptability for domestic utilization.

4.2.2 Variation in Quality of Rainwater from Different Roofs

The rainwater collected from roofs in control location at Obite recorded low values for all the parameters while from the study location, galvanized iron roofing sheets (zinc roof) had high turbidity, colour, TSS, Iron and Zinc (Table 4.3, figures 4.7- 4.12). Turbidity and TSS can be attributed to suspended particulates induced by gas flaring; zinc and iron are likely to have been elevated as a result of products of corrosion.

Acidic precipitation acts as corrosive agent exerting high oxidative stress on the metallic surface (Lawton 1997 and Bhatia, 2009). Acidic solution accelerates the corrosion of iron, steel and zinc (Akhionbare, 2009). Okere (2006) in his work agreed that acid rain causes corrosion of roofing zinc sheets. Corrosion of the zinc roof follows a reaction of acid rain and a layer of zinc oxide which usually covers the zinc roof (Akpan, 2003).

The rainwater collected from Aluminium roof had similar properties to the unintercepted rainwater in table 4.1 except for traces of Aluminium discovered. Potera (2009) stated that corrosion is more effective in Aluminium sheets of less than 0.50mm thickness. Ovri and Iroh (2003) concluded in their work that corrosion of Aluminium is not as rapid as the zinc roof. Akpan (2003) pointed out that aluminium oxide reacts sparingly with dilute acid. This accounted for the similarity of results obtained from Aluminium intercepted and unintercepted rainwater in this Study. Generally corrosion is less in Aluminum roof compared to the Galvanized Iron roof.

Rainwater intercepted by Asbestos roof had high turbidity, colour, TSS, Magnesium, Sulphate and Nitrate. It is possible that asbestos offer better adsorption surface for particulates. The Centre for Disease Control Canada (2007) reported that asbestos based roofs materials have stronger resistance to acid rain deterioration and corrosion but contributes more to high health risks due to its fine fibres that can penetrate the lungs and are persistent in the environment. The magnesium high value is likely to come from the composition of asbestos.

While galvanized iron roof corrodes faster, Aluminum roof has more acidic rainwater and asbestos roof makes rainwater a higher health risk. Ejeleonu *et al* (2011) stated that in Utorogu gas flaring Community, rainwater contains acid radicals like Sulphate (SO_4^{2-}) and Nitrate (NO_3^-). Sulphate and nitrate concentration was highest in the asbestos rainwater (120

and 60mg/dm^3 respectively) this could be as a result of particulate deposition and formation of magnesium sulphate induced by gas flaring.

4.2.3 Variation of Rainwater Quality at Various Periods of the Rainy Season.

The rainy season was categorized into early or First Rain (FR) in March, mid rain (MR) in July and Late Rain (LR) in November. The First rain and late rain are more polluted than the mid rain.

The unintercepted rainwater sampled in March as early or first rain recorded high temperature, colour, turbidity, PH, TSS, Manganese, lead, Cadmium and Nickel (Table 4.4, Figures 4.13-4.18). This is similar to the situation in the qualities of rainwater within 2000m from gas flare point in table 4.1.

The mid rain (MR) sampled in July had only high values for manganese (0.2mg/dm^3), other parameters were low. This could be as a result of higher dilution and wash out by higher amount and frequency of rainfall. Ubuoh (2012) pointed out that rainwater sampled in July in parts of Akwa Ibom communities experiencing gas flaring had mean pH of 6 which is in the acidic region, this was different from my finding of average pH value of 6.8 in July. Akhionbare (2009) stated that rain dissolves atmospheric gases like O_2, N_2, CO_2, SO_2, NO, NO_2 with SO_2 and NO which are primarily responsible for acid rain. Ovri and Iroh (2013) stated that pH varies with acidic gases. It can be

argued that the more amount and frequency of rainfall the more diluted the acidic rain, this is similar to results of Joseph (2003).

The Late Rain (LR) sampled in November showed that turbidity, pH, manganese, nickel, lead and Cadmium had high values (Table 4.1) but manganese and nickel levels were low. Ejeleonu *et al* (2011), Aririatu (2006), Mokhatab (2006) and Gamaliel (2003) all agreed that rainwater in the vicinity of gas flaring contains trace metals such as Arsenic, chromium, cadmium, Nickel, cobalt, lead, zinc, iron, and mercury.

In Odagwa the first rain is the most polluted followed by the late rain while the mid rain is least polluted due to removal of gases and particulates from the atmosphere via washout, rainout, and dilution.

