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Spatial Variation in Atmospheric Pollutants Distribution in The Vicinity of Gas Power Plants in The South-South Region

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Abstract: Air pollution is a challenging environmental issue of global concern traceable to different sources, flaring of gases, transportation, waste incineration, illegal refining of crude and emission from agricultural activities including gas power plants which produce electricity to meet our energy consumption need. Energy generation through this source emits different pollutant loads with devastating environmental and public health consequences into the atmosphere. This study assessed the spatial distribution of pollutant loads at varying distances in the vicinity of gas power plant stations in South-South, Nigeria. The study adopted direct field measurement approach to obtain in-situ records of different air quality parameters such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), particulate matter (PM), carbon dioxide (CO_2) and the measurement were taking in the morning, afternoon and evening at points systematically calibrated in 5 from 200, 400, 600, 800 and 1000 meters from the centroid of the gas plant stations. Descriptive statistics (standard deviation and means) were used to summarize the data measured and presented in tables. The Analysis of Variance (ANOVA) was employed for the analysis and results shows that the pollutants were mostly higher at 200m from the gas plants. There is a significant spatial variation in the pollutant concentration in the region at $P<0.05$; except for SO_2 which was not significant at $P>0.05$ (F-1.0211, sig-0.21). The study recommended periodic environmental auditing, institutionalization of conduct of Environmental Impact Assessment by National Electricity Regulatory Commission, investment in alternative energy sources and constant air quality monitoring.

Keywords: Investment, Pollutants, Variation, Distribution, Gas plants, Atmosphere

I. INTRODUCTION

Air pollution is the contamination of air due to the presence of substances called pollutants in the atmosphere that are harmful to the health of humans and other living beings, or cause damage to the climate or to materials. Cairncross, John & Zunckel, (2007) reported that air pollution is one of the world's leading causes of death, contributing to seven million deaths annually. Global estimates show that almost one billion people in urban settings are incessantly exposed to health hazards from air pollution. Similarly, Okunola, Uzairu, Gimba & Kagbu, (2012) asserted that environmental air pollution poses serious challenges to human health, the effects which are mostly seen are respiratory diseases, cardiovascular diseases and cancers. According to the study, urban air quality is presently a key area of concern in environmental health agenda in many countries. Thus, it is concluded that our health is closely related to our environment. In Nigeria particularly in the South-South one major source of air pollution apart from the rapid oxidation or burning of crude oil-associated with natural gas that releases gaseous, particulate, and heat matter into the atmosphere with negative impacts on ecosystem and health of residents in such vicinity is the power plants (Nelson, 2012).

Power generation plant is a facility designed to produce electric energy from another form of energy. Similarly, Pope& Dockery (2006) a power plant is an industrial facility that generates electricity from primary energy. Most power plants use one or more generators that convert mechanical energy into electrical energy in order to supply power to the electrical grid for society's electrical needs. In its simplest form, a Power Plant, known also as a Power Station, is an industrial facility used to generate electricity, (Alhaddad, 2015). To generate power, an electrical power plant needs to have an energy source. One source of energy is from the burning of fossil fuels, such as coal, oil and natural gas. Among most prominent power plant types for energy generation worldwide are; nuclear power plants, hydroelectric power plants, coal-fired power plants, diesel-fired power plants, geothermal power plants, gas-fired power plants, solar power plants and wind power plants (Eneh & Agbazue, 2011). Aruninta, (2012) reported that power plants that burn coal, oil and gas are the largest source of carbon pollution, the biggest driver of climate change. Accordingly, plants that burn oil and gas also emit methane, another potent greenhouse gas which contribute to warmer temperatures that drive changes that threaten health (Alhaddad, 2015). The results of studies by Tawari & Abowei (2012); Al-Haddad, (2012); Odigure &

Abdulkareem (2005) reveal that every year, concentration of air pollutants around industrial areas from power plants causes fine particle and ground-level ozone-related premature deaths, new asthma cases and asthma exacerbations, heart attacks, and lost school and work days. Power plants are the largest source of airborne emissions of mercury.

Everywhere in the world whether in Europe, America, Asia or Africa continents, proximity to natural gas power plants has been linked to increased air pollution levels within the landscape, which can have detrimental effects on respiratory health of the residents. Evidence of higher levels of nitrogen oxides (NOx), volatile organic compounds (VOCs), and particulate matter (PM) in the vicinity of natural gas power plants is reported in studies such as Khanfar, (2015), Ragothaman & Anderson, (2017), Turnock *et al*. (2016), Lurmann *et al*. (2015) & Mackie *et al*. (2016) that air pollutants emitted from this facility are known to be harmful to human health and the environment as the power plant emit annually over 200 tons of particulate matter, over 300 tons of nitrogen oxides and over 100 tons of volatile organic compounds (VOCs) (World Health Organization, 2017).In a related study, Bezuglaya, Yu, Shchutskaya & Smirnova, (1993) alleged that air pollutants are mobile components that occur in concentrations high enough to cause adverse effects on health, the environment, and indoor/outdoor structures, they affect human health in numerous ways and varying degrees of severity ranging from minor irritation, serious ill-health to premature death. The work of Attri, Kumar & Jain, (2001) shows that air pollutants can damage human health and cause harm to plants and animals. The emission of air pollutants has led to numerous air quality issues in cities such as photochemical smog, acid rain, and decreased visibility. Thus, the Niger Delta region of Nigeria has been identified as one of the most polluted areas on the planet earth with air pollution as one of the most serious environmental issues ravaging the region (Amuho, Amoo, Ajayi, Aiyesanmi & Akinnifesi, 2016). Against the backdrop that keeping the air quality suitable for human use is an essential issue for public health, this study was initiated to assess the air quality around gas power plants in the south-south region, Nigeria.

