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Impact of Gas Flaring on Rainwater Quality and Public Health: A Study of Soku Community, Rivers State, Nigeria

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ABSTRACT

This study assessed the rain water quality in a Gas flaring Environment as well as the health implication for Soku community in Rivers State, Nigeria. In-situ measurements and analysis of pH, turbidity, colour, electrical conductivity and temperature were done. 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 and H. Points A, B, C, D are 500m, 1000m, 2000m and 5000m away 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. 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. Soil samples were collected from eight different locations and labeled sample location A, B, C, D, E, F, G, and H. The samples collected were stored in 2 liter 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. $HNO_3 I^{-1}$ solution to the sampling bottle before storing the sample to ensure that all composites were well preserved. Samples were taken the laboratory and analyzed using standard methods. 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 a well-structured Likert 4-point scale close ended questionnaire instrument. Meteorological Data: Weather conditions for six months was extracted from secondary data spanning over ten years from the Nigeria Meteorological Agency (NIMET). Temperature, wind speed and wind directions of sampling points were obtained using the appropriate instruments. Results showed that in Soku Community the first rain is the most polluted followed by the late rain while the mid rain is least, polluted due to discharge of gases and particulates from the atmosphere via washout, rainout, and dilution. It is therefore recommended that government regulatory agencies should put appropriate measures in place to monitor the quantity of gas emissions into the environment and also set and implement polluter pay principle for polluting industries and facilities.

Keywords: Rainwater, Gas flaring, Environmental pollution, Soku community.

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Introduction

Rain water harvesting has become a worldwide practice to meet the increasing demand for fresh water (Ertop *et al*., 2023). Water harvesting has been practiced at state level in Nigeria. In Niger Delta it is widely practiced for over 8 months in a year with mean intensity of 180 to 225 cm. Rain water harvesting is practiced at individual level, household level, community level and occasionally at Local or State government level to augment the dwindling water supplies to urban centers (Richards *et al*., 2021). The three major sources of water are easily accessible in the Central Niger Delta area. The tributaries of the River Niger form a complex network of rivers, streams and lakes; groundwater is available at relatively shallow depths for abstraction; and rainfall lasts for about 9 months and varies from about 3500 to 2000 mm per annum. On relatively sophisticated water supply systems, groundwater is the most exploited but it is characterized with poor quality related to oxides of iron and magnesium (Isukuru *et al*., 2024). The surface water sources are open to all kinds of activities while rainwater harvesting is relegated to the background. However, the amount of rainfall falling in the Niger Delta area is worth exploiting, especially with the prevalent challenges to using other sources. Thus, the potential of harnessing rainwater in the Niger Delta is bright though this work will also look at the health implications especially in a gas flaring environment. Similar studies have been done elsewhere in Nigeria. For example, in a study carried out by water aid, it was discovered that at Obijago, a community of 1,371 people in Obi Local Government Area of Benue State, rain water harvesting was practiced using eight concrete tanks. Considering the population of this community it can be deduced that household rain water harvesting is very necessary in this community to supplement the effort of the local government. In another study, Njoku (2013), it was noted the magnitude of rain water harvesting in selected communities in peri-urban areas obtained from a house-to-house survey, their behavioral practices in harvesting, storage and usage of the rain water, the quality of such waters and design of a sustainable system in one of the constitute the major percentage of their water need.

Three major sources of water are easily accessible in the Niger Delta area. The tributaries of the River Niger form a complex network of rivers, streams and lakes; groundwater is available at relatively shallow depths for abstraction; and rainfall lasts for about 9 months and varies from about 3500 to 2000 mm per annum (Oti and Skinner, 2012). On relatively sophisticated water supply systems, groundwater is the most exploited but it is characterized with poor quality related to oxides of iron and magnesium. The surface water sources are open to all kinds of activities while rainwater harvesting is relegated to the background. However, the amount of rainfall falling in the Central Niger Delta area is worth exploiting, especially with the prevalent challenges to using other sources. Thus, the potential of harnessing rainwater in the central Niger Delta is explored in this paper using a mass curve analysis with an illustration of its efficacy, flexibility and the sensitivity of the analysis.

The Study Area

Soku community (4^o 40’41.85”N, 6^o40’57.02”N) is an ancient Kalabari Community located in Akuku Toru Local Government Area (AKULGA) of Rivers State. It comprises several small settlements separated by creeks. The closest large community is Abonnema Town (4^o 43’25.42”N, 6^o46’44.73”E), the administrative centre of AKULGA



Figure 1: Location Map of Study Area

Political Economy

Soku Community is one of the communities in Akuku Toru Local Government Area of Rivers State. It has a population of 4,565 people (NPC, 2012). Fishing and farming are the main stay of the local economy, the location of the fishing activities being the creeks around the community such as Agbani Toru, Oruwaritoru ogono, Ajei Toru, Kalo Toru, and Kala walala; fishing ports in the area include, Abakadiki Ama, Kalobama, Opukiri, Doma, Akpokolo, Russia, Bush Bar, Poboro, Kpokpokiri and Arikani.

According to key informants, Soku was the second location where oil was discovered, after Oloibiri in 1956. Soku has several oil facilities operated by SPDC, they include Ekulama I flow station, Soku flow station; 68 Gas and Oil wells, a Gas plant and Gas and Oil pipelines. Oil and Gas exploration and exploitation have been going on in Soku since the inception of oil exploitation in Nigeria dating back to 1957.

Vegetation

The area is characterized by the tropical rain forest vegetation (Nworgu, 2001). The popular trees in the area include Iroko, Obeeche and Mahogany. Plant species are scattered, heterogeneous and exist in different heights.

Drainage and Topography

The area has gently rolling topography below 100m above sea level, it belongs to the Niger Delta Coastal plain and classified as low land. The river flow to join the Niger and subsequently the Atlantic Ocean.

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, sandy, clay, highly weathered, moderately acidic and high soluble salt content (Obinna, 2010).

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 season, long rainy season (March to July) and the long dry Seasons (November/ February) as well as two major seasons, the short rainy season (September to October) and short dry season (August). Humidity of the area ranges from 55.6% in the dry season to 80.0% in rainy season. It has two distinct air masses, the tropical continental and the tropical marine.



Figure 2: SOKU GAS PLANT

Geographical Coordinates

These show the geographic Coordinates of study area using Garmin Global Positioning System, model etrex H.

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.

Instrumentation

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

Table 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

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.

Sampling Plan

The sampling of rainwater commenced with 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.

Plastic buckets, stand, plastic bottles and appropriate preservatives were used.

The analytes 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 instruments used included: meters, tetrimetric method, argentometric method, evaporation method, flame photometry, ultra violet spectro photometer and atomic absorption spectro photometer (AAS).

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.

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 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.

Soku Community Primary School 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 and temporal variation using March, July and November samples to represent early, mid and late rainy periods respectively.

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.

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. The frequency of sampling was monthly in the year 2014. The roofs sampled were 0-5 years old within 500m – 2000m from gas flare point and at the control location. 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.

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.

Meteorological Data

Data on monthly weather conditions for six months was extracted from secondary data spanning over ten years from NIMET. Temperature, wind speed and wind directions of sampling points were obtained using the appropriate instruments.

Residents Experience

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

Laboratory Analysis Methods

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.

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).

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.

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.

Electrical Conductivity

The conductivity meter 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. Hach Electrical Conductivity meter, model HQ40D was used.

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

pH

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.

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.

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^oC and $2dm^3$of buffer solution was titrated using EDTA standard titrant. The total hardness was calculated using the relation;

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

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

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.

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 ($0.1MAgNo_3$).

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 $0.1MBaCl_2$ (Barium Chloride). The light absorption by the precipitated suspension was measured by Spectrophotometer at wavelength of 420nm.

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

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 has a specific wavelength that will be absorbed. Example,

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

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

Data Presentation and Analysis

Results were tabulated for better organization and presentation. Bar charts were drawn to show variations with: distance from flare point, types of roof, period of rainfall and monthly pH variation. Line graph was used to present the variation of distance with temperature in four directions from flare point. 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. The percentile analysis was used to analyze the response of residents.

RESULTS AND DISCUSSIONS

Results

Variation of Physicochemical Properties of unintercepted Rainwater at Various Distances from the Flare Point

Table 2: Variation of Physicochemical Properties of Rainwater at Various Distances, from Gas Flare Point.

S/N	PARAMETER	UNITS	500M	1000M	2000M	CONTROL (Sangama) 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 $CaCO_3$	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

The result show that physical properties decreased with increase in distance from flare point (Temperature 30^oC-34^oC, 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).

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

Table 2 shows the Variation of Physicochemical Properties of Rainwater at Various Distances, from Gas Flare Point**.** The distances range from 500m, 1000m, 2000m, and 5000m which is the control location.

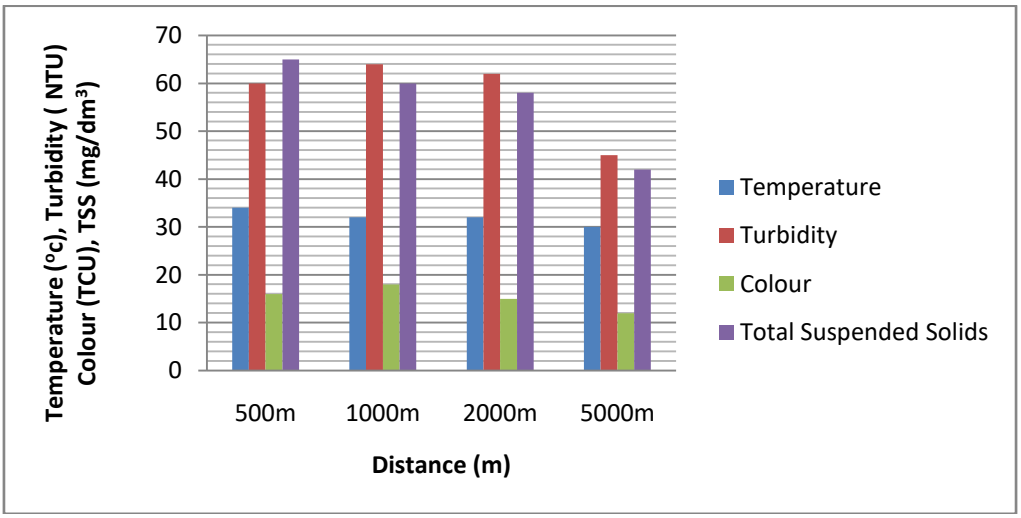


Fig 3: Variation of Temperature, Turbidity, Colour and TSS with Distance from Flare Point

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The chart shows the variation in Temperature, Turbidity, colour and TSS with their distances from the flare ranging from 500m, 1000m, 2000m, and 5000m as the control from the flare stack.

