IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 14, Issue 4 Ser. I (April. 2020), PP 10-19
www.iosrjournals.org

Applications of Gaussian Model and Field Measurements in Assessing Levels of Air Pollutants from Eleme Refinery, Portharcourt, Nigeria

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Abstract: *Levels of air pollutants from Eleme Refinery in River State, Nigeria were assessed. The main objective was to determine the concentration of selected air pollutants in the refinery and some communities around the refinery. Particulate matter (PM_{10}) was measured with AEROCET Mass particle counter/dust monitor. The values generated by this exercise were used in Gaussian model to compute the concentrations of the pollutants in Eleme, Agbonchia, Nchia, Aleso, Aleto and Alode communities. Field measurements of the pollutants were also carried out in these areas. Geographic Information System (GIS) was used to estimate the distance between the communities and the refinery while Arc GIS9.3 version software was applied in producing concentration raster of the pollutants. Comparisons were made of data generated with WHO standards. Results obtained from Gaussian Model calculation indicate that PM_{10} varied from 8.0 x 10^{-8} to 178.10 µg/m^3, NO_2 ranged from 2.0x10^{-7} to 480.0µg/m^3. Other were SO_2 (2 .3x10-7 to 534.20µg/m^3), H_2S (2.4x10^{-7} to 560.5 µg/m^3), and CO (3.3x10^{-1} to 782.50 µg/m^3). Similarly, data from the field measurements show that PM10 ranged from 40.0 to 234.4µg/m^3, NO_2 was from 35.0 to 631.0ug/m^3, and SO_2 varied from 200.0 to 703.1ug/m3. The values of H_2S and CO were 90 to 737.7µg/m^3 and 2.9 to 78.3µg/m^3, respectively. The outcome of the comparisons between the results and the standards revealed that the estimated concentrations of the pollutants from Gaussian model were all within WHO standards except the values obtained from the refinery which was above the limits. Similarly the values from the field measurement were all above the WHO limits. There is an urgent need to reduce emission rate of pollutants from the refinery and other sources in the vicinity.*

Keywords: *Concentrations, Emission, Model, Pollutants, Raster.*

Date of Submission: 21-03-2020 Date of Acceptance: 07-04-2020

I. Introduction

Petroleum is today the most important and widely used energy resources in modern world economy and is needed to power various forms of machines, produce plastics, fertilizers, pesticides, road construction, materials etc.

With a maximum crude oil production capacity of 2.5 million barrels per day, Nigeria ranks as Africa's largest producer of oil and falls between the sixth and fifteen largest oil producing country in the world depending on the ranking organization[1]. There are four major oil refineries in Nigeria, namely: the old and new Port Harcourt refineries, Warri refinery and Kaduna refinery. The Port Harcourt refinery that houses the old and new refineries is located at Alesa Eleme. Both oil refineries posses a combined capacity of 210,000 barrels per stream day making PHRC the biggest oil refinery company in Nigeria[2]. Petroleum refinery processes are a major source of hazardous pollutants including BTEX compounds (benzene, toluene, ethylbenzene, and xylene). They are also a major source of criteria air pollutants: particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2). Refinery processes also release less harmful hydrocarbons such as natural gas (methane) and other light volatile fuels. Some of these chemicals released are suspected cancer-causing agents, responsible for most developmental and reproductive problems. The presence of unaccepted levels of foreign gaseous and particulate matters in the atmosphere is referred to as air pollution[3]. Oil refineries pollute the air, water, and land. They do not only produce petroleum products, which are used in other industries as fuel for automobiles, aircraft, and ships, but they also produce emissions as a result of combustion. Air pollution can be defined as any atmospheric condition in which certain substances are present in such concentrations that they can produce undesirable effects on man and his environment[4]. Air pollution is said to be a consequence gaseous emissions from mainly industry, thermal power stations, automobiles, domestic combustion, etc [5]. The most direct impact of human health are thought to result from breathing air borne acidified particles, which can impair respiratory processes and lead to lung damage[6].

One of the first challenges in the history of air pollution modeling[7,8] was the understanding of the diffusion properties of plumes emitted from large industrial stacks. For this purpose, a very successful, yet simple model was developed – *the Gaussian Plume Model*. This model was applied for the main purpose of

calculating the maximum ground level impact of plumes and the distance of maximum impact from the source[9]. The model became commonly used models for dispersion of gaseous (non-reacting) air pollutants are based on the Gaussian profile[10]. This model provides a simple method of interpreting dispersed data from a plume in y and z directions. This model is based on the diffusion equations developed in Turner's workbook [11]. The aim of this study is to use Gaussian mathematical model and field measurements in assessing spatial concentrations of air pollutants from Port Harcourt Refinery.

II. Materials and Methods

Eleme is a local government area in Rivers State, Nigeria, located east of the Port Harcourt Local Government Area. It is bounded in the North by Obio/Akpor and Oyigbo LGAs, in the South by Okrika and Ogu/Bolo LGAs, in the East by Tai LGA. It is also bound on the West by Okrika. It lies between latitude 4^0 079.00" and longitude 7^0' 13.99" E. Its mean elevation is 22m/72.18ft above sea level, and as land area of 138km^2.