II. MATERIALS AND METHODS

The study was carried out within the vicinity of gas plant stations in the six states in the South-South of Nigeria, namely; Rivers (Afam Gas Plant), Bayelsa (Gbarain Gas Plant), Delta (Okpai Gas Plant), Akwa Ibom (Ibom Gas Plant), Cross River (Cross River Gas Plant) and Edo (Edo Gas Plant) respectively. Air quality samples were obtained in-situ around the gas plant stations and extended to other locations from the gas plant stations. These points were systematically calibrated in 5 from 200, 400, 600, 800 and 1000 meters from the centroid of the gas plant stations in the windward direction aligning with the distance decay assumption as shown in Figure 1. The recognition of the distance trend was essential in order to effectively determine the extent to which the gas plant stations emissions affect air quality in the study area. Air quality sampling were carried out in the morning, afternoon and evening, each day at the sampled location over a period of 6 months (January to June), 2024 in line with the UK Environmental Agency, **(**2011) and analyzed in-situ with potable air measurement equipment and the averages recorded for necessary statistical analysis. The need to do the measurements for a period of six (6) months was to establish the seasonal variation in the gas distribution in the area. The following pollutant parameters were measured using potable in-situ direct reading instruments and at a sampling height of 2m: Sulfur dioxide (SO_2), nitrogen oxides (NO_X), particulate matter ($PM_{2.5}$), carbon dioxide (CO_2). A digital hand-held probe (Hold Peak 1aser PM – meter-HP 58001D Zheliar Jida Hupau Instrument Company Limited, China) which houses a laser optical sensor for detecting and measuring particulate concentrations up to 1 milligram per cubic meter was used for measuring ($PM_{2.5}$). The Industrial Scientific Corporation ITX Multigas-Gas monitor was used for the detection and measurement of Nitrogen oxide (NO_2), Sulphur Oxides (SO_2), and volatile organic compounds (VOCs) whereas the ANOVA test statistic was used for the analysis.