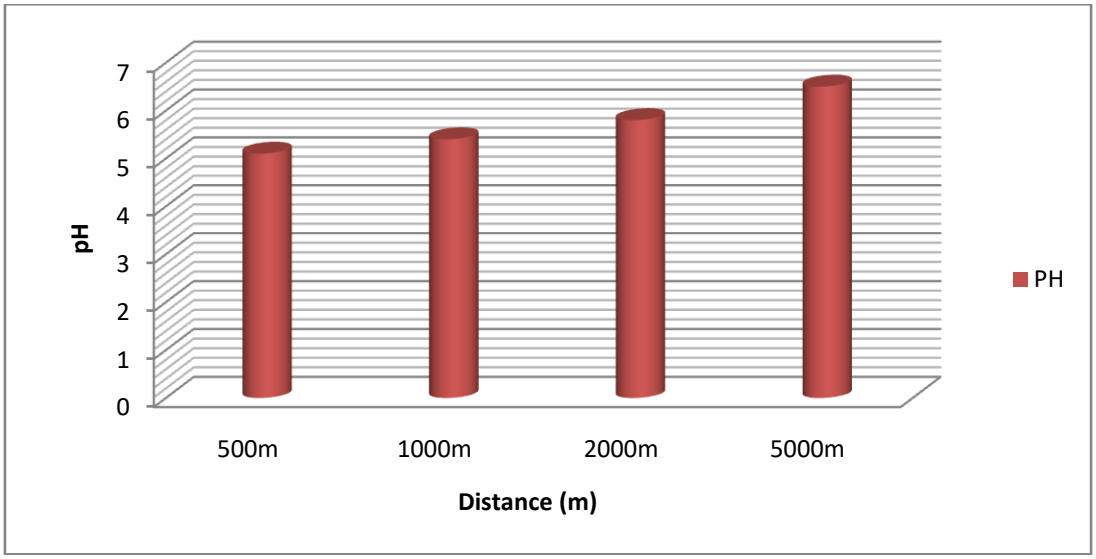


Fig 4: Variation of Rainwater pH with Distance from Flare point.

The chart above shows the variation in rainwater pH according to their distances from the flare point ranging from 500m, 1000m, 2000m, and 5000m.

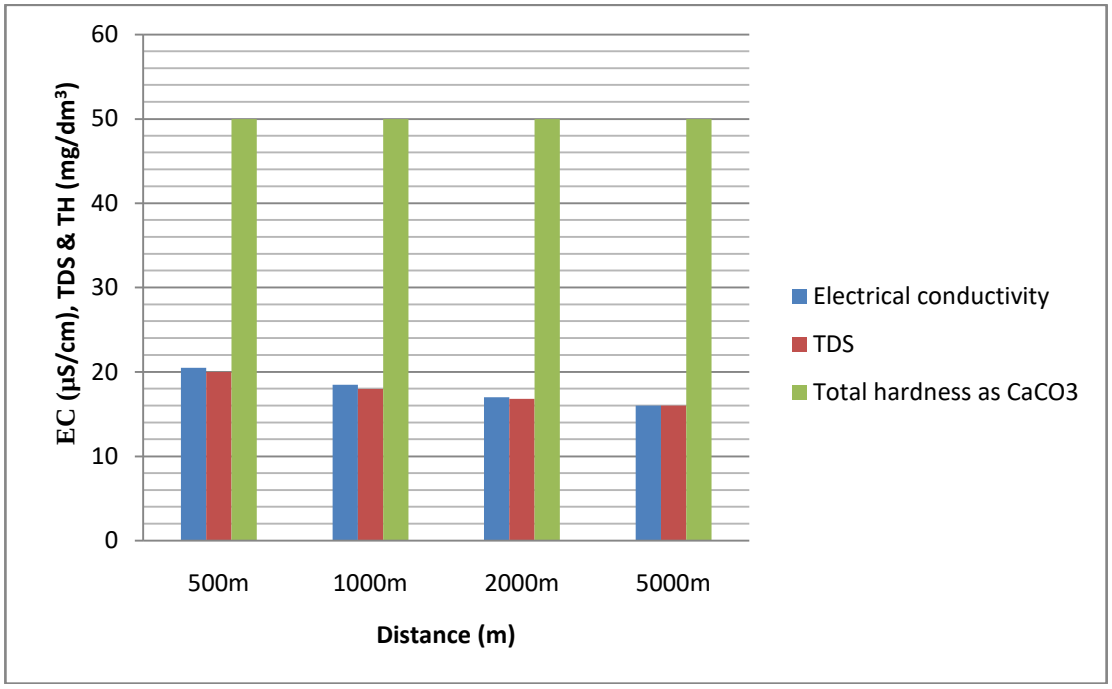


Fig 5: Variation of EC, TDS and TH with Distance from flare point

The Fig 5 is the variation of electrical conductivity (EC), total dissolved solutes (TDS) and total hardness (TH) according to their distances of 500m, 1000m, 2000m and 5000m.

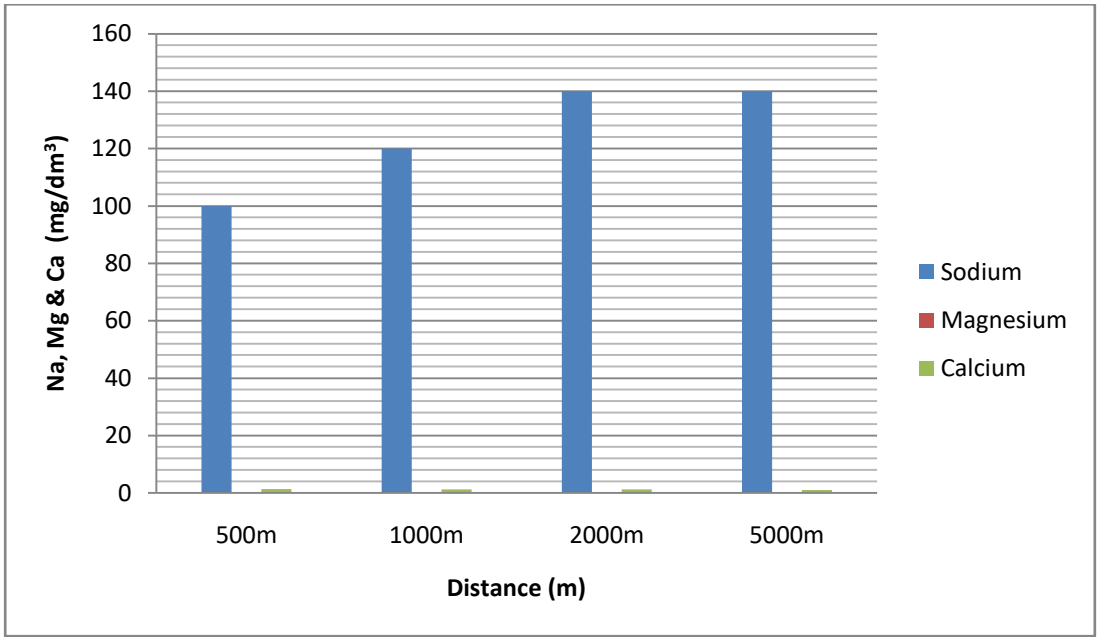


Fig 6: Variations of Sodium, Magnesium and Calcium with Distance from flare point

Fig 6 shows the variations of sodium, Magnesium, and calcium with their distances of 500m, 1000m, 2000m, and 5000m where sodium had 100, 120, 140 and 140 at the different distances respectively. Magnesium and calcium were zero.

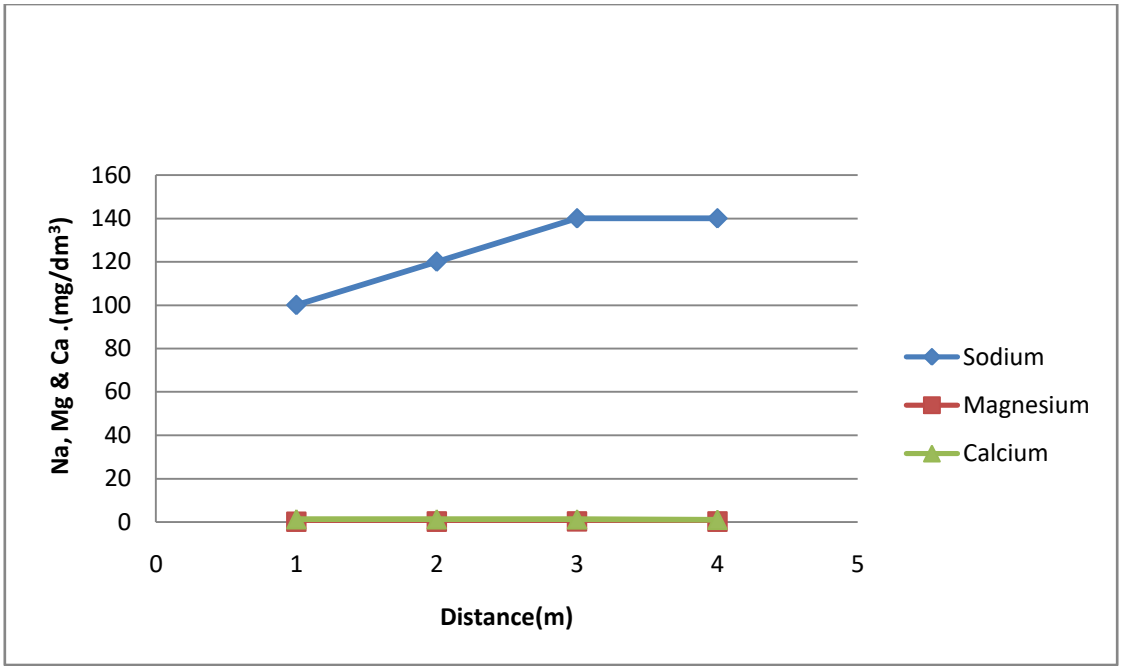


Fig 7: Variation of Sodium, Magnesium and Calcium with Distance from Gas Flare Point.

Fig 7 shows the variations of sodium, Magnesium, and calcium with their distances of 500m, 1000m, 2000m, and 5000m where sodium had 100, 120, 140 and 140 at the different distances respectively. Magnesium and calcium were zero.

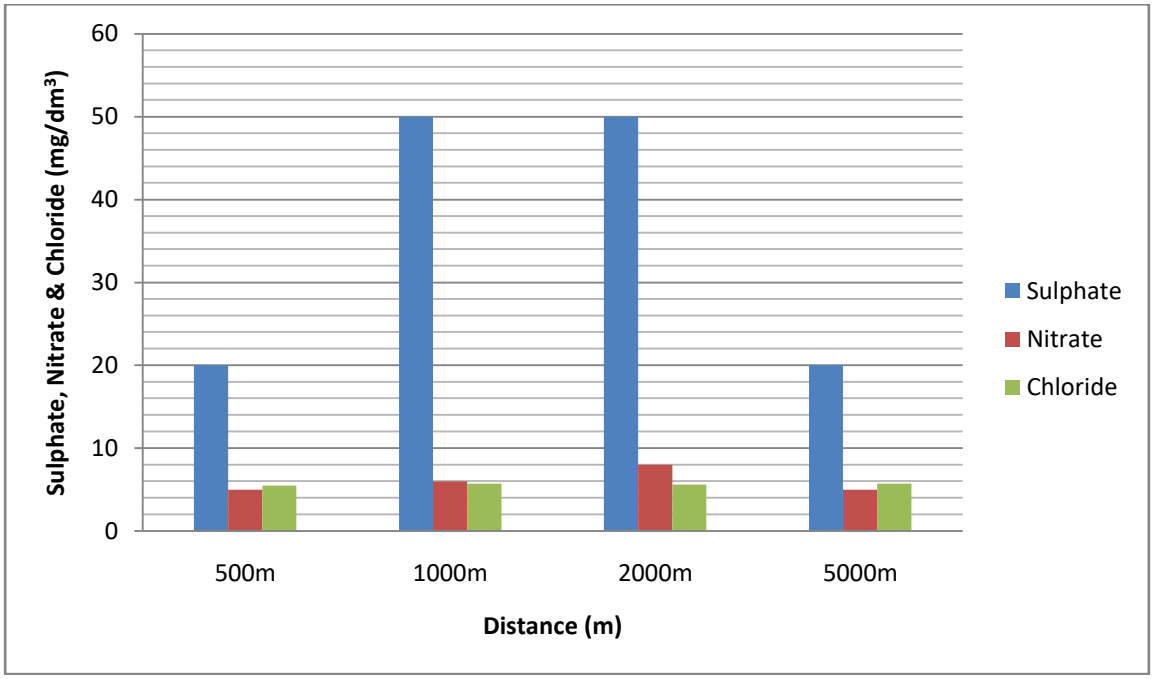


Fig 8: Variation of Sulphate, Nitrate and Chloride with Distance from Flare Point

Fig 8 shows variation in sulphate, nitrate and chloride with distance from flare point where at 500m, sulphate was 20, nitrate was 3 and chloride was 4. At 1000m, sulphate was 50, nitrate was 4 and chloride was 3, at 2000m, sulphate was 50, nitrate was 8 while chloride was 20.