4.2.4 Variation of Ambient Temperature with Distance and Wind Direction around Flare Point.

Ambient temperature decreased with increasing distance from flare point for the first 240m in the North, South, East and West directions (Table 4.5, Fig 4.19).

The temperature within the first 80m was highest in the East direction followed by the North direction. This could be as a result of the predominant South West (SW) wind that blows towards the North East direction.

Oseji (2010) observed that gas flaring communities in Niger Delta experience about 1.4^0C surface temperature elevation above mean normal daily temperature. He further stated that it is more pronounced in the first 300m

radius from flare point, causing gaseous pollutants to become more reactive affecting environmental flora and fauna. Avwiri and Obeniro (1996) supported the view that increase in temperature due to gas flaring has undesirable effects on man and his environment. They identified thermal radiation, stunted growth of crops and plants, migration of animal species, migration of inhabitants who are predominantly farmers due to discomfort and poor crop yield as some of the experiences observed in their study.

Effects of high temperatures on plants and animals

Denaturation of plant enzymes is expected from temperatures of 40^{o}C and above. Failure of only one critical enzyme system can cause the death of a plant (Yash and Keigth, 2004). Denaturation of membrane proteins as well leads to injury of membrane from sudden heat stress, membrane rupture and loss of cellular contents (Ahrens and Ingram, 1988). Mishra and Singhal (1992) observed the occurrence of peroxidation of membrane lipids at high temperatures causing heat stress. Most plants show reduction in photosynthesis at temperatures above 40^{o}C. Crop growth development is low in the first 300m from flare point but within 10 to 30^{o}C it has a direct linear relationship with temperature while above 30^{o}C the relationship is non linear. bhullar and Jennar (1985) found out that temperatures above 34^{o}C causes reduced dry matter accumulation in plants. Grain crops show a declined yield with temperatures above 34^{o}C. Kropff *et al* (1993) found out that crop growth stimulation show that rice yields decrease 9% for each degree rise in average temperature.

Vegetables die at a temperature of 46^{o}C and are negatively affected at temperatures above 34^{o}C. Kim D.C (2003) stated that at temperatures above 32^{o}C, dry winds are introduced causing heat buildup in vegetables which leads to rapid water loss, heat injury, and eventually tissue death.

Temperatures above 34^{o}C will cause the following episodes in plants; decrease in photosynthesis, increased respiration, cell membrane leakage (signaling change in protein synthesis), continued physical water loss, growth inhibition, plant starvation and poor crop yield.

High temperatures affect animals negatively especially through heat stress. Hansen P.J (2004) identified that mammal as endotherms tolerate the highest temperatures as they function at high core temperatures that range from approximately 35^{o}C to 39^{o}C. There is less resistance to body temperatures above set point temperatures (Heldmaier *et al*, 2004). Death is likely to occur if temperatures exceed 40^{o}C because of disruptions in membrane fluidity, protein structure, for animals in which sweating and panting exist electrolyte and fluid loss (Jardine, 2007).

The correlation results reveal a strong inverse relationship between temperature and distance from the flare point in the north, south, east and west directions.

4.2.5 Monthly Variation of Rainwater pH, Amount of Rainfall and Wind Speed.

The pH of rainwater collected from the ambient environment between January to December 2013 varied from 5.5 to 6.9 in the year 2013 (Table 4.5, fig 4.18). The values showed that rainwater for 7 months of the year was acidic. The more the amount of rainfall, the less the acidity of rainwater. The wind speed reduced and increased in a continuous undulating trend as the year progressed from January to December while wind direction was predominantly South West. Ubuoh (2012) identified location, rainfall amount, rainfall frequency, wind direction and wind speed as factors that influence acid rain formation in the vicinity of gas flaring. Nkwocha *et al* (2010) found that wind characteristics are factors affecting the level of impact of gas flaring while Garret *et al* (2007) observed that gas flaring leads to changes in meteorological conditions. Although the pollution by gas flaring is local, Narayanan (2009) pointed out that, meteorological conditions globalizes the effect of pollution from gas flaring.

The correlation result shows a strong direct relationship between rainwater pH and amount of rainfall while there was no relationship between amount of rainfall and wind speed (table 4.8).