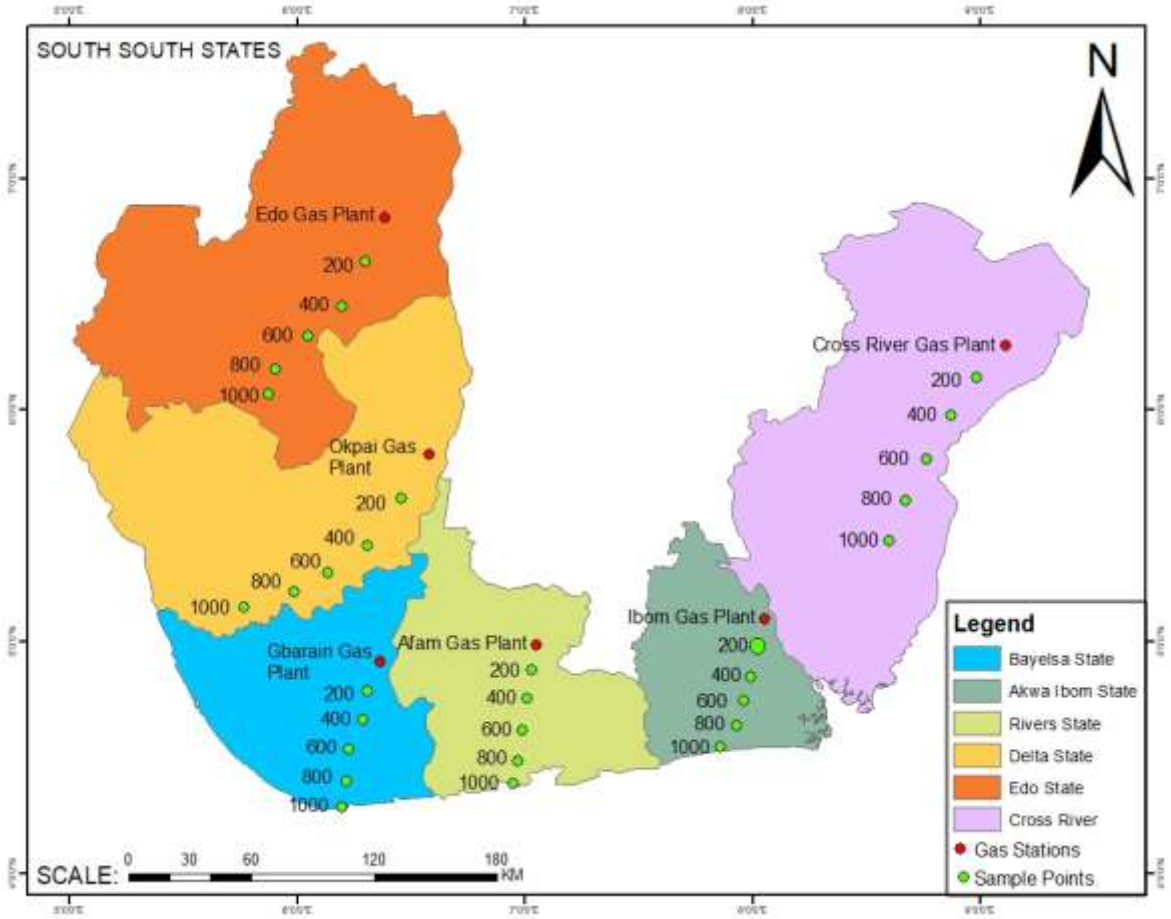


Figure 1: Air Quality Sampled Points within the study area

III. Discussion of Results

Table 1: Mean CO concentration in PPM in the vicinity of the gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	270.6	266.6	261.9	275.8	273.9	263.3
February	256.3	252.3	247.6	261.5	259.6	249.0
March	240.9	238.9	234.3	250.0	246.3	235.7
April	232.3	228.3	223.6	238.5	235.6	225.0
May	225.3	221.3	216.6	230.6	228.6	218.0
June	218.3	214.3	209.6	223.6	221.6	209.2

The data presented in Table 1 show the monthly distribution of carbon monoxide for the period under investigation in different cities in the South-South region and it is obvious that variation in the concentration of pollutant loads in the different months exists across the cities. The highest concentration of CO within the period is 275.8 ppm recorded in the month of January in Yenagoa which is slightly higher than Port Harcourt and Benin in the same month whereas the lowest is recorded in the month of June (209.2ppm) in Warri. There is a continuous reduction in the concentration of CO as time progresses from January to June. The last month under investigation recorded the lowest concentration of CO (218.3ppm) in Port Harcourt. The case is replicated in Uyo, Calabar, Yenagoa, Benin and Warri where there is a conspicuous reduction in the concentration of CO as the year progresses from January to June. It is inferred that this pattern is a function of the influences of meteorological parameters. The highest concentration of CO in January which is the peak of the dry season in Nigeria with marked reduction in rainfall and rising temperature could account for the high retention of CO in the atmosphere. It is

inferred that as progress is made into the year, and rainfall increases, wet deposition tends to reduce the CO concentration in all the cities in the South-South region.

Table 2: Mean NO_2 Concentration in PPM in the vicinity of the gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	214.5	210.5	206.5	219.1	219.0	211.1
February	209.1	205.1	201.1	213.8	213.6	205.8
March	203.4	200.5	196.5	211.0	209.0	201.1
April	201.1	197.1	193.1	206.7	205.6	197.8
May	197.8	193.8	189.8	202.5	202.3	194.4
June	194.5	190.5	186.5	199.1	199.0	173.9

The data presented in Table 2 shows the monthly distribution of nitrogen dioxide (NO_2) in the different cities under investigation from January to June. NO_2 could contribute to the formation of other pollutants such as O_3 and nitric acid (HNO_3, and NO_3), but the concentration of NO_3 in the air varies with direct emissions level and the intensity of the activities where it is emitted. The atmospheric condition of the place and the intensity of sunlight also determine the retention of NO_2 in the atmosphere. Evidently, the concentrations of NO2 in Port Harcourt show a gradual reduction as the year progresses from January to June. The month of January recorded 214.5ppm, while the month of June recorded 194.5ppm. This pattern is also replicated in Uyo, Calabar, Yenagoa, Benin and Warri which reinforces the assertion that the meteorological characteristics in the region influences the concentration of pollutant loads from gas power station.

Table 3: Mean O_3 Concentration in PPM in the vicinity of the gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	193.1	190.8	188.4	195.8	188.4	188.3
February	186.4	184.1	181.8	189.1	181.8	181.6
March	178.9	177.8	175.4	183.8	175.4	175.3
April	175.4	173.1	170.8	178.6	170.8	170.6
May	170.8	168.4	166.1	173.4	166.1	166.0
June	166.1	163.8	161.4	168.8	161.4	170.8

The data presented in Table 3 shows the concentration of ozone in the different cities under investigation from the month of January to June. Ozone is not visible and it mixes with other pollutants retained in the atmosphere, some authors tend to call it smog. Other writers have reported that O_3 is the least controlled pollutant in the world but it is also one of the most pervasive and dangerous with verified public health consequences. The data presented in Table 3 confirm previous reports that the month of January record the highest concentration of pollutants in the atmosphere. For example, 188.3ppm is recorded in Warri in the month of January, but there is a gradual reduction in the concentration of O_3 with progression into the year. Curiously, the difference between January and February is 6.7ppm which can be linked to the similar meteorological characteristics in the two months. But there is a more significant reduction in March. Unlike other cities, the month of June recorded a slight increase from what was recorded in May.