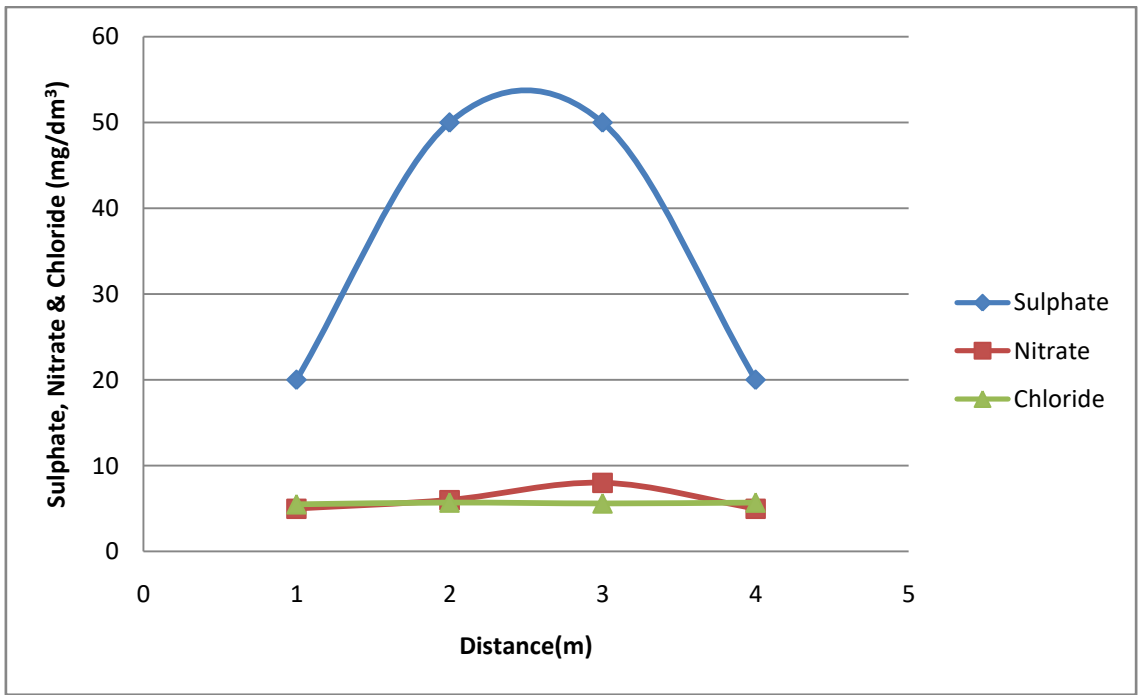


Fig 9: Variation of Sulphate, Nitrate and Chloride with Distance from flare point

Fig 9 shows variation in sulphate, nitrate and chloride with distance from flare point where at 500m, sulphate was 20, nitrate was 3 and chloride was 4. At 1000m, sulphate was 50, nitrate was 4 and chloride was 3, at 2000m, sulphate was 50, nitrate was 8 while chloride was 20.

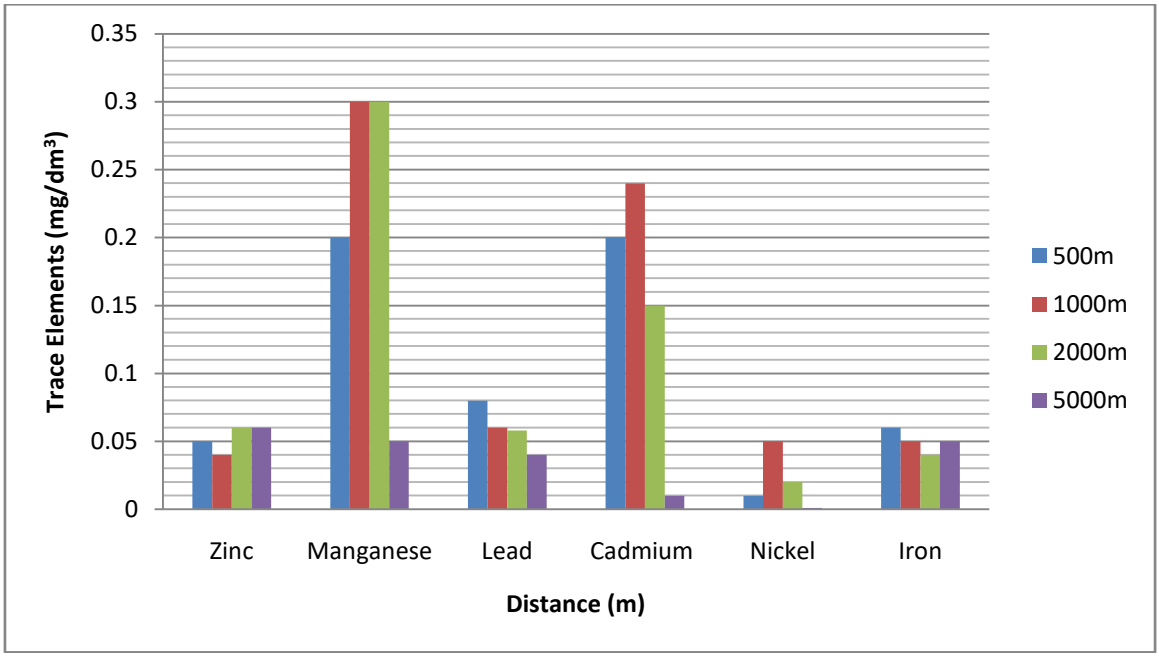


Fig 10: Variation of Heavy metals with Distance from flare point.

Fig 10 shows variation of heavy metals with distance from the flare point at 500m zinc was 0.05, 0.04 at 1000m, 0.06 at 2000m and 0.06 at 500m. At 500m, manganese was 0.02, 0.03 at 1000m, 0.03 at 2000m and 0.05 at 5000m. At 500m, lead was 0.07. 0.06 at1000m. 0.06 at 2000m and 0.04 at 5000m. At 500m, cadmium was 0.02, 0.25 at 1000m, 0.15 at 2000m and 0.1 at 5000m. At 500m nickel was 0.1, 0.5 at 1000m, 0.03 at 2000. And 0 at 5000m., while as at 500m iron was 0.6, 0.5 at 1000m, 0.3 at2000m and 0.5 at 5000m.

Variation of Physicochemical properties of Rainwater Intercepted by Various Roofs

The result 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).

Table 3: Variation of Physicochemical Properties of Rainwater Intercepted by Various Roofs.

			STUDY LOCATION (Soku Community)			CONTROL LOCATION (Sangama)		
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

G.I.R = GALVANIZED IRON ROOF. Al.R = ALUMINIUM ROOF. As.R = ASBESTOS ROOF
S - Represent study location. c – Represent control location

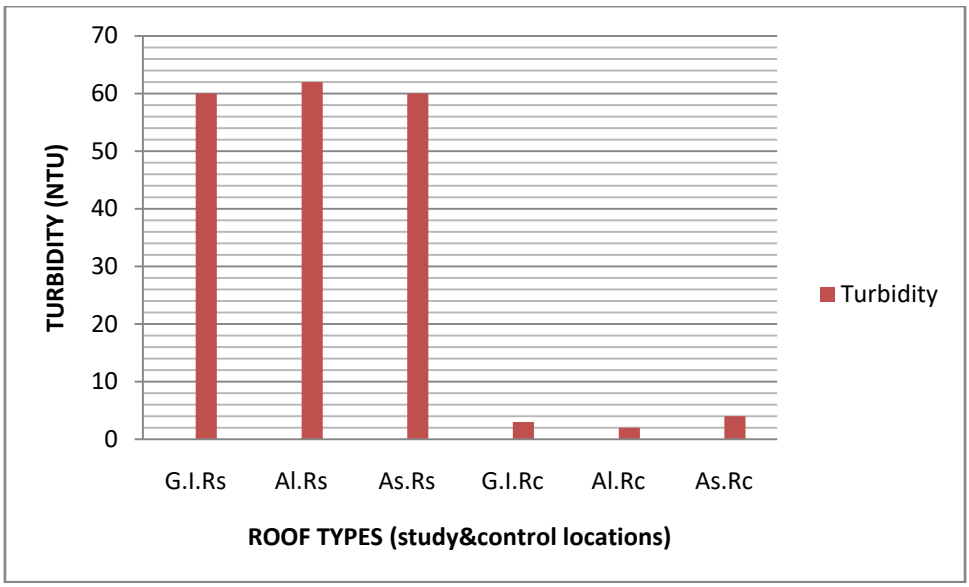


Fig 11: Variation of Rainwater Turbidity from roofs in study and control locations.

Fig 11 shows variation of rainfall turbidity from roofs in study and control locations. Turbidity was 60 (NTU) in G.I.Rs, 60.1 in AI.Rs, 60 in As.Rs, 0.2 in G,I,Rc, 0.1 in AI.Rs and As.Rc

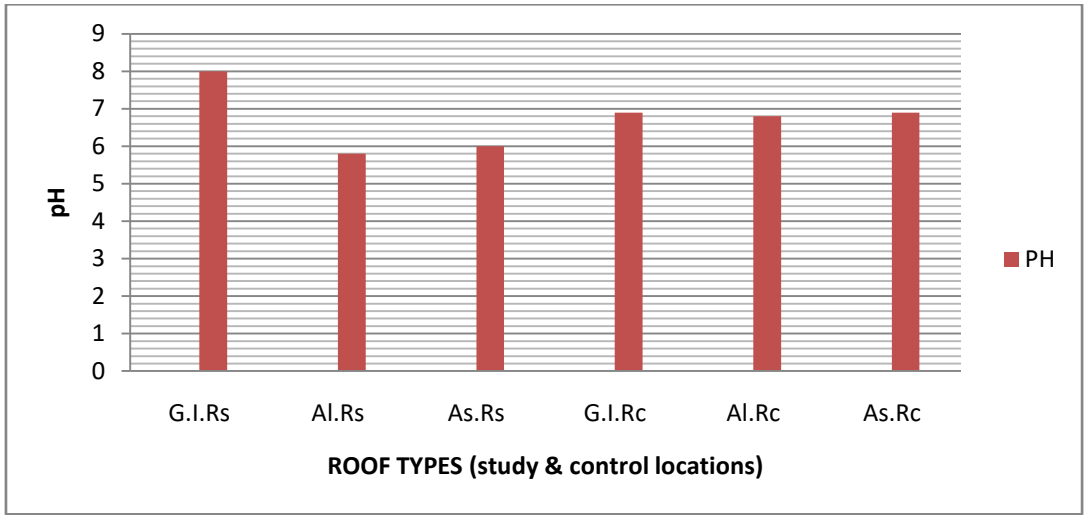


Fig 12: Variation of Rainwater pH from roofs in study and control locations.