4.2.6 Perception of Odagwa Community Dwellers on Gas Flaring in the Area.

Over 70% of Residents believe that gas flaring is the major source of environmental pollution in Odagwa. They were of the view that their rainwater is coloured. This was confirmed by the high values of colour and turbidity gotten from the analytical results which was supported by Ejelonu *et al* (2011). Rapid corrosion of roofs was also identified; it was supported by Akpan (2003), Sexton et al (2007), Nkwocha and Mbano (2010), Potera (2009) and Rothman (1998). The analyses show that Odagwa rainwater is acidic which makes it a corrosive agent. Gas flaring causes decline in plant and animal species, pollution of soil and water bodies, thermal radiation and poor crop yield. These impacts were confirmed by the result of the physicochemical analysis of rainwater and supported by Narayana (2009), Bhatia (2009), Okereke (2006) and Oseji (2010).

Gas flaring is the major cause of environmental pollution of Odagwa community.

CHAPTER FIVE

5.0 SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSION

5.1 Summary of Findings

In the course of this research work, findings were made and summarized as follows;

At various distances from flare point, values of physical properties (Temperature, Turbidity, Colour, and T S S) decreased, pH increased with distance, electrical conductivity and TDS decreased slightly while total hardness remained constant. For Alkali earth metals sodium increased with distance while magnesium and calcium were very low. Sulphate and nitrate increased, peaked and decreased with distance while chloride recorded slight upward and downward variation with distance. For heavy metals, lead decreased with increased distance from flare point, zinc and iron decreased and increased while manganese, cadmium and nickel increased and decreased with increase in distance from flare point. Generally, temperature, turbidity, colour, TSS, pH, manganese, lead cadmium and nickel values were high and unacceptable (appendix III & IV).

Analysis of rainwater properties collected from roofs show that turbidity was highest in Aluminum roof and constant for zinc and Asbestos roofs. Colour was highest in Asbestos and lowest in zinc roof, TSS was lowest in Aluminum roof. Sulphate and nitrate recorded highest values in Asbestos roofs and lowest

in Aluminum roofs while Chloride was highest in zinc roofs. Zinc and Iron was more in galvanized iron roof while magnesium was most in Asbestos roof. Generally turbidity, colour, magnesium, sulphate, nitrate, zinc, iron recorded high values in some roofs rainwater (Table 4.2, appendix III & IV).

Temperature, Turbidity, Colour and TSS decreased and increased from First Rain (FR), through Mid Rain (MR) to Late Rain (LR), pH increased and decreased. Electrical Conductivity, TDS and Total hardness decreased reaching minimum in July and increased. Sodium, magnesium and calcium followed similar trend though magnesium and calcium were very low. Sulphate, Nitrate and Chloride also decreased reaching minimum in July and further increased, similar trend was observed in manganese, nickel and lead. Cadmium and zinc decreased while iron increased from a constant value. Generally turbidity, lead, cadmium, pH, TSS, manganese and Nickel recorded high values which are unacceptable (table 4.3, appendix III & IV).

Ambient temperature within the first 240m from flare point in the North, South, East and West directions was found to be above the mean temperature of the area. This temperature decreased with increasing distance from the flare point and was highest in the East direction and lowest in the West direction.

The monthly variation of rainwater pH, show a range of 5.5 to 6.9 with about seven months having acidic rainwater. The pH was found to increase with increased amount of rainfall with the south west wind dominating.

The experiencee of Odagwa dwellers show that gas flaring is the major source of environmental pollution in the area. They related that; their rainwater is coloured, roofs corrode easily, there is decline in plant and animal species, crop yield is poor, they experience excessive heat, rain falls heavily, rainwater is a major source of water supply in the community and is harvested more with the galvanized iron roof.

5.2 Environmental Implications

The findings show that gas flaring has effect on the rainwater quality and hence portend far reaching implications:

The rainwater quality will be affected negatively creating challenges in water utilization as rainwater remains a veritable source of water for drinking and domestic purposes in the community. The ground flaring will not encourage proper dilution and dispersion of products of gas flaring. The formation of acid rain/precipitation is very high and will lead to chains of environmental impacts. Emission of green house gases from the flare vents can encourage global warming, green house effects and hence climate change. Acid rain, high temperatures air, soil and water pollutants affects flora and fauna negatively. Impact on building walls, roofs, paints and structure will be high. Polymers and other materials that come in contact with the polluted water will fade or deteriorate easily. Metallic structures and materials will experience corrosion on exposure to the rainwater polluted by gas flaring. Soil properties will be

affected negatively leading to poor crop yield and decline in essential soil organisms. Ground and surface water will be polluted through run off, depositions, infiltration and aquifer recharge. There will be a shift in local weather and climate, thermal pollution and light pollution will be common occurrence in the vicinity of gas flaring. To protect the health of the people by the provision of portable water more cost will be incurred in the treatment of rain, surface or ground water in the community. Waste of enormous resources that would have been generated from the flared gas, damaged materials and properties, loss of biodiversity, loss of agricultural income, loss to ill health and loss to community unrest will not be over emphasized.