Table 4: Mean SO_2 concentration in PPM in the vicinity of the gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	0.1	0.1	0.1	0.1	0.1	0.1
February	0.1	0.1	0.1	0.1	0.1	0.1
March	0.1	0.1	0.1	0.1	0.1	0.1
April	0.1	0.1	trace	0.1	Trace	0.1
May	0.1	0.1	0.1	0.1	0.1	0.1
June	Trace	0.1	0.1	0.1	0.1	Trace

The data presented in Table 4 show the concentration of sulfur dioxide around gas power plants in the different months under investigation. SO_2 is colourless and can be produced from different activities such as gas

processing and the incineration of Sulphur bearing fossil fuels. Importantly**,** the data presented in Table 4 show relative uniformity in the concentration of SO_2 with 0.1ppm in virtually all the cities and all the months. Some of the months such as June in Port Harcourt, April in Benin and April in Calabar recorded insignificant trace concentration of SO_2.

Table 5: Mean $PM_{2.5}$ Concentration in PPM in the vicinity of the gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	115.8	114.1	111.5	118.5	125.5	109.9
February	110.5	108.8	106.2	113.2	120.2	104.6
March	103.4	103.2	100.5	108.6	114.5	99.0
April	100.8	99.2	96.5	104.0	110.5	95.0
May	100.0	98.3	95.7	102.7	109.7	94.1
June	99.2	97.5	94.8	101.8	108.8	90.7

The data presented in Table 5 show the concentration of $PM_{2.5}$ in the vicinity of gas power plants in different cities in the Niger Delta region. Although incineration of gas is not as visibly dirty as coal, the concentration of fine particulate matter has been reported within the vicinity of gas power plants in previous studies. But NOx and VOCs emitted from gas plants can also mix to form $PM_{2.5}$ in the atmosphere. Authors have reported that the secondary emission could be more pervasive with public health implication than direct emission of $PM_{2.5}$ into the atmosphere. It is evident in Table 5 that the months of January recorded the highest concentration of $PM_{2.5}$ in all the cities under investigation. For example, the city of Calabar recorded over 100ppm in the months of January, February and March, but April, May and June recorded significant reduction. The case is the same in all the cities across all the months where the same pattern reported in previous tables is replicated.

Table 6: Mean CH_4 Concentration in PPM in the vicinity of gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	190.6	188.6	186.6	192.6	184.6	183.8
February	181.3	179.3	177.3	183.3	175.3	174.4
March	171.3	170.9	168.9	175.7	166.9	166.1
April	166.3	164.3	162.3	168.7	160.3	159.4
May	160.6	158.6	156.6	162.6	154.6	153.8
June	154.9	152.9	150.9	156.9	148.9	151.6

The data presented in Table 6 show the concentration of methane from the vicinity of gas power plant in the cities under investigation. The pattern of distribution of CH_4 in all the months show similarity with previous presentation where there is gradual reduction of pollutant loads with progression into the year. A cursory look at the concentration of pollutant in the area shows that Uyo recorded more loads of CH_4 in the month of January, but the subsequent months show significant reduction and the lowest concentration is recorded in June with 152.9mm. The case is the same in Benin, Warri, Calabar and Port Harcourt where January recorded the highest concentration of CH_4. It is inferred that the pattern is linked to influences of meteorological parameters in the cities.

Table 7: Mean VOC Concentration in PPM in the vicinity of gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	35.2	33.9	32.5	36.5	34.0	33.3
February	26.5	25.2	23.8	27.8	25.3	24.6
March	18.2	17.4	16.0	20.6	17.5	16.8
April	16.1	14.7	13.4	17.7	14.9	13.3
May	14.9	13.6	12.2	16.2	13.7	11.2
June	16.2	14.9	13.6	17.6	15.1	13.7

The data presented in Table 7 show VOC concentration in PPM in the vicinity of the gas power plants in the different cities under investigation. VOCs can be released from organic and inorganic materials into the atmosphere and could have deleterious short- and long-term effects on human health, plants, animals and the

stability of the environment. The pattern of VOC concentration in the atmosphere show that the month of January and February which is the peak of the dry season in the Niger Delta region recorded the highest concentration of VOCs in the cities. But there is a gradual reduction as the year progresses. It is also evident that the month of June recorded the lowest concentration of VOCs which can be linked to high precipitation and deposition which reduce the loads retained in the atmosphere.

Table 8: H_2S Concentration in PPM in the vicinity of the gas power plants in the study area

Months	Port Harcourt	Uyo	Calabar	Yenagoa	Benin	Warri
January	4.6	4.5	4.4	4.7	4.7	4.5
February	4.4	4.3	4.2	4.5	4.5	4.3
March	4.2	4.1	4.0	4.4	4.4	4.2
April	4.1	4.0	3.9	4.2	4.2	4.0
May	3.7	3.6	3.5	3.8	3.8	3.6
June	3.7	3.6	3.5	3.8	3.8	3.7

The data presented in Table 8 show the concentration of hydrogen sulphide (H_2S) around the vicinity of gas power plant in the cities under investigation. H_2S is colourless, poisonous, corrosive and flammable. But the trace amount in the atmosphere could have the characteristic of foul stench like rotten egg. Though discovered in 1777, it has been investigated to expose the public health consequences in recent years. The concentration of H_2S in the cities under investigation show similar pattern with previous presentations across the different months. For example, all the cities recorded the highest concentration of H_2S in the month of January, but there is a gradual reduction as the year progresses. Expectedly, the month of June recorded the lowest concentration of H_2S in the region.