Fig 12 shows Variation of Rainwater pH from roofs in study and control locations. G.I.Rs. has 8, AI.Rs 5.9, AsRs 6, G.I.Rc 7, AI.Rc 6.9 and AsRc 6.9

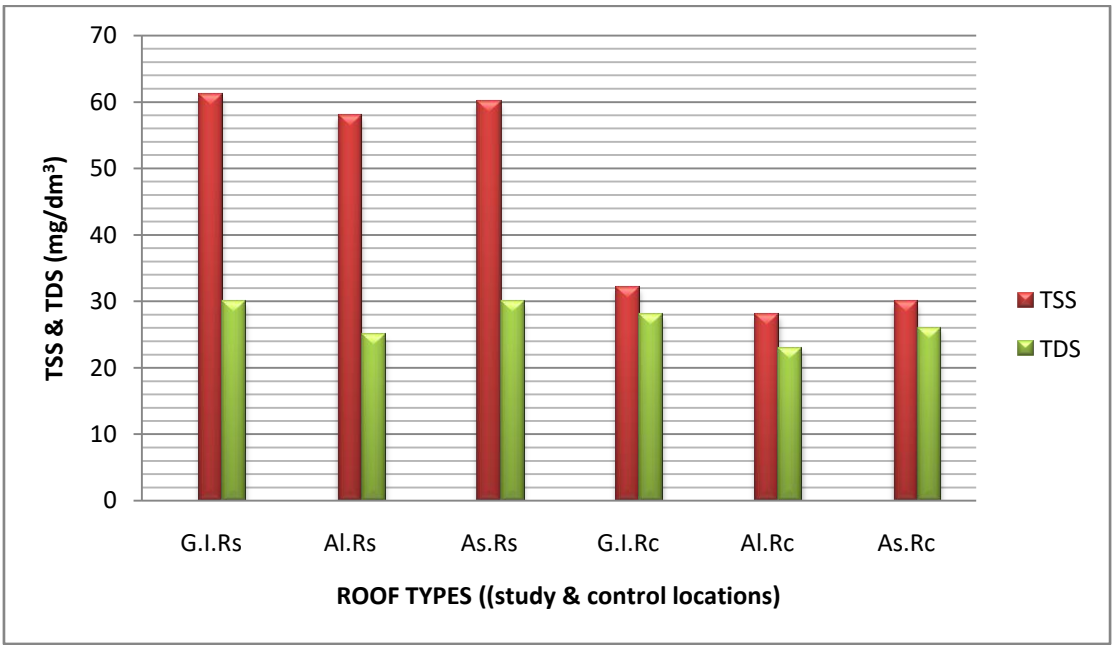


Fig 13: Variation of Rainwater TSS and TDS from roofs in study and control locations.

Fig 13 shows Variation of Rainwater TSS and TDS from roofs in study and control locations. At G.I.Rs TSS wa 60.1 TDS was 30, at AI.Rs TSS was 59 while TDS was 23, at AsRs TSS wea 60 while TDE was 30, at G.I.Rc TSS was 31 while TDS was 28, at AI.Rc TSS was 28 while TDS was 24, at As.Rc TSS was 30 while TDS was 24.

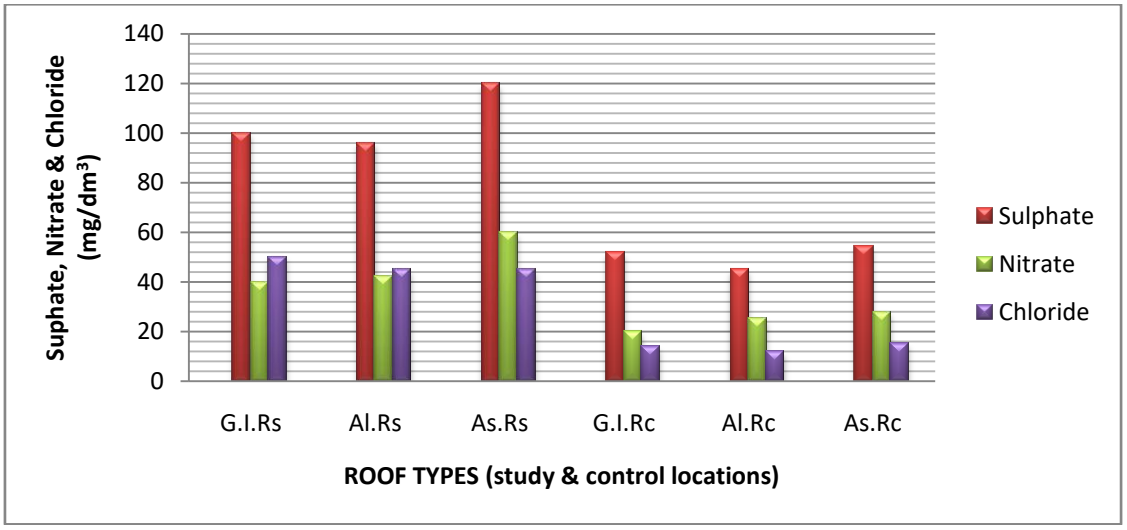


Fig 14: Variation of Rainwater sulphate, Nitrate and Chloride in study & control locations.

Fig 14 shows Variation of Rainwater sulphate, Nitrate and Chloride in study & control locations. In G.I.Rs sulphate was 100, nitrate was 40, while chloride was 50. At AI.Rs sulphate was 99, nitrate was 41, while chloride was 42, at As.Rs sulphate was120, nitrate 60 and chloride 43. At G.I.Rc sulphate was 45, nitrate 22 and chloride 8. At AI.Rc, sulphate was 45, nitrate 25 and chloride was 10, At As.Rc sulphate was 58, nitrate was 25 and chloride was 9.

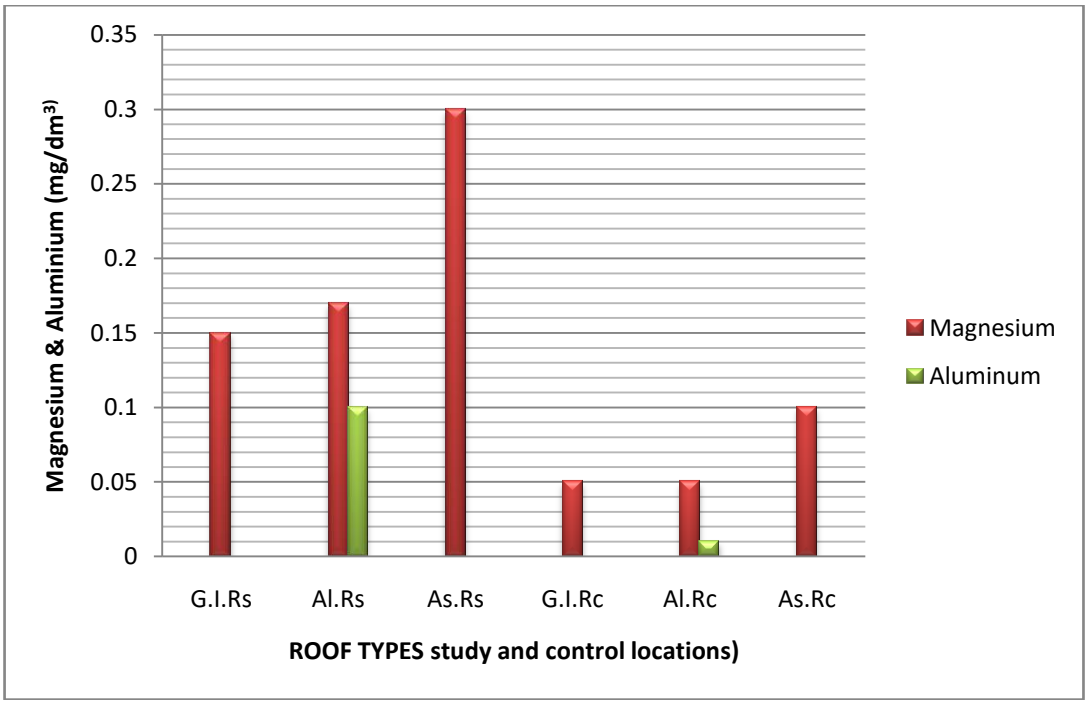


Fig 15: Variation of Rainwater Magnesium and Aluminum in study & control locations.

Fig 15 shows Variation of Rainwater Magnesium and Aluminum in study & control locations. At G.I.Rs, magnesium was 0.15, at AI.Rs Magnesium was 0.17 while aluminum was 0.1, At As.Rs magnesium was 0.3, at G.I.Rc magnesium was 0.05, at AI.Rc magnesium was 0.05 while aluminum was 0.1. At As.Rs magnesium was 0.1.

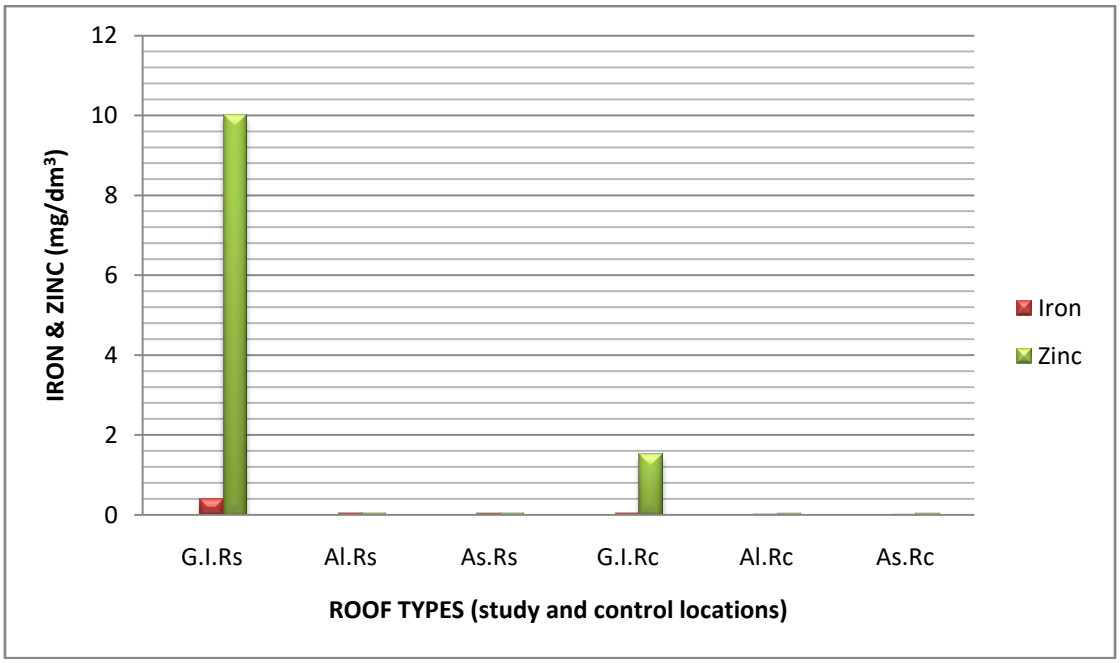


Fig 16: Variation of Rainwater Iron and Zinc in study & control locations

Fig 16 shows Variation of Rainwater Iron and Zinc in study & control locations. At G.I.Rs iron was 0.1 while zinc was 10, at AI.Rs and As.Rs both iron and zinc were zero. At G.I.Rc iron was zero and zinc was 1.9. At other points both iron and zinc were all zero.