5.3 Recommendations

Gas flaring is a major contributor to environmental pollution in Odagwa. It has been found to have effect on rainwater quality of the community and by implication the environment. To solve the problem of gas flaring and it's numerous impacts on the Odagwa community and environment, I recommend that:

The Petroleum Industry Bill (PIB) should be passed into law as gas flaring was treated extensively in sections 275 to 281 of the bill which aims at stopping gas flaring. If a company must flare gas, it should always be done under controlled conditions. The ground flaring system should be stopped as a matter of urgency and appropriate elevated flare system installed. The SPDC should

officially acquire agricultural land within 500m radius around the flare point and put it into use other than agricultural cultivation. The flaring company and relevant stakeholders should establish a robust water scheme to ensure the community water sources are treated before utilization. Appropriate soil treatment methods should be adopted to ensure the restoration of affected soil properties. Creation of forest reserves with special trees around the flare zone to promote Bio remediation. Combination of staged flare system and gas recovery to minimize the volume of gas been flared. Alternative technologies such as gas Re – injection, Gas transport, Gas to Liquid, Gas utilization, incineration and Gas conservation should be adopted. Gas emission cleanup programme should be carried out in the Community. Appropriate environmental management systems like the ISO14001 should be implemental strictly. Establishment of environmental programmes to ensure sustainable operation in the oil and gas sector similar to EPA Natural Gas STAR and API STEP Programmes should be encouraged

5.4 Suggestions for further Studies

The work is an individual effort within Odagwa Community in Etche LGA of River State. Other Communities experiencing gas flaring, other forms of industrial pollution, Oil activities such as, spillage and effluent discharge from drilling, refinery, transport and exploration activities should be studied. More so, solid waste and hazardous waste associated with oil and gas activities

can as well be studied, Alternative technologies to promote sustainable oil and gas operations is another area begging for attention.

Therefore, I, suggest that other individuals, corporate bodies, Non – Governmental Organizations (NGOs) Community Based Organizations (CBOs), Government and other interest parties should embark on a wider scope of studies suggested above.

5.5 Contribution to Knowledge.

Several researches have been carried out on impacts of gas flaring on Niger Delta communities by various authors.

In this research work, I studied Odagwa community which is host to SPDC's Nkali Flow station that has not witnessed many studies. The use of rainwater as sample matrix provided the link between various environmental factors unlike most studies. More so, the incorporation of elements of weather and climate, opinion of community dwellers made the work multi disciplinary.

It was discovered that: temperature, turbidity, colour and TSS decrease as you go further away from flare point, EC and TDS was low, total hardness was constant through the various distances, sodium was the alkali earth metal with significant level in the rainwater within 500m-5000m distance, nutrients had low concentration, lead decreased with increasing distance from flare point, other heavy metals increased and decreased while zinc and iron recorded moderate values but behaved differently from other heavy metals. Rainwater

in July recorded normal (acceptable) values in most of the parameters. Rainwater from roofs behaved differently with respect to the roof material. Aluminium was found in rainwater collected from aluminium roofs. Ambient temperature around flare point was higher than mean normal temperature of the area and it decreased with increase in distance from flare point. Ambient temperature was highest in the east direction and lowest in the west direction from flare point. Rainwater in the community was acidic for most part of the year and the rainwater pH varied directly with amount of rainfall. Community dwellers perceive that gas flaring is the major cause of various negative impacts on their community rainwater and air quality.

5.6 Conclusion

This research work sought to find out the effect of Gas Flaring on the Rainwater Quality of Odagwa Community in Etche LGA of Rivers State.

Within the limits of resources available to me, l was able to study the properties of rainwater in Odagwa with respect to distance from flare point, period (Early, Mid and late rain) and type of roof used in intercepting the rainwater. I also determined the ambient temperature around flare point, monthly rainwater pH, amount of Rainfall, wind speed & direction and the view of residents on the environment of Odagwa.

The findings show that Odagwa is been affected by gas flaring which is a major contributor to; acid rain formation, green house gas emission, poor

water quality, corrosion of metals especially roofs, fading of materials, poor crop yield, decline of flora and fauna, change in weather conditions and climate.