3.1 Spatial variation and distribution of air pollutants in the study area

The spatial variation and distribution of air pollutants such as CO, NO_2, O_3, SO_2, H_2S, CH_4, $PM_{2.5}$, and VOC in Port Harcourt is presented in Figure 1. It is obvious that concentration of pollutant loads is a function of distance as significant reduction of pollutant loads with distance from the gas power plants is observed in Port Harcourt. For example, the zone between 0 – 200m recorded 300ppm of carbon monoxide in Port Harcourt, which is slightly different from what obtain at 400m, but the significant reduction is noticeable at 600m away from the gas plant where the CO concentration reduced to 250 ppm, the concentration reduced to 200ppm at 1000mm. it is also shown in the Figure 1 that the concentration of NO_2 reduces with distance from the gas plant in Port Harcourt city. The zone between 0 – 200m recorded 250ppm, but there is a slight reduction at 400mm where less than 250ppm of NO_2 but more than 200 is recorded. Evidently, there is a reduction to less than 200ppm at 1000m away from the gas plant which show the role of distance in the dispersion and retention of pollutant from source in the atmosphere. The changes in the dispersion and atmospheric retention of O_3 is more abrupt, for example, the zone between 0 – 200mm recorded 190 ppm, while 400m away from the gas plant recorded 190ppm but there is a significant reduction at 600m and 1000m where 170ppm and 160pmm are recorded respectively. Curiously, there is evenness in the spread of SO_2 in Port Harcourt city given that 0 – 200m and the point 1000m recorded 0.1ppm. The distribution of $PM_{2.5}$ show that distance influences the load in the atmosphere as the zone between 0 – 200m recorded 120ppm, with a slight reduction at 400m while at 1000m there was a reduction below 100 ppm. The case for CH_4 is different with significant reduction with distance from the source. For example, the zone between 0 – 200m recorded over 185ppm which is slightly different at 400m, but the difference between 0 – 200m and 1000m is very conspicuous given that 155ppm is recorded at 1000m. The concentration of VOCs in Port Harcourt show variation at different intervals from the gas plants, the zone between 0 – 200m recorded over 25ppm with slight reduction to less than 25ppm at the interval of 400m. The case is very different at 1000m where less than 20ppm is recorded. This is also similar to the case of H_2S, though there is a slight variation between 0 – 200m and the 400m, but there is a remarkable difference in the concentration of H_2S. The zone between 0 – 200m recorded 5ppm which slightly reduced to 4.5ppm, but a significant reduction to less than 3.5ppm at the interval of 1000m.