Table 4: 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

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).

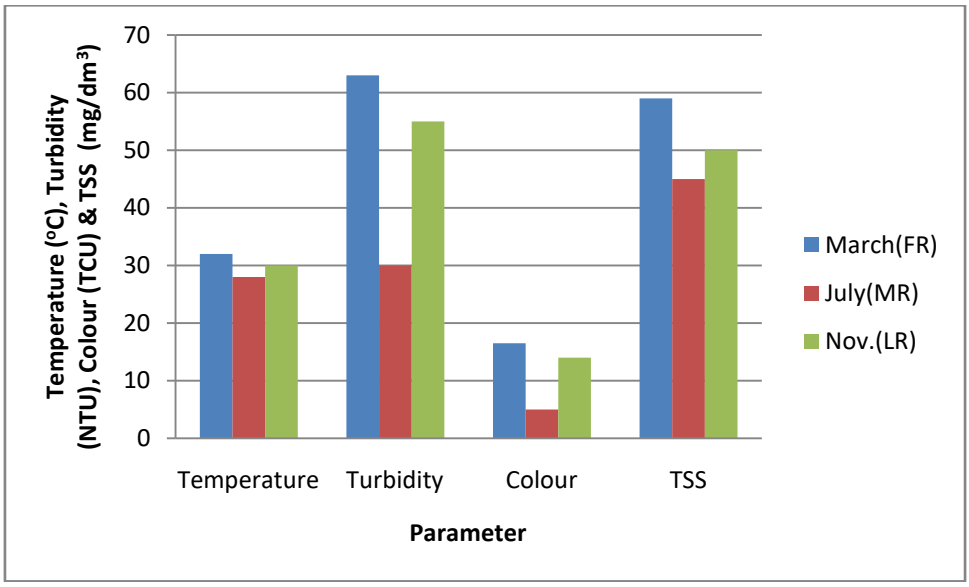


Fig 17: Temporal Variations of Temperature, Turbidity, Colour and TSS.

Fig 17 shows Temporal Variations of Temperature, Turbidity, Colour and TSS. Temperature in March was 31, 29 in July and 30 in November. Turbidity was 61 in March, 30 in July and 55 in November; Colour was 18 in March, 5 in July and 13 in November. TSS was 59 in March, 45 in July and 50 in November.

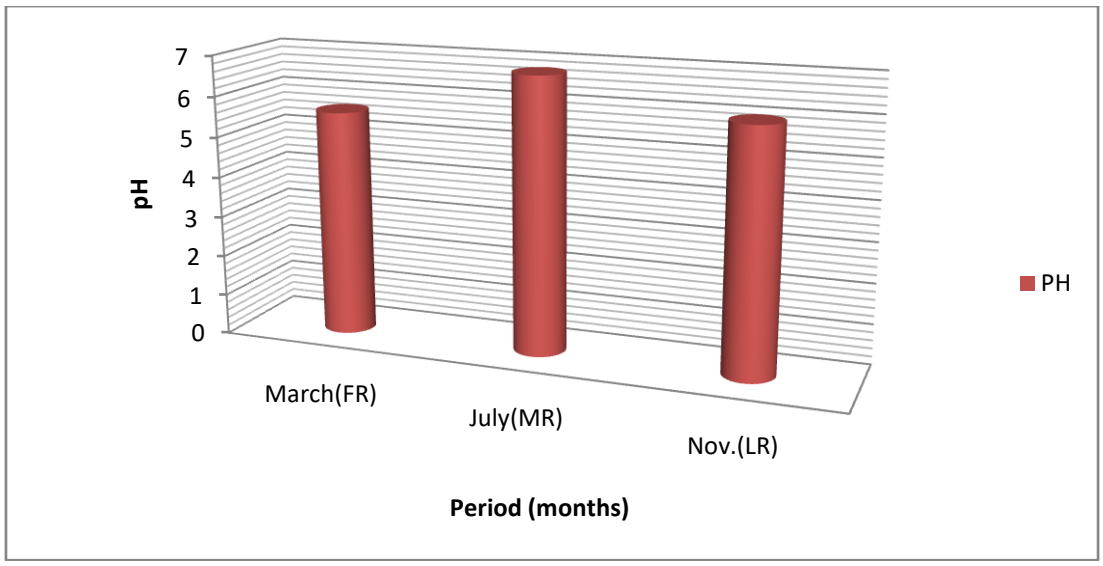


Fig 18: Temporal Variation of Rainwater pH

Fig 18 shows Temporal Variation of Rainwater pH. pH in March was 5.2, in July pH was 6.8 and in November it was 5.9.

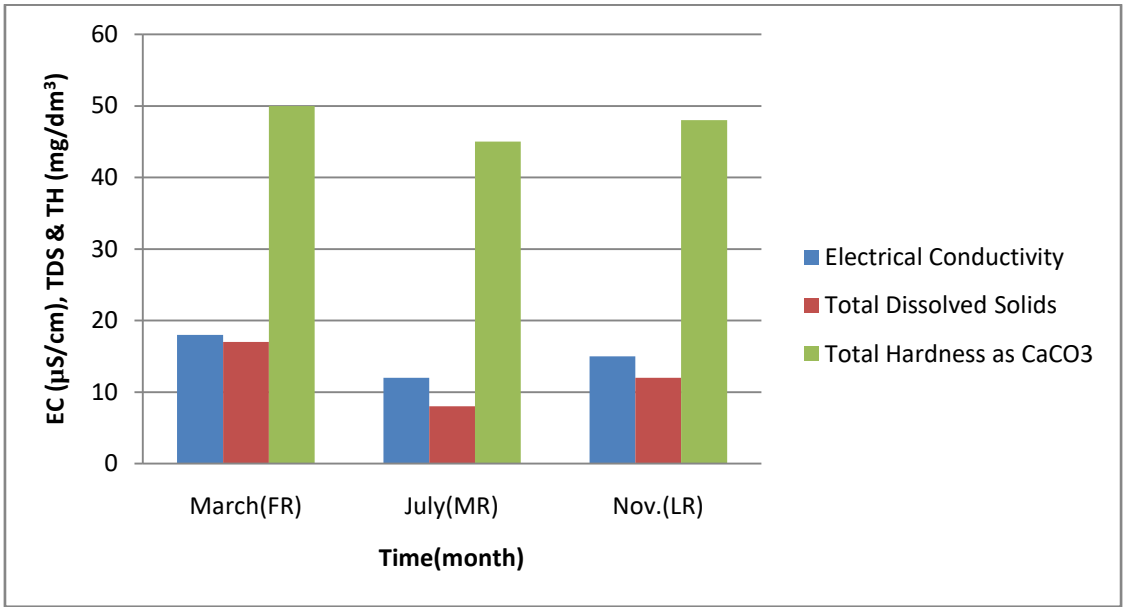


Fig 19: Temporal Variation of EC, TDS and TH.

Fig 19 shows the temporal variation of Temporal Variation of EC, TDS and TH. In March, electrical conductivity was about 28; total dissolved solid was 8 while total hardness was 50. I n July, electrical conductivity was 12, total dissolved oxygen was 8 and total hardness was 43, In November, electrical conductivity was 13, total dissolved solids was 11 and total hardness was 48, Total dissolved solids ranked highest in all the months.

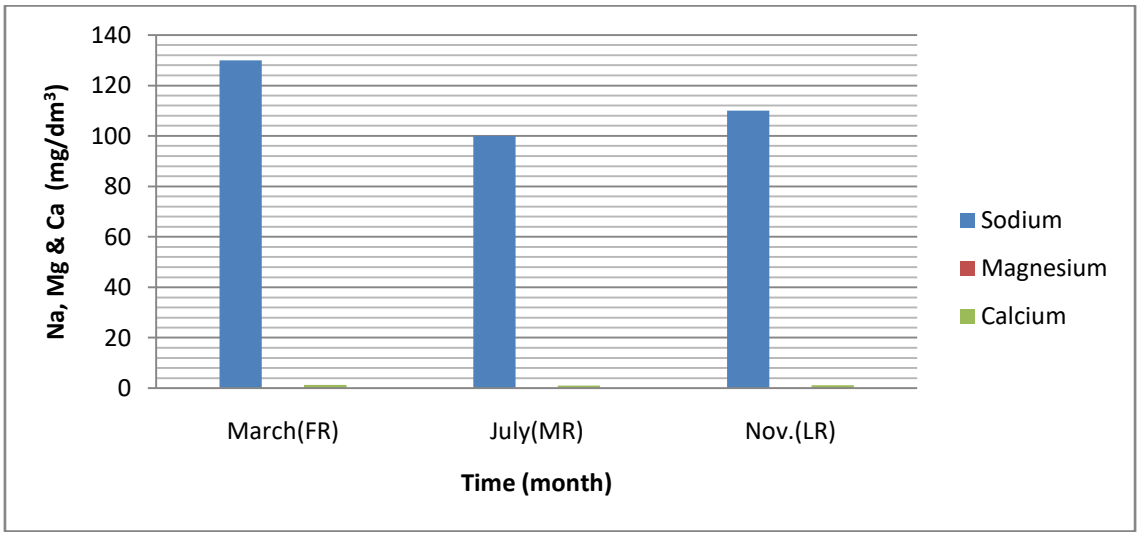


Fig 20: Temporal Variation of Sodium, Magnesium and Calcium.