It was recommended that the use of rainwater in the community take into consideration necessary treatments and oil & gas operators should carry out proper mitigations in host communities.

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APPENDIXES

Appendix I

Correlation Matrix of Rainwater Properties Between 500m-5000m from Gas Flare Point

	Temp	Turbidity	Colour	EC	pH	TSS	TDS	Mn	Na	Mg	Ca	SO_4	NO_3	Cl^-	TH	Pb	Cd	Ni	Zn	Fe
Temp	1																			
Turbidity	0.70749995	1																		
Colour	0.65319726	0.91272063	1																	
EC	0.93831486	0.59009575	0.6810052	1																
pH	-0.9438798	-0.8267937	-0.8587517	-0.941889	1															
TSS	0.94409886	0.89931225	0.8412358	0.8644644	-0.97414	1														
TDS	0.93864651	0.55119665	0.6361134	0.9981788	-0.92394	0.845719	1													
Mn	0.51832106	0.96567525	0.8323078	0.360258	-0.65231	0.762387	0.316238162	1												
Na	-0.8528029	-0.4324066	-0.591864	-0.978019	0.86244	-0.74387	-0.98058853	-0.1842	1											
Mg	-0.6154575	0.01741744	-0.1809068	-0.795657	0.54772	-0.389053	-0.820329728	0.27647	0.89227	1										
Ca	0.88610151	0.95291349	0.8913506	0.7981845	-0.95108	0.989332	0.771851087	0.84508	-0.66499	-0.2705	1									
SO_4	0	0.70038921	0.5773503	-0.147442	-0.19069	0.319277	-0.199116993	0.85519	0.30151	0.69631	0.451129	1								
NO_3	0	0.51740203	0.1885618	-0.300965	0	0.213291	-0.325156689	0.69826	0.49237	0.78174	0.306955	0.816497	1							
Cl-	-0.8528029	-0.3519588	-0.1740777	-0.711287	0	-0.673859	-0.7404444	-0.1842	0.63636	0.57735	-0.57431	0.301511	-2.18654E-15	1						
TH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1					
Pb	0.99813026	0.68616875	0.9573729	0.9573729	-0.94884	0.935164	0.95797154	0.48717	-0.88313	-0.65731	0.873831	-0.035289	-0.057627077	-0.8405682	##	1				
Cd	0.77309904	0.94423868	0.9833941	0.7635898	-0.92723	0.925297	0.725666711	0.84361	-0.6593	-0.25043	0.95762	0.517892	0.211428444	-0.3470006		0.771654	1			
Ni	0.17251956	0.73641406	0.8561257	0.2238308	-0.47042	0.465415	0.164633797	0.77332	-0.15121	0.23831	0.574791	0.799711	0.320946912	0.3392053		0.172675	0.75813	1		
Zn	-0.4264014	-0.593302	-0.8703883	-0.622376	0.68995	-0.568842	-0.580348314	-0.4789	0.63636	0.3674	-0.60454	-0.301511	0.246182982	-0.0909091		-0.457524	-0.7981	-0.8051	1	
Fe	0.5	-0.0943333	0.1632993	0.7298004	-0.47194	0.287334	0.750917207	-0.3455	-0.8528	-0.98473	0.17722	-0.707107	-0.866025404	-0.4264014		0.548972	0.20345	-0.1917	-0.4264	1

APPENDIX II

Result of Correlation Analysis of Weather Elements.

Parameter	Coefficient	Relationship
Distance versus T. North	-0.882575078	Strong but inverse
Distance versus T. South	-0.923695471	Strong but inverse
Distance versus T. East	-0.877806648	Strong but inverse
Distance versus T.West	-0.898974596	Strong but inverse
pH versus Amount Of Rain	0.859126026	Strong but direct
Amount of Rain versus Wind Speed	-0.211299233	Weak but inverse

APPENDIX III
Nigerian Standards for Drinking Water Quality.

S/N	PARAMETER	UNIT	MAX. PERMITED LEVELS
1	TEMPERATURE	^{o}C	Ambient
2	TURBIDITY	NTU	5
3	COLOUR	TCU/Pt/Co	15
4	ELECTRICAL CONDUCTIVITY	µS/cm	1000
5	PH	-	6.5-8.5
6	TOTAL SUSPENDED SOLIDS	mg/l	50
7	TOTAL DISSOLVED SOLIDS	mg/l	500
8	TOTAL HARDNESS AS CaCO3	mg/l	150
9	SODIUM	mg/l	200
10	MAGNESIUM	mg/l	0.2
11	CALCIUM	mg/l	-
12	SULPHATE	mg/l	100
13	NITRATE	mg/l	50
14	CHLORIDE	mg/l	250
15	CADMIUM	mg/l	0.003
16	IRON	mg/l	0.3
17	LEAD	mg/l	0.01
18	MANGANESE	mg/l	0.2
19	NICKEL	mg/l	0.02
20	ZINC	mg/l	3
21	ALUMINIUM	mg/l	0.2

Source: Nigeria Industrial Standards (Standards Organization of Nigeria) (NIS, 2007)

APPENDIX IV

Guidelines for Drinking Water Quality.