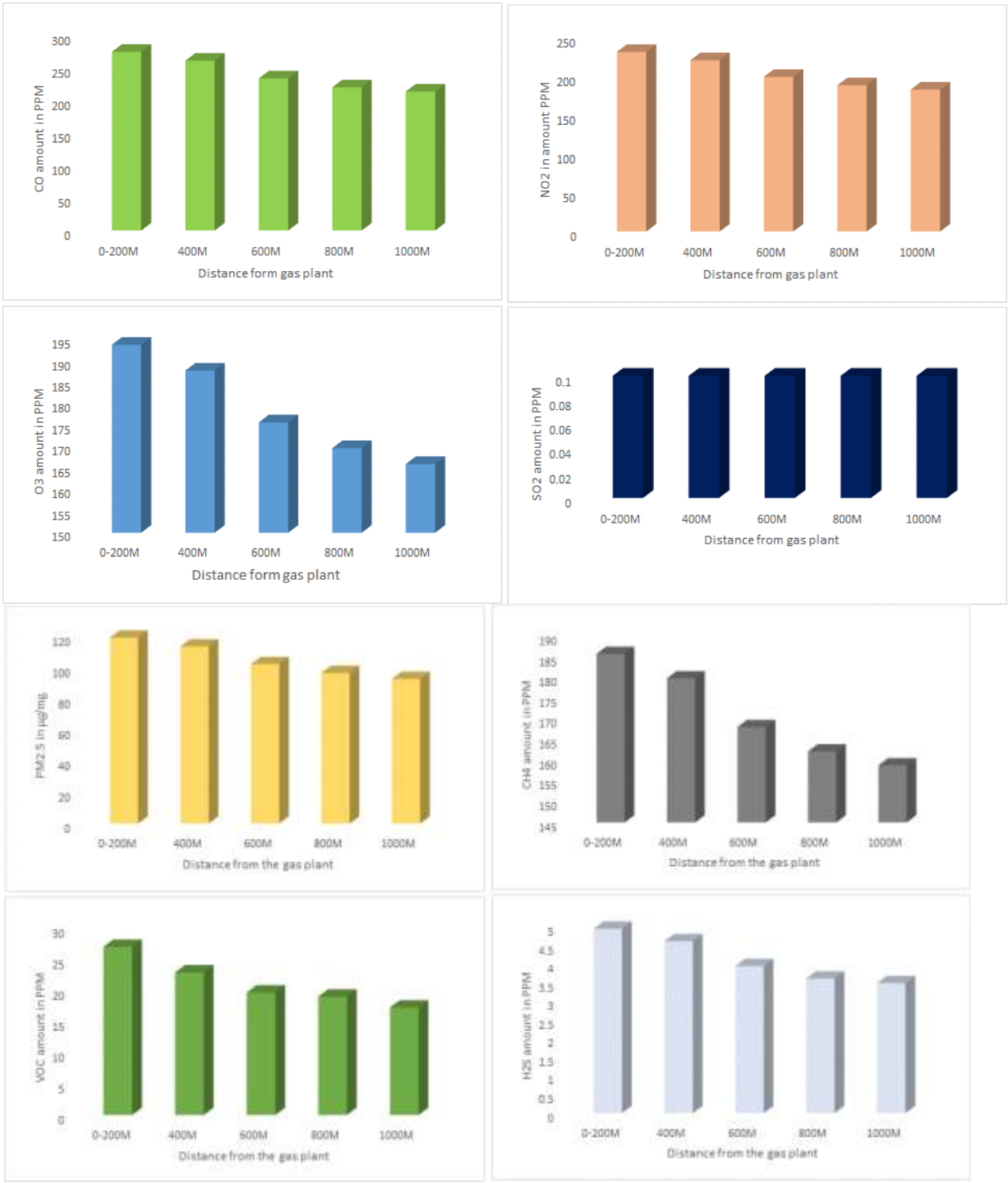


Figure 1: Spatial distribution of Pollutants in the Vicinity of Gas Plants in Port Harcourt

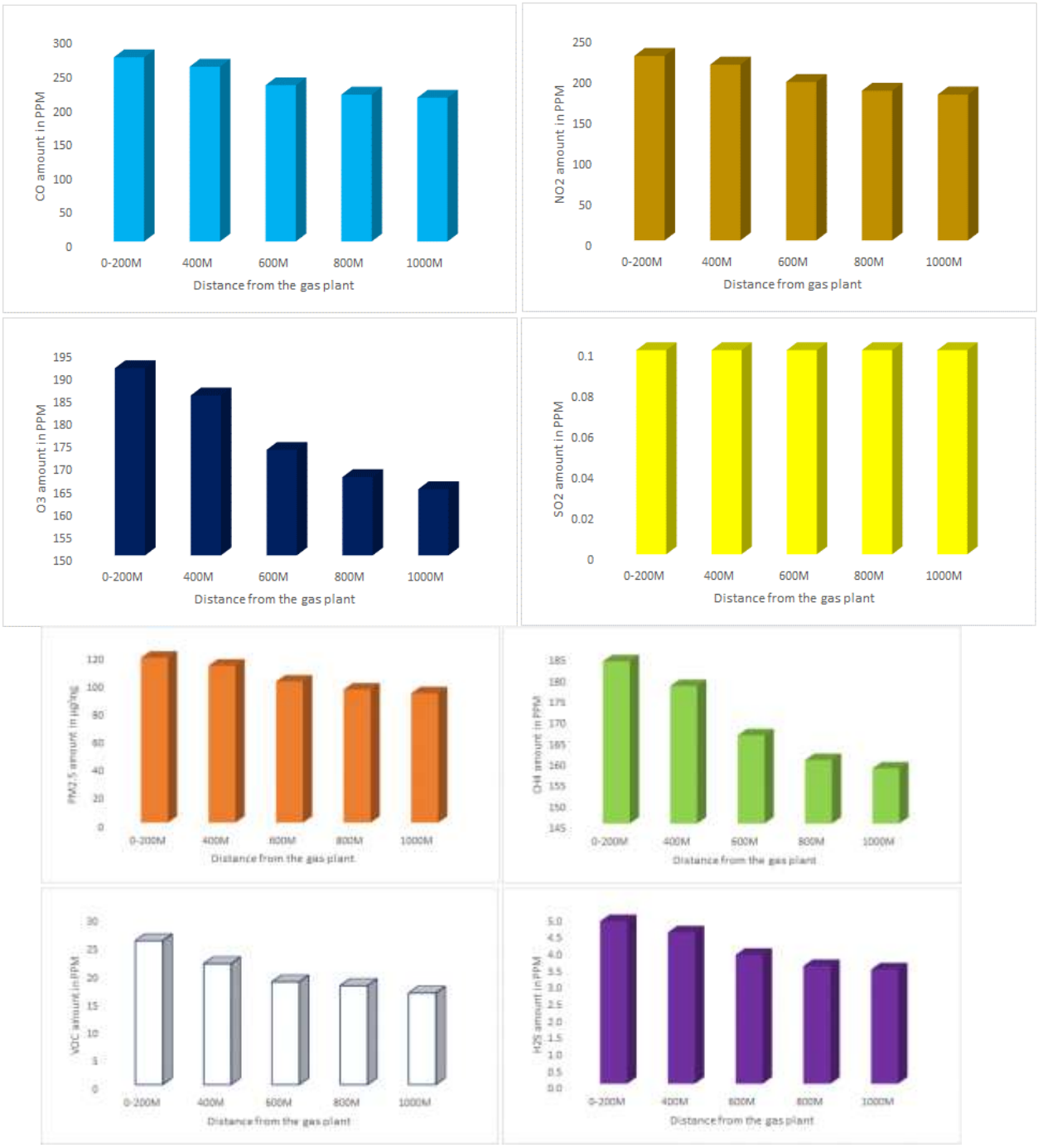


Figure 2: Spatial distribution of Pollutants in the Vicinity of Gas Plants in Uyo