Fig 20 shows the temporal variation of sodium, Magnesium and calcium. Here in the month of March, July and November, sodium ranked highest of 120, 100 and 140 respectively while magnesium and calcium ranked zero

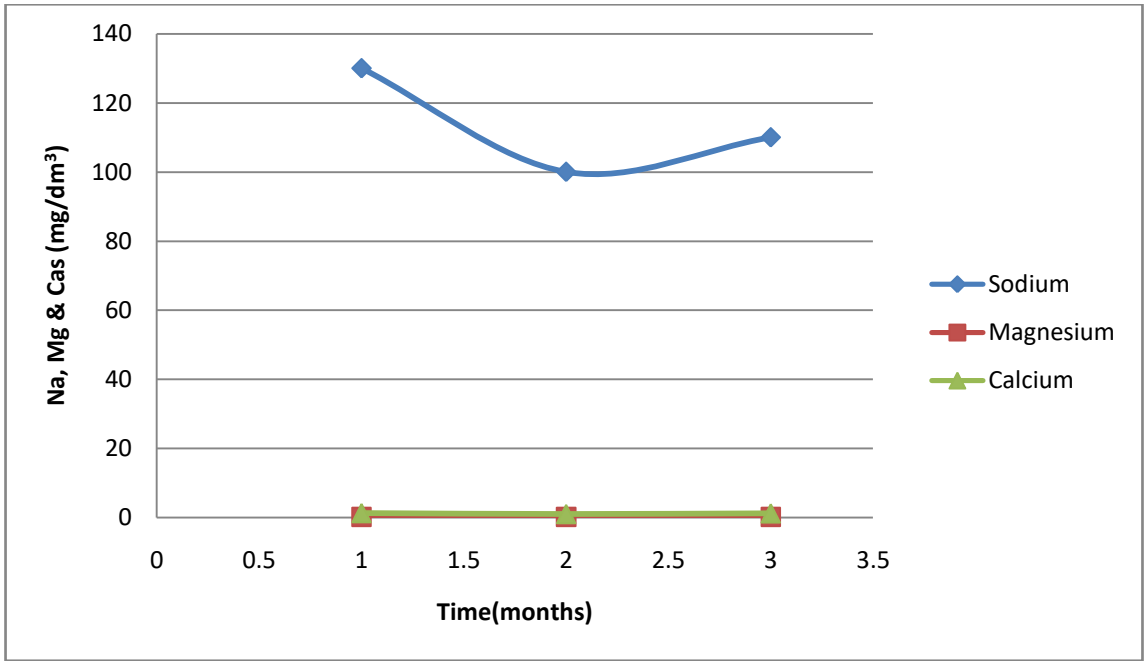


Fig 21: Temporal Variation of Sodium, Magnesium and Calcium.

Fig 21 shows the temporal variation of sodium, Magnesium and calcium. Here in the month of March, July and November, sodium ranked highest of 120, 100 and 140 respectively while magnesium and calcium ranked zero.

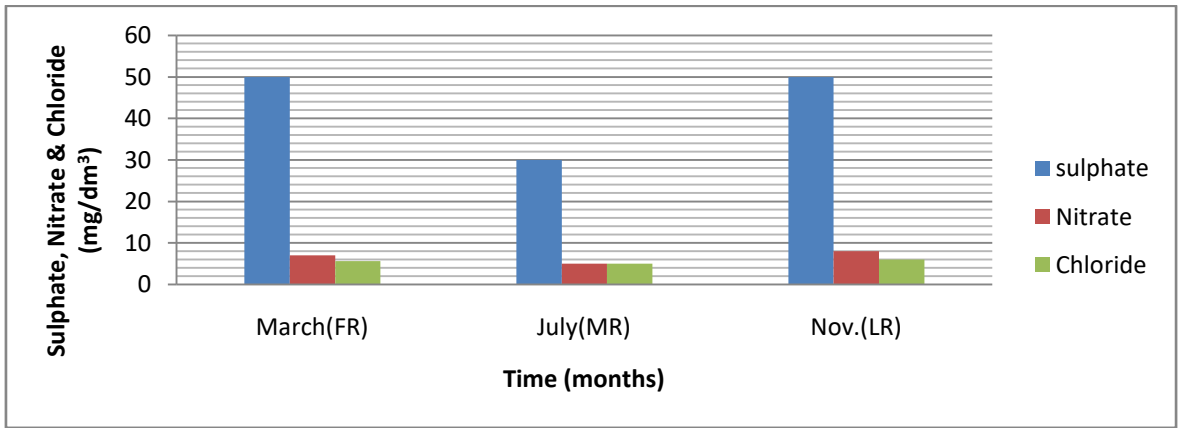


Fig 22: Temporal Variation of Sulphate, Nitrate and Chloride.

Fig 22 shows the temporal variation of sulphate, nitrate and chloride where sulphate is the highest in March, July and November and nitrate came second in March and November while in July, nitrate and chloride were equal.

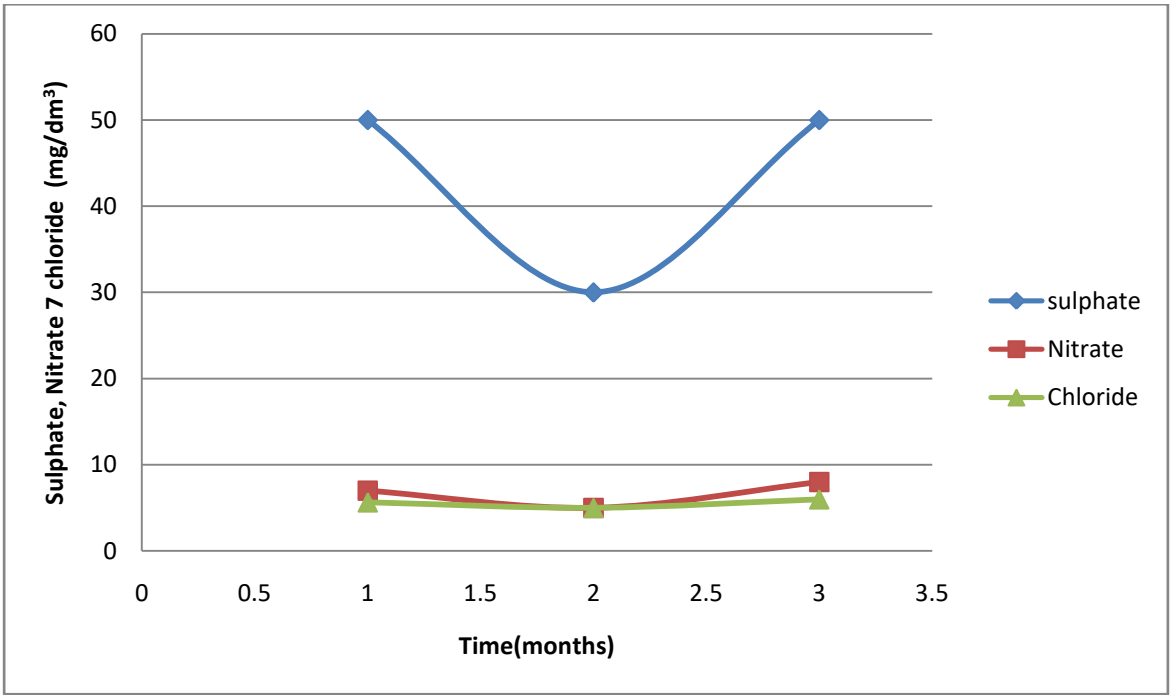


Fig 23: Temporal Variation of Sulphate, Nitrate and Chloride

Fig 23 shows the temporal variation of sulphate, nitrate and chloride where sulphate is the highest in March, July and November and nitrate came second in March and November while in July, nitrate and chloride were equal.

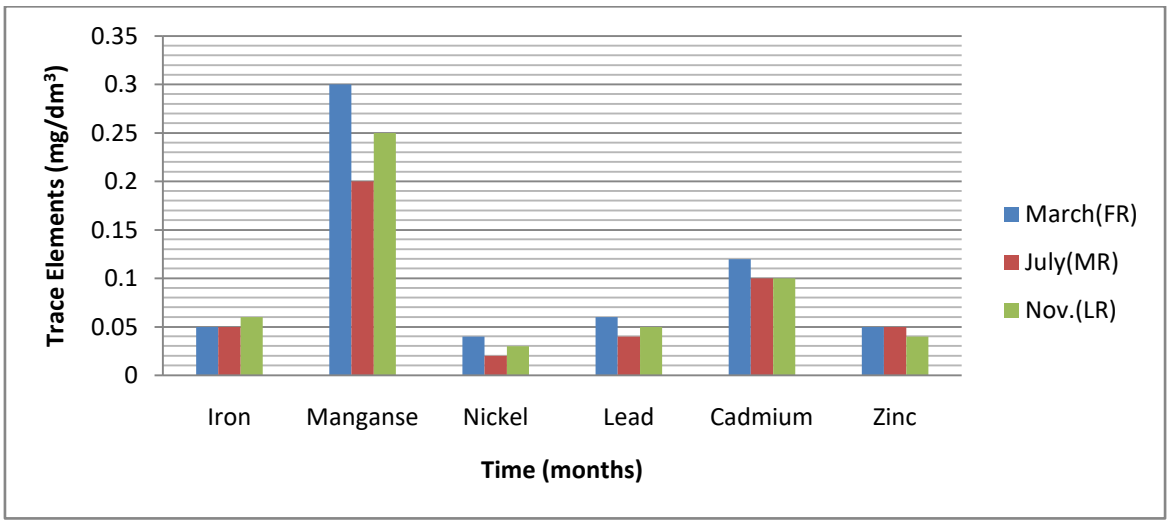


Fig 24: Temporal Variation of Heavy metals in Rainwater

Fig 24 shows the temporal variation of heavy metals in rainwater where in the month of March, iron and manganese are equal 0.05 while a little higher of 0.06. Manganese ranked 0.3 in March, 0.2 in July and 0.25 in the month of November. Nickel ranked 0.04 in March, 0.02 in July and 0.03 in November. Lead ranked 0.06 in March, 0.04 in July and 0.05 in November. Cadmium ranked highest in March, followed by July and November that are equal. Zinc ranked equal in the months on March and July and lowest in the month of November.

Table 5: 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

The result 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).

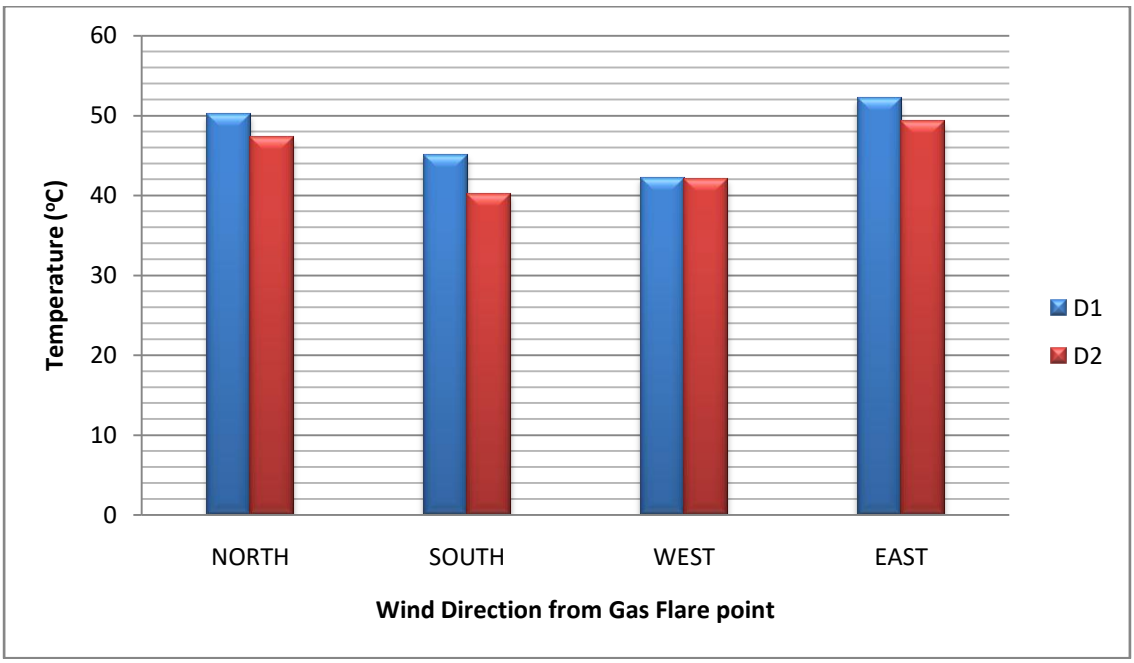


Fig 25: Temperature variation with wind direction at D1 and D2.