The climate of Eleme Local Government Area is characterized by a tropical monsoon with lengthy and heavy rains and very short dry season. The heaviest rainfall occurs in September with an average of 367mm of rain. December has an average rainfall of 20mm and is the direst month on average. Temperature variation throughout the year is little and on average is between 25 -28^{0}C.

The Eleme community is a traditional agricultural society that grows crops such as yams, cassasva, oil palm, fluted pumpkin, plantain etc. This dynamic has however been modified by industrial establishments. Two major refineries, a foremost fertilizer plant in West Africa, Dangote Cement Company, a sea port with so many other companies have industrialized the area in recent time. There are settlements areas with 190,994 people (NPC, 2006) reside. All these activities are linked by network of roads.

Experimental Procedure

Air quality sampling was carried out at mid-day in March, 2017 using AEROCET Mass particle counter/dust monitor and gray-wolf toxic gas probe, at Port Harcourt Refinery, in Eleme Local Government Area of Rivers State for five air quality parameters (PM_{10}, SO_2, H_2S, NO_2 and CO) in 30 minutes. Each sampling was replicated three times and their means calculated. The mean concentration of each pollutant was readjusted and corrected using Gaussian equation (3.1). The average wind speed at the stack height was evaluated by modifying the meteorological value of average wind velocity measured at 10meters as collected from online weather forecasting site using equation (3.2). The surface wind speed calculated above was used to determine the stability category in the Gaussian/Turners key to stability category table (table 3.1). Hence, the spreading coefficient of gases, Δ_y and Δ_Z in the y and z directions are estimated using equations (3.3. and 3.4), respectively with the values of their constants taken from Gaussian/Turners fitted values for Δ_y and Δ_z in table 3.2. Gaussian plume model equation for estimation of ground level concentration at any distance downwind of an elevated source equation (3.5) was used to calculated the concentrations of pollutants at selected towns (Aleto, Alode, Nchia, Agbbonchia and Alese and Alesa) within Eleme Local Government Areas. Geographic Information System (GIS) software distance analyst tool was used to estimate the horizontal distances between the towns and Eleme refinery while the estimated ground level concentration of pollutants at the towns were converted to a database file, exported to ArcGIS9.3 version software and produced as a concentration raster of pollutants emitted from the refinery.

Basically, the application of GIS in this project involved data acquisition, data conversion and data processing. The spatial data sets were captured in vector mode as points, polyline and polygon while the attribute records were structured into tabular database. The attribute records stored additional information about the spatial features and both databases ultimately linked through a functional multi relational linkage. Keeping both spatial and attribute databases in a single GIS data base is a step towards eliminating data redundancy, inconsistency, update anomalies and data maintenance and uncertainty which would impair data quality to give bias information about the problem under view. Besides, a well-structured database enhances the speed of data retrieval and conserves storage space among others.

The data sets that were collected in analogue format required digital conversion to specification. Based on the design structure for this project, a GIS database was created by conversion of both spatial and attributes data collected into a digital format. This process involved using hardware accessories and software packages to convert analogue to raster through a scanning process. Scanner is a device that enables the scanning of a picture, line drawing, text or other graphic element into a form useable in CAD (Computer Aided Design)/GIS environment. The AutoCAD/Raster Design software was used to convert the scanned raster image into vector entities.

Gaussian Plume Model

Gaussian plume model for ground concentration of pollutants at any given distance downwind of an elevated source is given by:

$$P(A)(x,y,0,H) = \frac{Q}{pieD_yD_zu} \exp[-1/2(y/D_z)^2] \exp\{-1/2(H/D_z)^2]\} \ldots\ldots\ldots eq3.5$$

Where y = 0, the equation reduces to

$$P(A)(x,0,0,0) = \frac{Q}{pie\Delta_y\Delta_zu} \exp[-1/2(H/D_z)^2] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq3.6$$

Where:

X = concentration at a point in the plume
Q = Source strength (mass/unit time)
U = Wind speed
D_Z = Vertical plume standard deviation at distance x form source
D_y = Horizontal plume standard deviation at distance x from the highway
H= Height of the plume centre line
D_y = Horizontal distance from the emission source

III. Results

Tables 4.1, 4.2, and 4.3 are the measured values of the pollutants, their mean concentrations and their corrected values respectively using Gaussian model. Table 4.4presents the calculated emission rate for the five air pollutants while table 4.5 shows air pollutants concentrations from the selected towns in Eleme Local Government Area. Figures 4.1 to 4.5 indicate the relationships between pollutants concentrations and distance from the refinery , while figures 4.6 to 4.11 present the comparisons of the pollutants concentrations in the six locations; namely the refinery, Agbonchia, Nchia, Alese, Aleto and Alode with WHO standards. The raster concentrations of the pollutants are shown in plates 1 to 5.