The data presented in figure 2 show the spatial distribution of CO, NO_2, O_3, SO_2, H_2S, CH_4, $PM_{2.5}$, and VOC in Uyo. The concentration of CO shows slight reduction at different intervals from the gas plant. The zone between 0 – 200m show over 250ppm while less than 200ppm is recorded at the interval of less than 1000m.The case is similar for NO_2 where the zone between 0 – 200m recorded 250ppm, slightly less than 250ppm at the interval of 400m and above 150ppm at 1000m. Similar case is recorded for the concentration of O_3 in Uyo where the zone between 0 - 200m recorded 195ppm with a reduction to 185ppm at the interval of 400m. The reduction is more significant at 1000m with less than 165m. The concentration of SO_2 from gas plant in Uyo recorded uniformity across the different calibrated distances with 0.1ppm. The data presented in figure 2 show the distribution of pollutant loads across different distance interval from gas plant in the city of Uyo. The concentration of $PM_{2.5}$ show gradual reduction in concentration across the different calibrated intervals. The zone between 0 – 200m recorded the highest concentration with 120ppm which is expected given the closeness to the gas plants. But there is a slight reduction at 400m where less than 120ppm is recorded whereas the distance at

1000m recorded slightly above 80ppm. The case for CH_4 is different in terms of the pattern of changes as the reduction is more significant. For example, the zone between 0 – 200m recorded 185ppm, but at the interval of 400m, there is a reduction in the concentration of methane. This is more visible at the interval of 1000m where less than 100ppm is recorded. The case for VOCs is also similar to other pollutants where the area between 0 – 200m recorded above 25ppm, less than 25ppm at 400m and less than 20ppm at the interval of 1000m. The concentration of H_2S also showed remarkable and gradual reduction in the concentration across different calibrated distances. The zone between 0 – 200m recorded 5.0ppm, 4.5ppm at 400m, 4.0ppm at 600m, 3.5ppm at 800m and 3.9 at 1000m.