S/N	PARAMETER	UNIT	MAX. PERMITED LEVELS
1	TEMPERATURE	^{o}C	-
2	TURBIDITY	NTU	5
3	COLOUR	TCU/Pt/Co	15
4	ELECTRICAL CONDUCTIVITY	µS/cm	-
5	PH	-	6.5-8.5
6	TOTAL SUSPENDED SOLIDS	mg/l	50
7	TOTAL DISSOLVED SOLIDS	mg/l	600
8	TOTAL HARDNESS AS CaCO3	mg/l	200
9	SODIUM	mg/l	200
10	MAGNESIUM	mg/l	0.5
11	CALCIUM	mg/l	75
12	SULPHATE	mg/l	250
13	NITRATE	mg/l	50
14	CHLORIDE	mg/l	250
15	CADMIUM	mg/l	0.003
16	IRON	mg/l	0.3
17	LEAD	mg/l	0.01
18	MANGANESE	mg/l	0.4
19	NICKEL	mg/l	0.07
20	ZINC	mg/l	5
21	ALUMINIUM	mg/l	0.2

Source: World Health Organization (WHO, 2008)

APPENDIX V

Department of Environmental Technology
Post Graduate School
Federal University of Technology
PMB 1526
Owerri, Imo State.
21st January, 2014

Dear Respondent,

I am a student of the above Institution carrying out a research on "Effect of Gas Flaring on the Rainwater Quality of Odagwa in Rivers State, Nigeria".

Please you are requested to supply the information as indicated in the questionnaire instrument as your sincere response and contribution to the study.

The research is purely for academic purpose and will be handled with utmost confidentiality.

Thanks for your anticipated Co-operation.

Yours faithfully,

Uzoma Henry Chijioke,
20114774358.

APPENDIX VI

SECTION A – PERSONAL DATA

Please tick (√) in spaces provided.

1. I reside in Odagwa ( ) yes ( ) no.

2. Number of years you have been residing in Odagwa

   ( ) 1 – 2 years ( ) 2 – 5 years ( ) 5 years +

3. Highest academic qualification ( ) O'Level ( ) TC II ( ) NCE / OND

   ( ) HND ( ) Bachelors Degree ( ) Masters ( ) PHD / D. SC

4. Gender ( ) Male ( ) Female

5. Age Group ( ) below 18 years ( ) 18 - 30 years ( ) 31-40 years ( )

   41 - 50 years ( ) 50 years +

6. Occupation: ( ) Farming ( ) Business

   ( ) Public / Civil Servants ( ) Others.

SECTION B; gas flaring and experience of residents.

SA = Strongly Agree

A = Agree

SD = Strongly Disagree

D = Disagree

Tick (√) in the spaces provided.

(1) Gas flaring is the major source of environmental pollution in Odagwa

SA ☐ A ☐ SD ☐ D ☐

(2) Rainwater in Odagwa is usually coloured

SA ☐ A ☐ SD ☐ D ☐

(3) Roofs of buildings corrodes easily while paints and other materials fade easily

SA ☐ A ☐ SD ☐ D ☐

(4) Some wild animals are no more found in Odagwa while some are rarely seen.

SA ☐ A ☐ SD ☐ D ☐

(5) Some plants no longer grow in Odagwa while some foreign ones are now seen.

SA ☐ A ☐ SD ☐ D ☐

(6) The community experiences hot weather conditions

SA ☐ A ☐ SD ☐ D ☐

(7) Crop yield have reduced over the years

SA ☐ A ☐ SD ☐ D ☐

(8) We now experience heavy rains and flooding.

SA ☐ A ☐ SD ☐ D ☐

(9) Many families make use of rainwater for drinking and other domestic purposes.

SA ☐ A ☐ SD ☐ D ☐

(10) Rainwater is mainly harvested from Zinc roofs.

SA ☐ A ☐ SD ☐ D ☐