Table 4.1 replicated sample concentration of pollutants at Eleme Refinery in µg/m^3.

Parameter	**A**	**B**	**C**
PM_{10}(µg/m^3)	254.8	224.64	224.88
NO_2(µg/m^3)	630.8	63.7	633.6
SO_2(µg/m^3)	705.1	702.5	701.8
H_2S (µg/m^3)	734.2	740.5	738.5
CO (µg/m^3)	1027.9	1027.7	1033.8

Table 4.2 Mean concentrations of pollutants at Eleme refinery

Location	Longitude	Latitude	PM_{10} µg/m^3	NO_2 µg/m^3	SO_2 µg/m^3	H_2S µg/m^3	CO µg/m^3
Eleme Refinery	7.1176.81	4.784.564	234.4	631.7	703.1	737.7	1029.8

Table 4.3 Corrected values of pollutant concentrations in the refinery

Location	Longitude	Latitude	PM_{10} (µg/m^3)	NO_2 (µg/m^3)	SO_2 (µg/m^3)	H_2S (µg/m^3	CO (µg/m^3)
Eleme Refinery	7.1176.81	4.784.564	178.1	480.0	534.2	560.5	782.5

Table4.4 Calculated refinery emission rate for the five air pollutants (g/s)

Air Pollutant	**PM_{10}**	**NO_2**	**SO_2**	**H_2S**	**CO**
Emission Rate	40.3	109	121	127	177

In table 4.2, the average concentrations of the pollutants were PM_{10} (234.4µg/m^3), NO_2 (631.7µg/m^3), SO_2 (7031.µg/m^3), H_2S (737.7µg/m^3), and CO (1029.8µg/m^3).

The corrected levels of PM_{10}, NO_2, SO_2, H_2S and CO were 178.1, 480.0, 534.2, 560.5, and 782.5µg/m^3, in that order (table 4.3). From table 4.4, the calculated refinery Emission Rates for the five air pollutants were PM_{10} (40.3), NO_2 (109.0), SO_2 (121.0), H_2S (127.09) and CO (177.0)g/s. Presented in table 4.5 are the distances of the selected towns, and the concentrations of the pollutants in the areas. Nchia town is 771 meters from the refinery and the concentration of PM_{10}, NO_2, SO_2, H_2S and COwere 3.99 x10^{-4}, 1.05x10^{-3}, 1.16x10^{-3}, 1.22x10^{-3} and 1.70x10-3 µg/m^3. Agbonchia is 992m from the pollutant source, the levels of the pollutants were PM_{10} 8.0x10^{-5} (µg/m^3), NO_2 (2.04µg/m^3), SO2 (2.7µg/m^3), H_2S (2.38µg/m^3), and CO (3.32µg/m^3). Aleto town is

624m from the refinery. H_2S has the lowest concentration of air pollutant while PM_{10} with concentrations 3.47µg/m^3 was the highest.

Alesa is the nearest town to the source of the pollutants with a distance of 170m. Concentrations of the pollutants in the settlement varied from 94.3µg/m^3 for PM10 to 141.1 µg/m^3 for CO. other results shown in table 4.5 are Alode town with a distance of 590m from the refinery and had the following values PM_{10} (0.086µg/m^3), NO_2 (0.244µg/m^3), SO_2 (0.258µg/m^3), H_2S (0.271µg/M^3), and CO (0.3778µg/m^3). The concentrations of the pollutants in the refinery were PM (178.1µg/m^3), NO2 (4.80µg/m^3), SO_2 (5.34.2µg/m_3), H_2S (560.5µg/m^3) and CO (782.5µg/m^3).

Corrected values of pollutants concentrations in table 4.2 were derived using equation 3.1 where (PA), = measured concentration, t_1= 10 minutes, t_2 = 30 minutes and ∞= 0.18.

Table 4.5 Air pollutant concentrations for the selected towns in Eleme LGA

Location	Longitude	Latitude	Distance from refinery (m)	PM_{10} µg/m^3	NO_2 µg/m^3	SO_2 µg/m^3	H_2S µg/m^3	CO µg/m^3
Agbonchia	7.12224	4.791985	992	0.00000008	0.00000020	0.00000023	0.00000024	0.33000
Nchia	7.122365	4.789717	77	0.00105000	0.00105000	0.00116000	0.00122200	1.7000
Alese	7.113616	4.789175	658	0.01340000	0.3620000	0.04016000	0.04215000	15.87000
Aleto	7.117138	4.790385	624	0.03470000	0.09400000	1.0440000	0.11000000	xxxxxxxx
Alode	7.122914	4.785159	590	0.08600000	0.23300000	0.25800000	0.27100000	3.77800
Refinery	7.11768	4.784564	0	178.10000000	480.00000000	534.2000000	560.50000000	78.50000

Table 4.6: Measured values of pollutants from the six towns in the study area and the WHO standard.