Fig 25 shows temperature variation with wind direction at D1and D2 locations. Wind direction shows North, South, West and East. AT north D1 was higher than D2, A South, D1was also higher than D2, At West, D1 and D2 were equal while at East, D1 was also higher than D2.

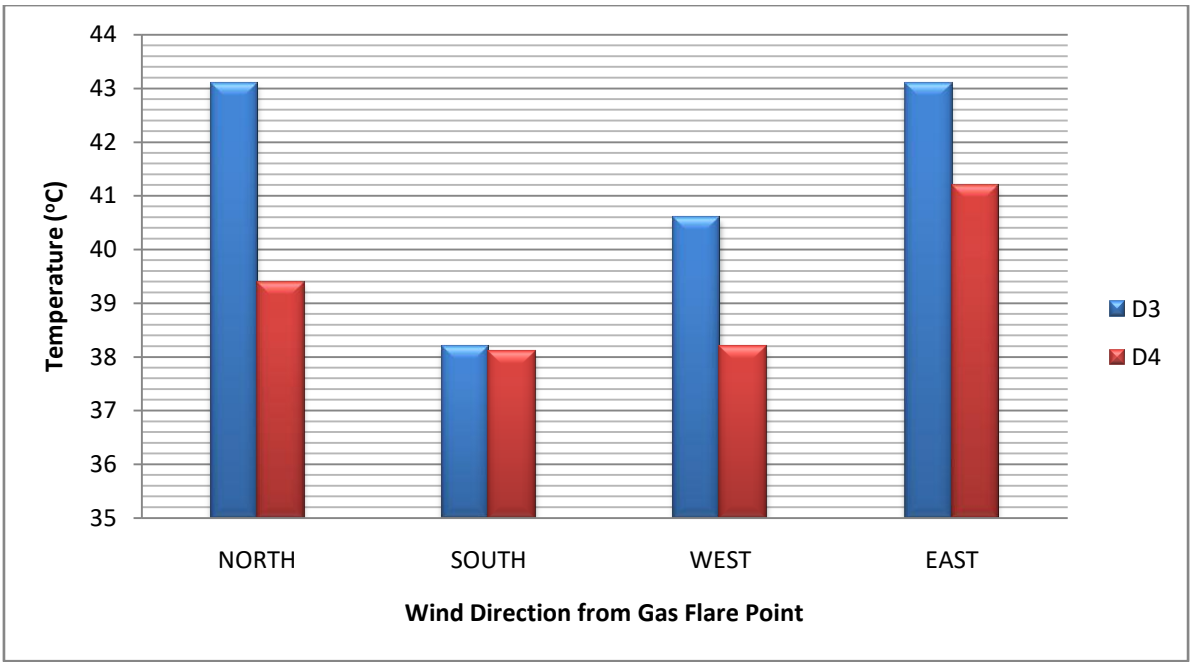


Fig 26: Temperature variation with wind direction at D3 and D4.

In fig 26, D3 was higher than D4, At South D3 and D4 were equal, At West, D3 was higher than D4 while at East, D3 was higher than D4

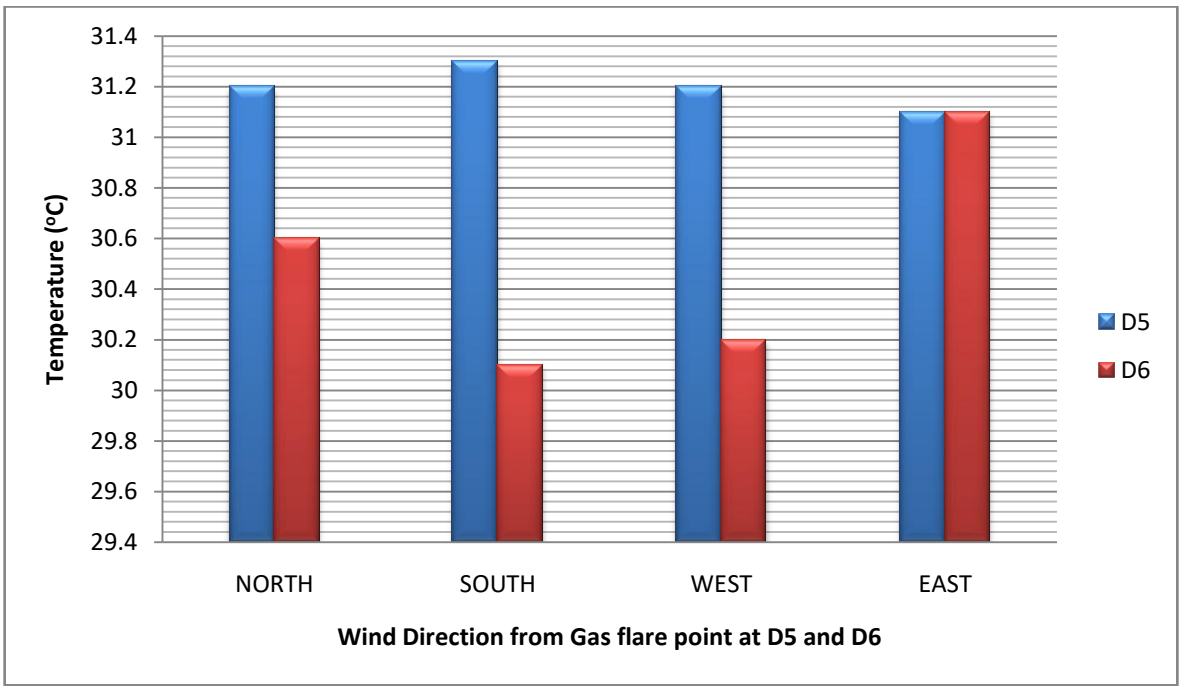


Fig 27: Temperature variation with wind direction at D5 and D6.

In the fig 27 represented above, at the North D5 was higher than D6. At South, D5 was higher too than D6, At West, D5 was also higher than D6 while at East D5 and D6 are equal

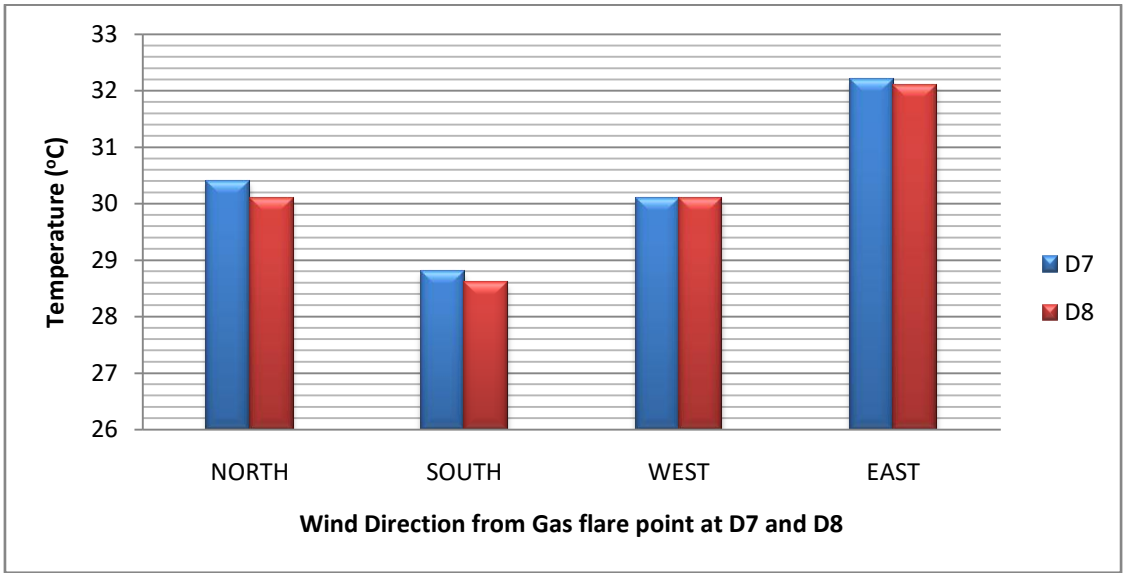


Fig 28: Temperature variation with wind direction at D7 and D8.

Fig 28 represents temperature variation with wind direction at D7 and D8 where at the north, D7 is higher than D8, at the South, and D7 was higher than D8. At the West, D7 and D8 are equal while at the East, D7 is a little higher than D 8.

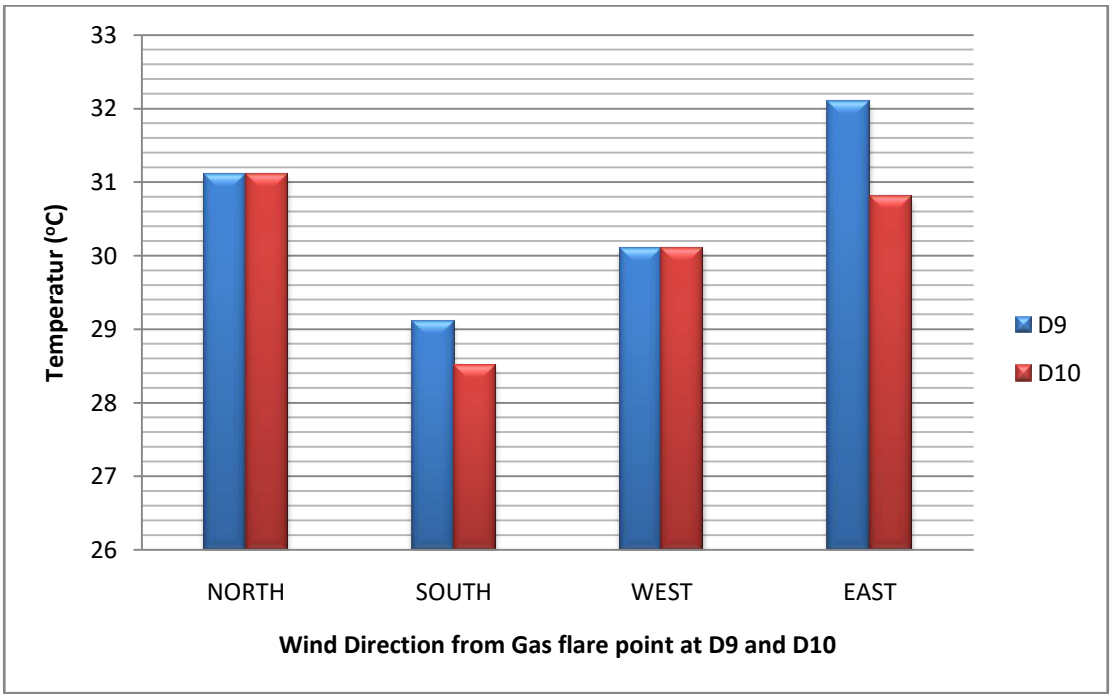


Fig 29: Temperature variation with wind direction at D9 and D10

Fig 29 shows Temperature variation with wind direction at D9 and D10 where in the north D9 and D10 are equal. In the South, D9 is higher than D10, and in the west the two are equal while in the East, D9 is higher than D10.