Location	Distance (M)	Parameter				
		PM_{10} µg/m^3	NO_2 µg/m^3	SO_2 µg/m^3	H_2S µg/m^3	CO mg/m^3
Agbonchia	992	70.0	120.0	208.0	200.0	3.2
Nchia	771	66.0	205.0	200.0	220.0	4.5
Alesa	658	720	115.0	300.0	110.0	6.0
Aleto	624	40.0	35.0	35.0	90.0	2.9
Alode	590	127.0	200.0	610.0	120.0	11.2
Refinery	0.	234.4	631	703.1	737.7	78.3
WHO standard		50	200	500	150	10

From table 4.6, the distances of the selected towns the refinery ranged from 590 to 992 meters. The values of PM_{10} varied from 40 to 234.4µg/m^3 while NO_2 was from 35 to 631 µg/m^3. Sulphur dioxide concentrations ranged from 50 to 703.1µg/m^3, and the values of H_2S and CO also ranged from 90 to 737.7µg/m^3, and 2.9 to 78.3mg/m^3, respectively.

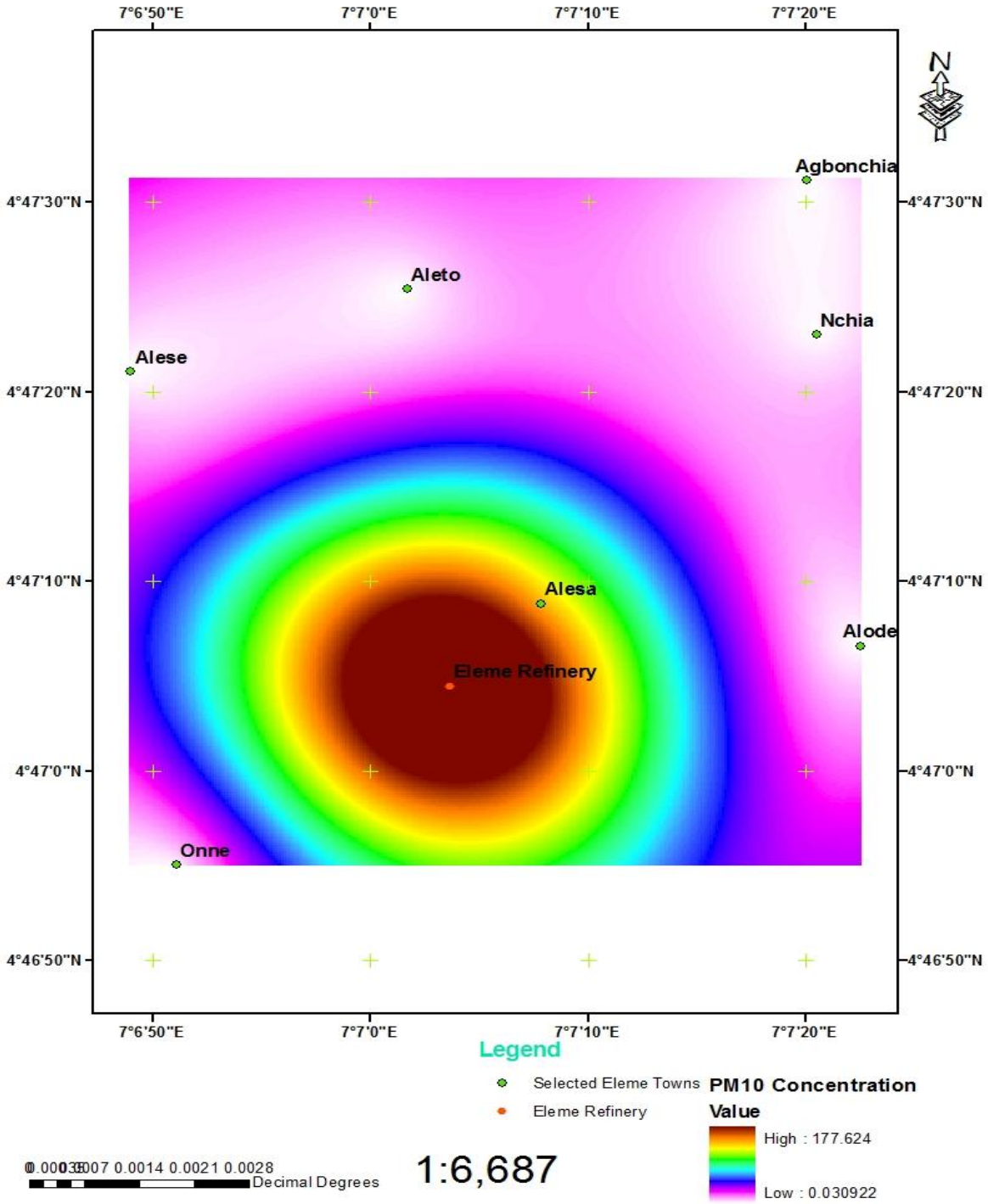

Plate 1: Raster of PM_{10} concentration

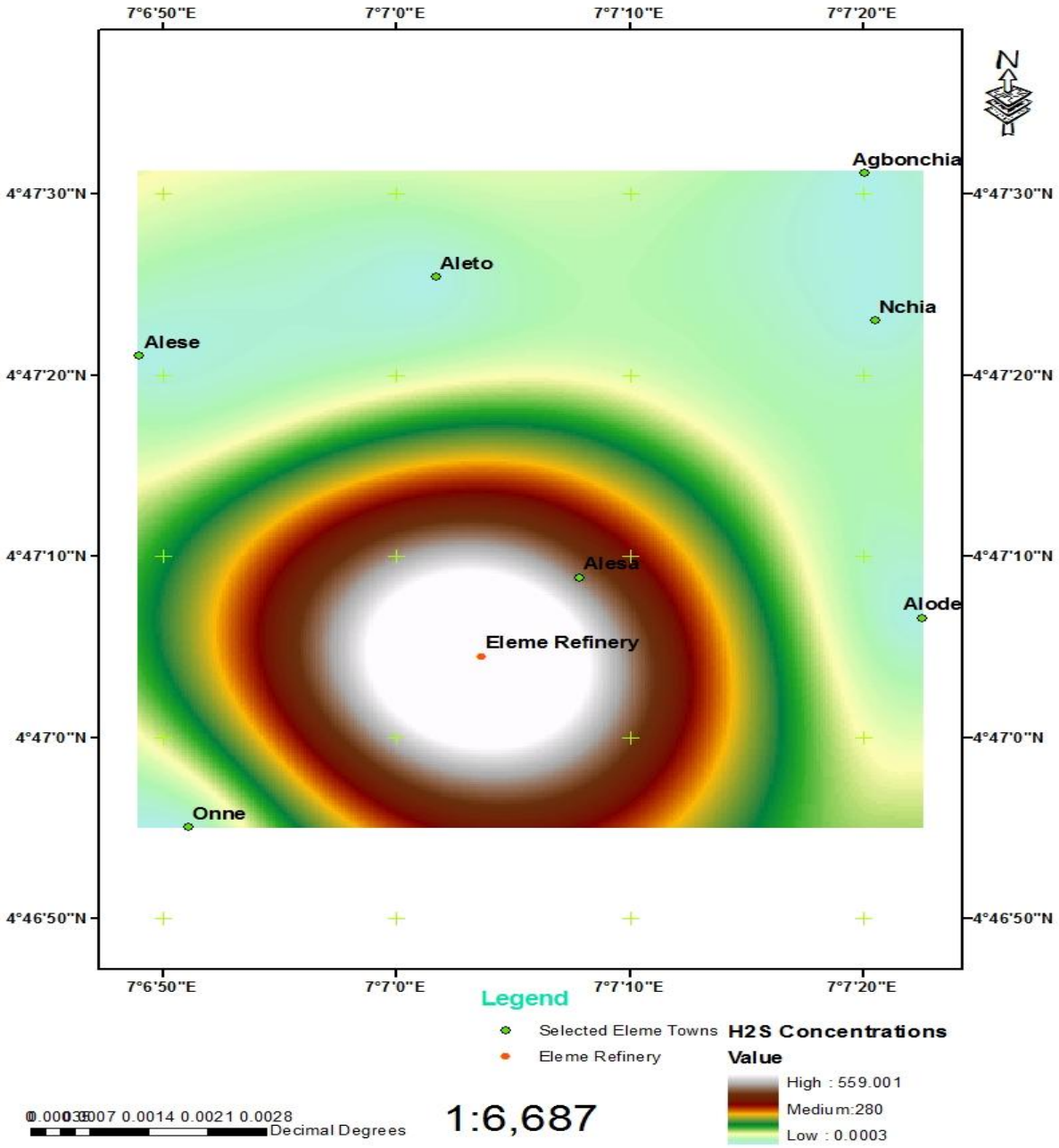

Plate 2: Raster of H_2S concentration

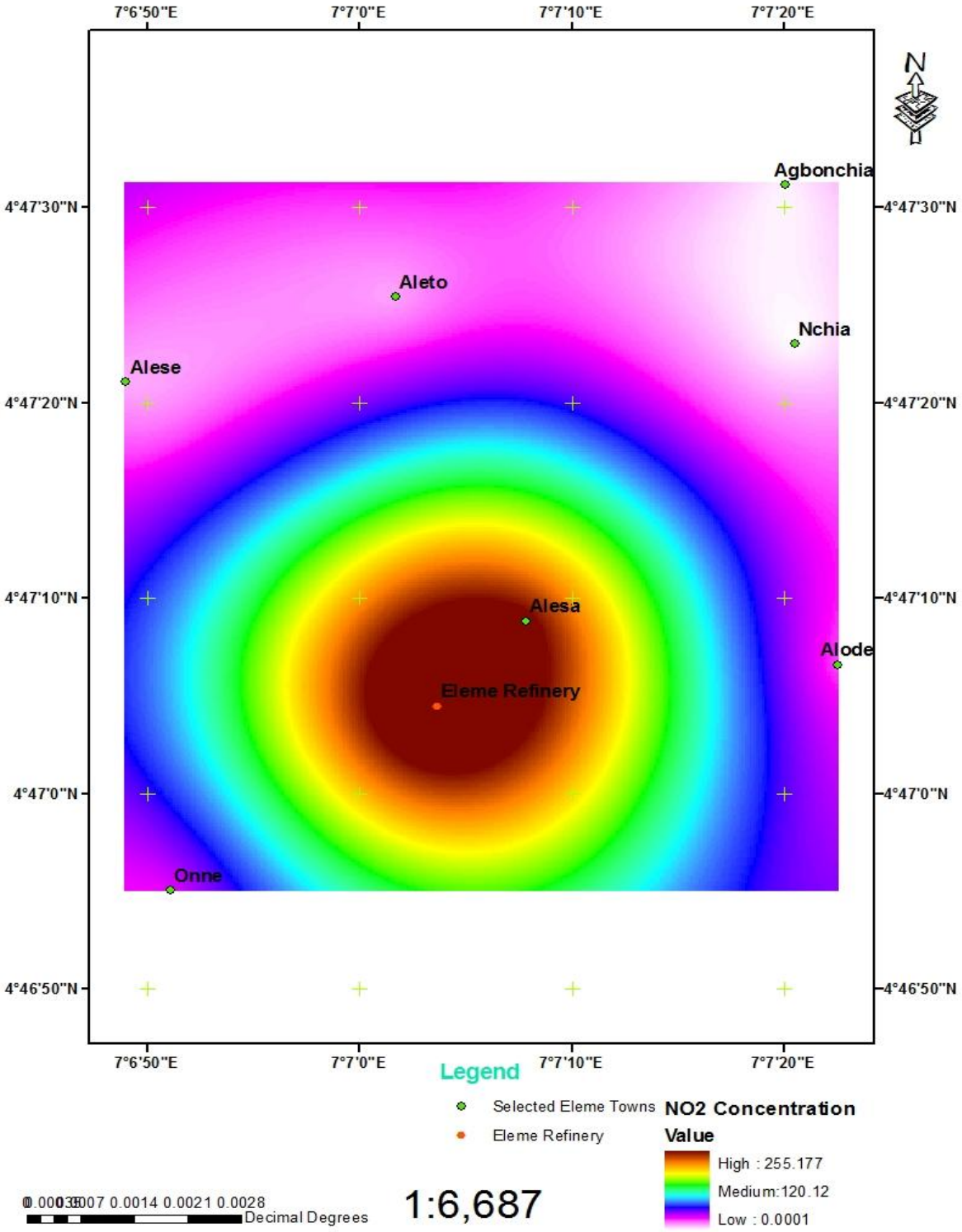

Plate 3: Raster of NO_2 concentration

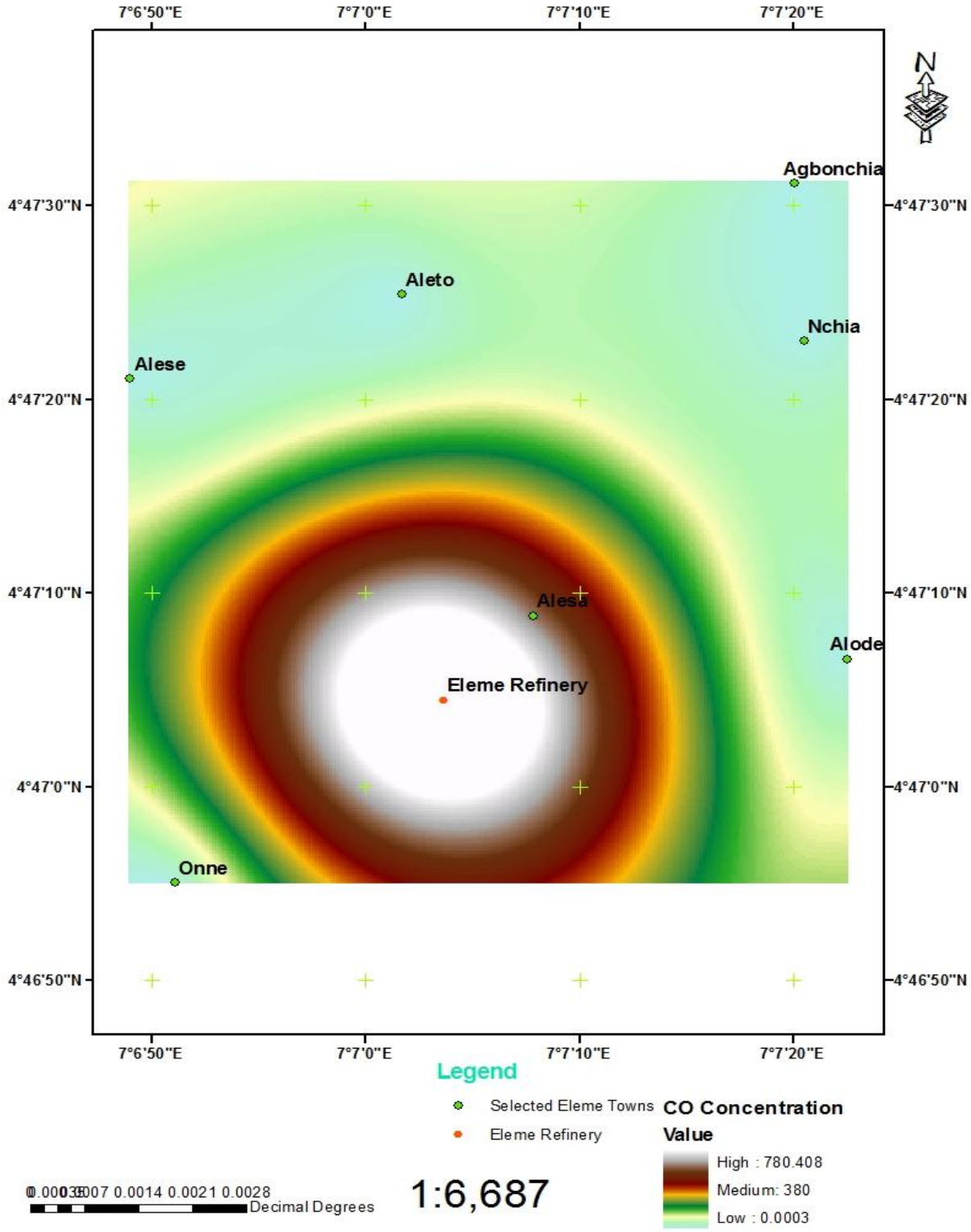

Plate 4: Raster of CO concentration

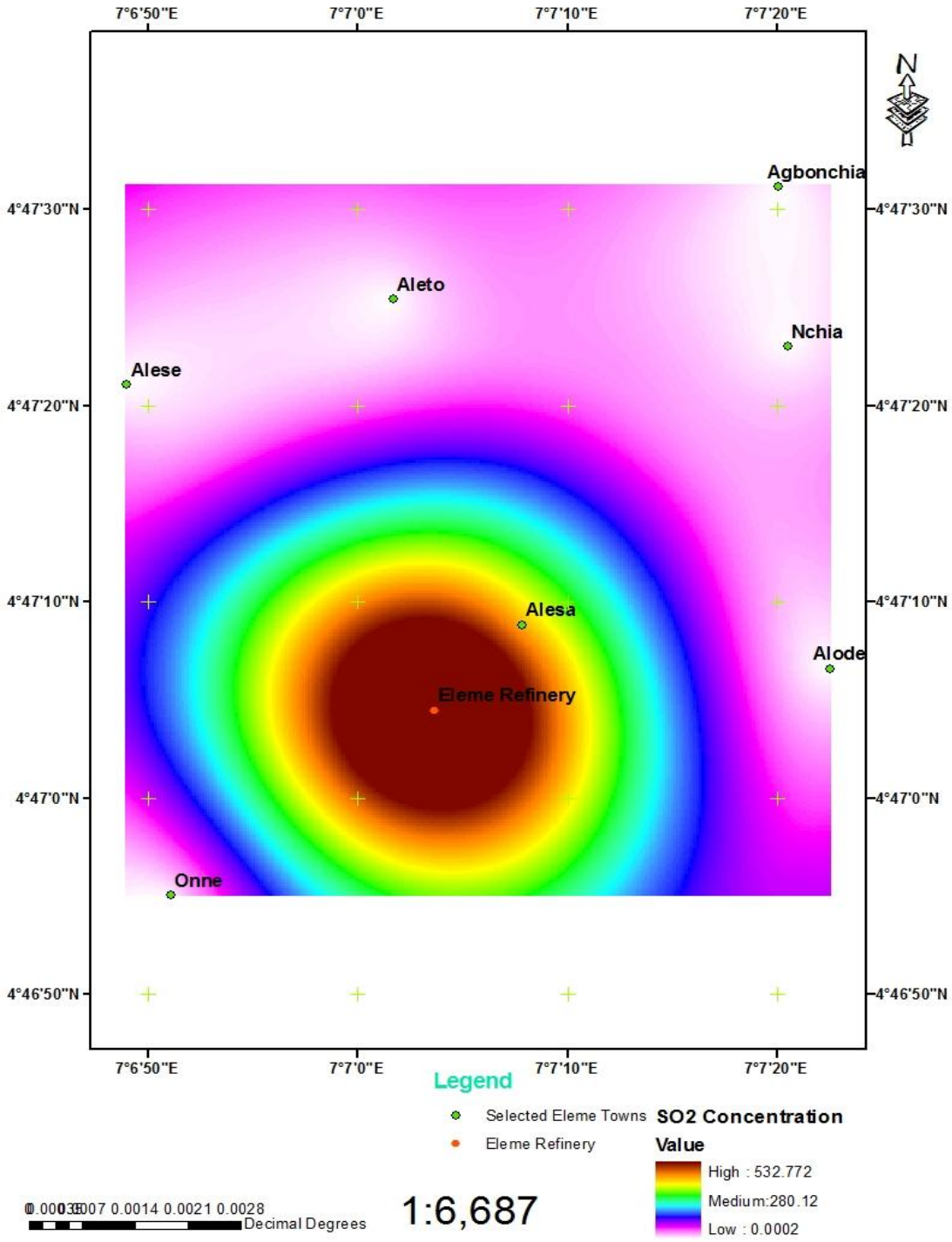

Plate 5: Raster of SO_2 concentration

IV. Discussion

Table 4.5 shows that the PM_{10} values computed from the Gaussian model varied from 8.0^{-8} to 8.6^{-2} µg/m^3. From table 4.6, the measured PM_{10} concentrations ranged from 40.0 to 234.4 µg/m^3. The calculated values in all the towns were within standard except the values obtained from the refinery which was higher than the standard. Similarly, all the measured concentrations were higher than WHO maximum limit apart from that of Aleto with 40µg/m^3 concentration. The high PM_{10} obtained from most of the towns will cause serious health and environmental problems such as respiratory and visibility challenges.

The estimated NO_2 levels were low and within WHO standards except the value obtained from the refinery (480.0µg/m^3) that was higher than the limit (200µg/m^3). Measured values (35.0 µg/m^3) from Aleto (Table 4.6) was within WHO standard while the level of the NO_2 from other towns were higher than the limit.

Nitrogen Oxide combines with water in the atmosphere to form nitric acid, which fall as precipitation. Acid precipitation can kill living things, destroy entire ecosystem and also destroy historic monuments (Arms, 2000).

From table 4.6, SO_2 concentrations were higher than the WHO standard at the refinery at Alode with measured values 703.1 and 610.0 µg/m^3, respectively. All the other measured values were within the standard and no danger was posed from these concentrations (table 4.5). This indicates that only the values obtained from the refinery were higher than the WHO standard while others were within the limits. Sulphur dioxide compound has similar environment impact as NO_2 by causing respiratory disease and acid rain formation. It also causes cough, shortens of breath and irritation to the eyes. When converted to sulphuric acid can damage the lungs.

Hydrogen sulphide is a highly toxic gas produced from industrial discharge among other sources. Computed H_2S varied from $2.4X10^{-7}$ to 560.50 µg/m^3. The measured values also varied from 90.0 to 737.7 µg/m^3. Concentrations of this gas in Alesa, Aleto and Alode were within WHO maximum limits; all other towns in the study area had higher values above the limits. High concentration of H_2S above the stipulated limit has adverse effects on humans. It causes conjunctival irritation and workers exposed to hydrogen sulphide concentrations of less than 30 µg/m^3 are reported to have rather diffuse neurological and mental symptoms (Wilkie, 1995).