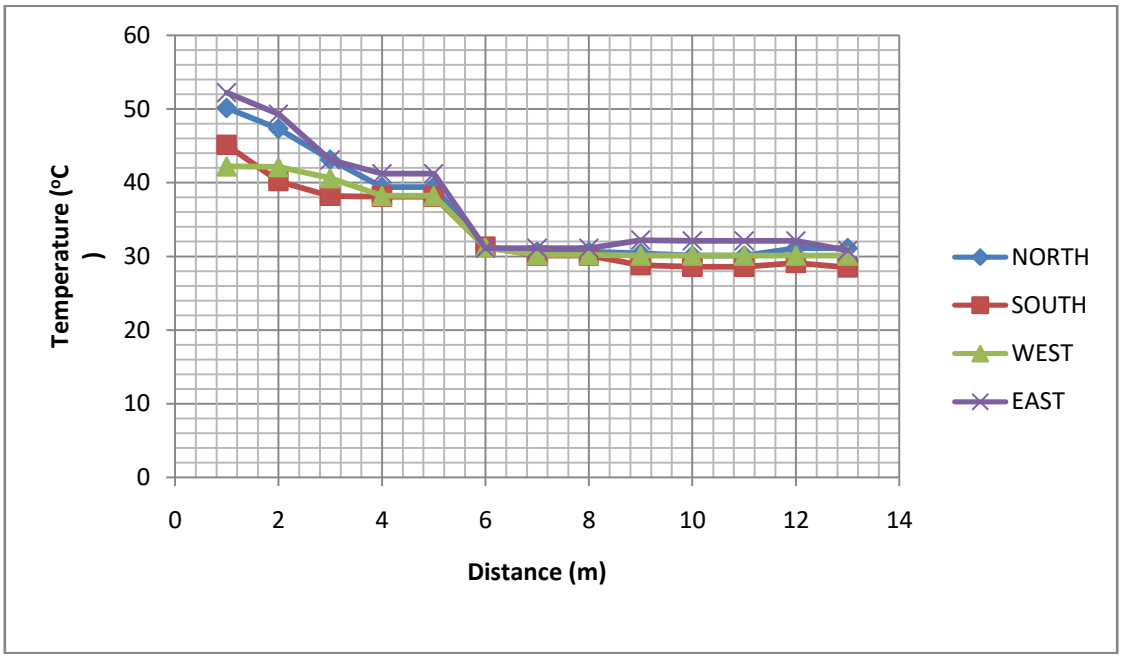


Fig 30: Variation of temperature with distance in various directions

Fig 30 shows variation in the temperature with the distance in various directions.

Monthly Variation of Rain water pH, Amount of Rainfall and 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 Soku Community was 5.5-6.9 and its correlation with amount of rainfall was strong and positive (R^2=0.859).

Table 6: 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.

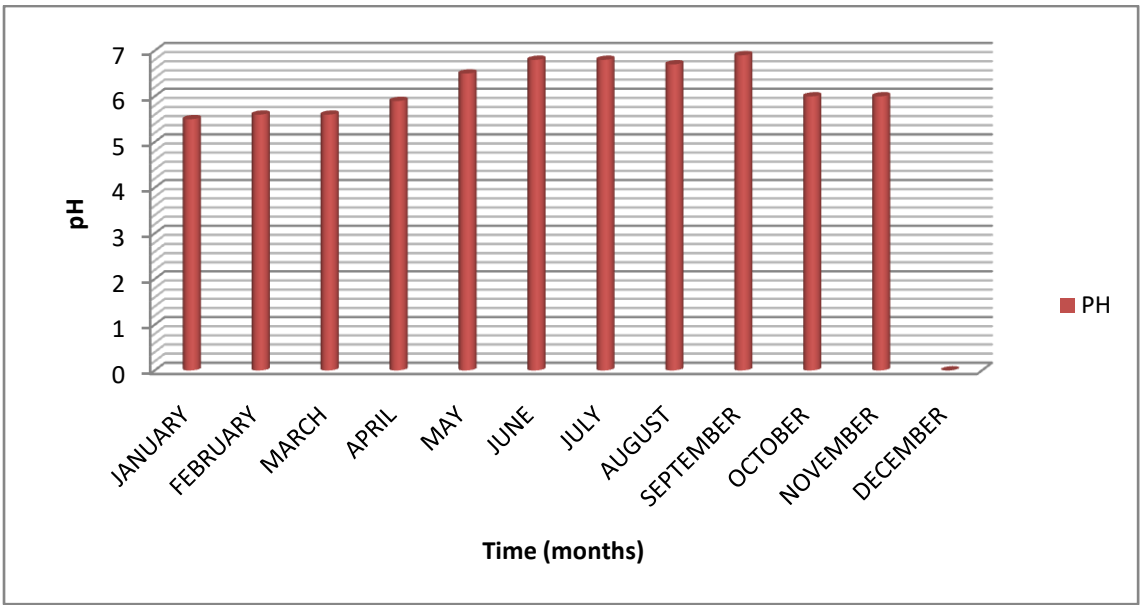


Fig 31: Monthly Variation of Rainwater pH.

Fig 31 shows monthly variations in rainwater pH June, July and September have the highest Ph while January, February and March showed the lowest pH values.

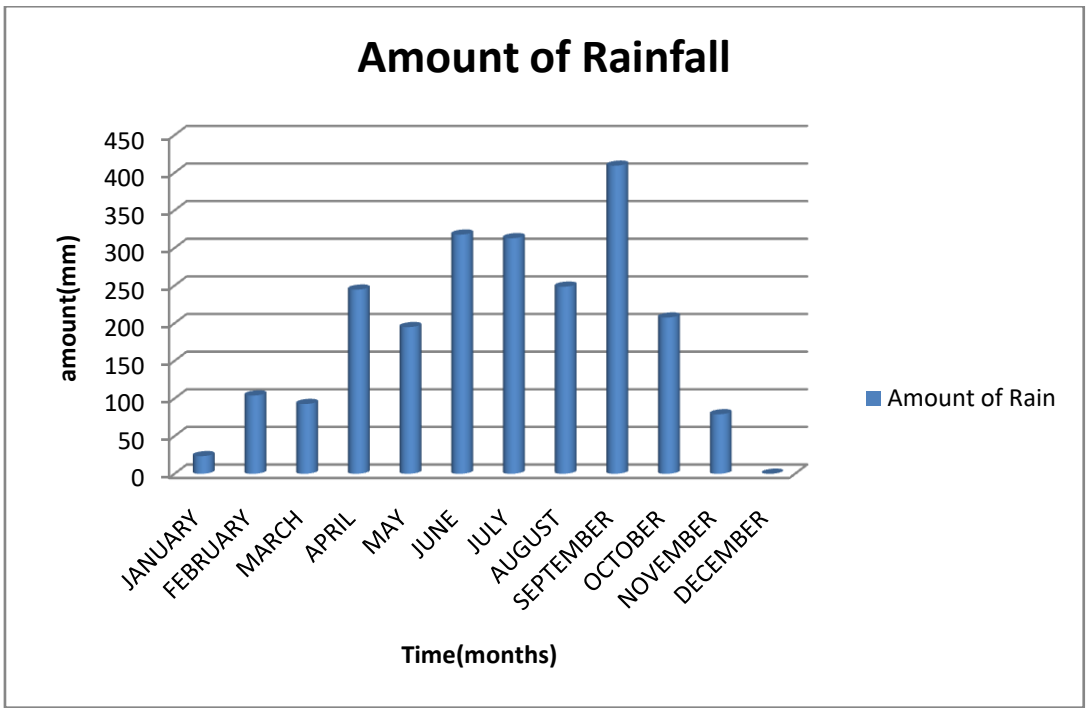


Fig 32: Monthly Variation of Amount of Rainfall.

Monthly variation of amount of rainfall was shown in fig 32 where rainfall was highest in September with 400mm and lowest in December with zero amount of rainfall.

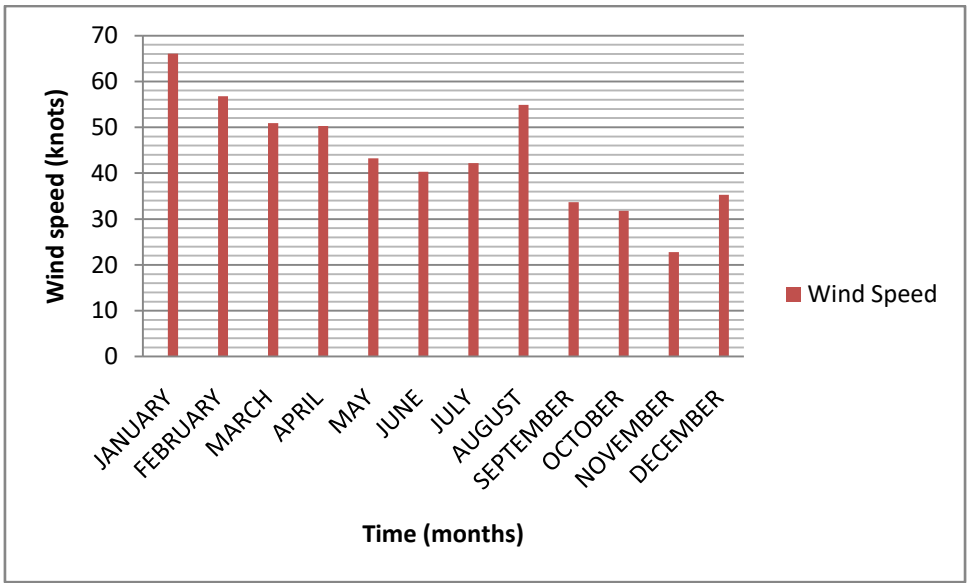


Fig 33: Monthly Variation of Wind speed.

Fig 33 revealed the monthly variation of wind speed with highest value in January followed by February and August, March and April, July, May and June December, September and October then the least in December.

Summary of Findings

At various distances from flare point, values of physical properties (Temperature, Turbidity, Colour, and TSS) 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.

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.

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).

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 experience of Soku 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 aquatic 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, which affected their health conditions.

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 greenhouse 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.

Recommendations

Gas flaring is a major contributor to environmental pollution in Soku Community. 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 its numerous impacts on the Soku community and environment, I recommend that:

1. 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.
2. The SPDC should officially acquire agricultural land within 500m radius around the flare point and put it into use other than agricultural cultivation.
3. 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.
4. Creation of forest reserves with special trees around the flare zone to promote Bio remediation.
5. Combination of staged flare system and gas recovery to minimize the volume of gas been flared.
6. Alternative technologies such as gas Re – injection, Gas transport, Gas to Liquid, Gas utilization, incineration and Gas conservation should be adopted.
7. Gas emission clean-up programme should be carried out in the Community.
8. Appropriate environmental management systems like the ISO14001 should be implemental strictly.
9. 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

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