This gas is one of the most common and widely distributed air pollutants. According to Park (2000), it is a product of incomplete combustion of carbon containing materials such as in automobiles, industrial processes, heating facilities and incinerators. Table 4.5 shows that the estimated CO concentrations from the selected towns were all within WHO standard of 10mg/m^3 except for Aleto and the refinery which had higher values of 15.87000 and 78.3mg/m^3, in that order. Carbon monoxide seriously affects the respiratory system. For example, when CO is absorbed into the lungs it reduces the haemoglobin available to carry oxygen to the body. This may cause injury to vital organs (Sharma and Kumar, 2013).

The results obtained from this study indicate that values computed from Gaussian mathematical model decreased with distance from the refinery and were lower than the concentrations obtained through measurements. The measured values however did not show any definite trend in its spatial distribution, and this is probably due to the influence contribution of other sources of pollutants such automobiles, generators and other non-petroleum industries that generate air pollutants.

V. Conclusion

Analysis of results obtained through the application of Gaussian mathematical model indicate that most of the concentrations of the pollutants were within WHO limit except for values calculated from the refinery. All the parameters decreased with increase in distance from the refinery, this is expected because the flare stake is very high and the prevailing up-wind contributes to dispersion of the pollutant. The field measurements gave higher concentrations of the parameters and had no definite distribution pattern with distance. The high concentrations of most of the measured values above WHO standard could be due to other activities that generate air pollutants in the towns. From the results, people working in Port Harcourt refinery and those living in surrounding towns are exposed to great health danger and environmental degradation.

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Uwasomba, C.H. etal. "Applications of Gaussian Model and Field Measurements in Assessing Levels of Air Pollutants from Eleme Refinery, Portharcourt, Nigeria." *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 13(4), (2020): pp 10-19.