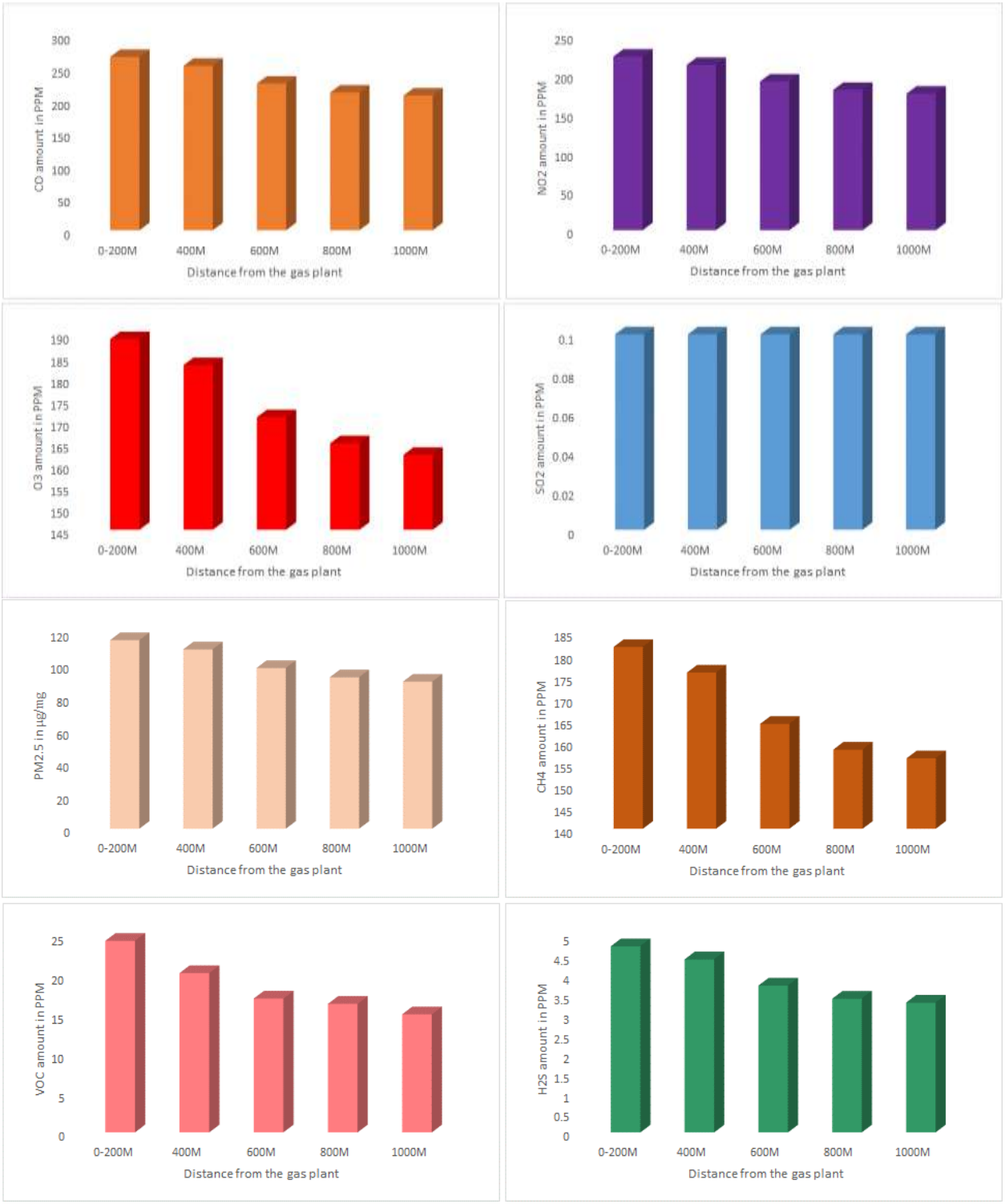
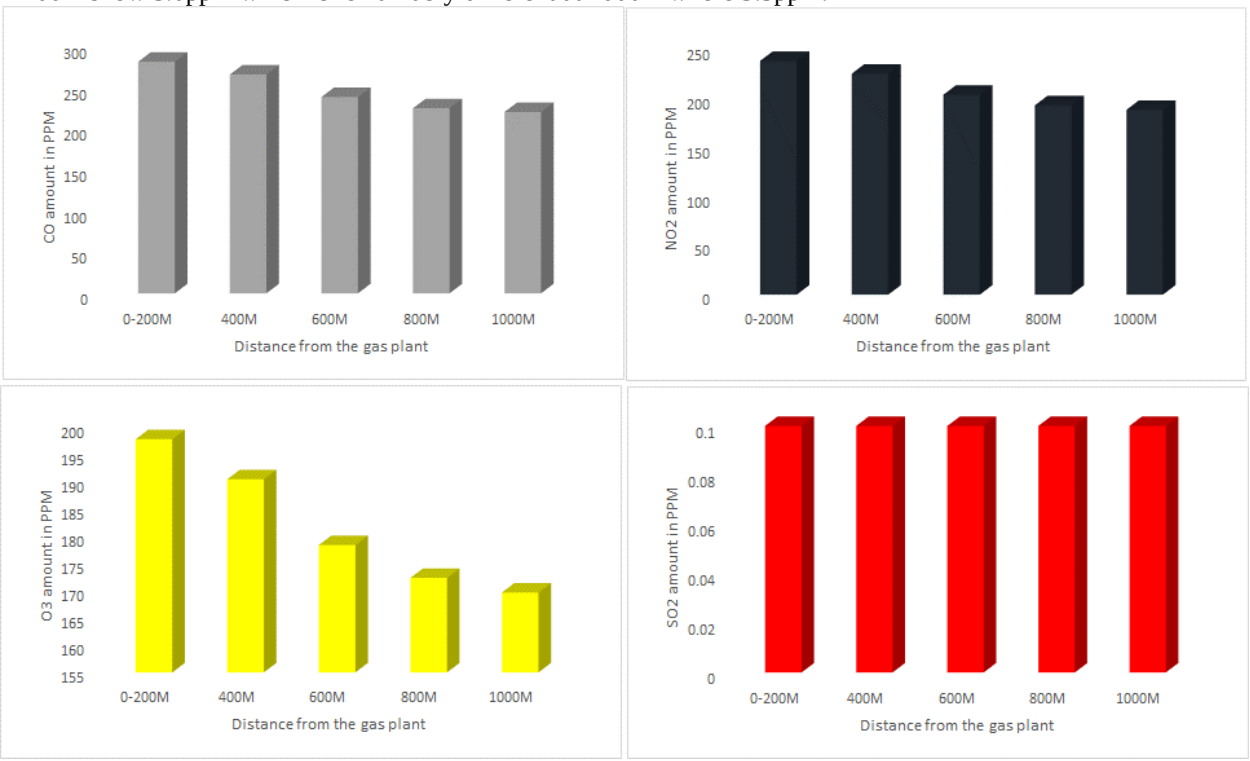


Figure 3: Spatial distribution of Pollutants in the Vicinity of Gas Plants in Calabar

The data presented in figure 3 show the distribution of pollutant from gas plant in Calabar. The outlook of the data show similarity with previous presentation where gradual and significant reduction of pollutant load is recorded with distance from the source. For example, the zone between 0 – 200m recorded more than 250ppm for CO, but there was a slight reduction at 400m at 250ppm, less than 200ppm at 600m, and slightly less than 200ppm at 1000m. The case is the same for NO_2 where there is a visible reduction in concentration across the different calibrated distance. The concentration of O_3 show that the area closer to the gas plant (0 – 200m) is 190ppm, 185ppm for 400m, 170ppm for 600m, 165ppm for 800m and 160ppm for 1000m. Curiously, similar to previous presentation, there is evenness in the concentration of SO_2 where all the calibrated distances showed the same level of concentration. The zone between 0 – 200m recorded $PM_{2.5}$ concentration of 120ppm, but there is a slight reduction at 400m with less than 120ppm, 100ppm at 800m, the interval at 800m and 1000m recorded less than 100ppm respectively. The trajectory is different for the distribution of CH_4 where the zone between 0 – 200m where 185ppm, 175ppm for 400m, 165ppm for 600m, 155ppm and less than 155ppm at 1000m. The concentration of VOCs also showed significant reduction in the concentration and dispersion across different intervals, for example, the zone between 0 – 200m show recorded 25ppm, 20ppm at 400m, and less than 20ppm at 600 to 1000m. The spread of H_2S show significant changes across different intervals. For example, the zone between 0 – 200m show 5.0ppm which is remarkably different at 1000m where 3.5ppm.



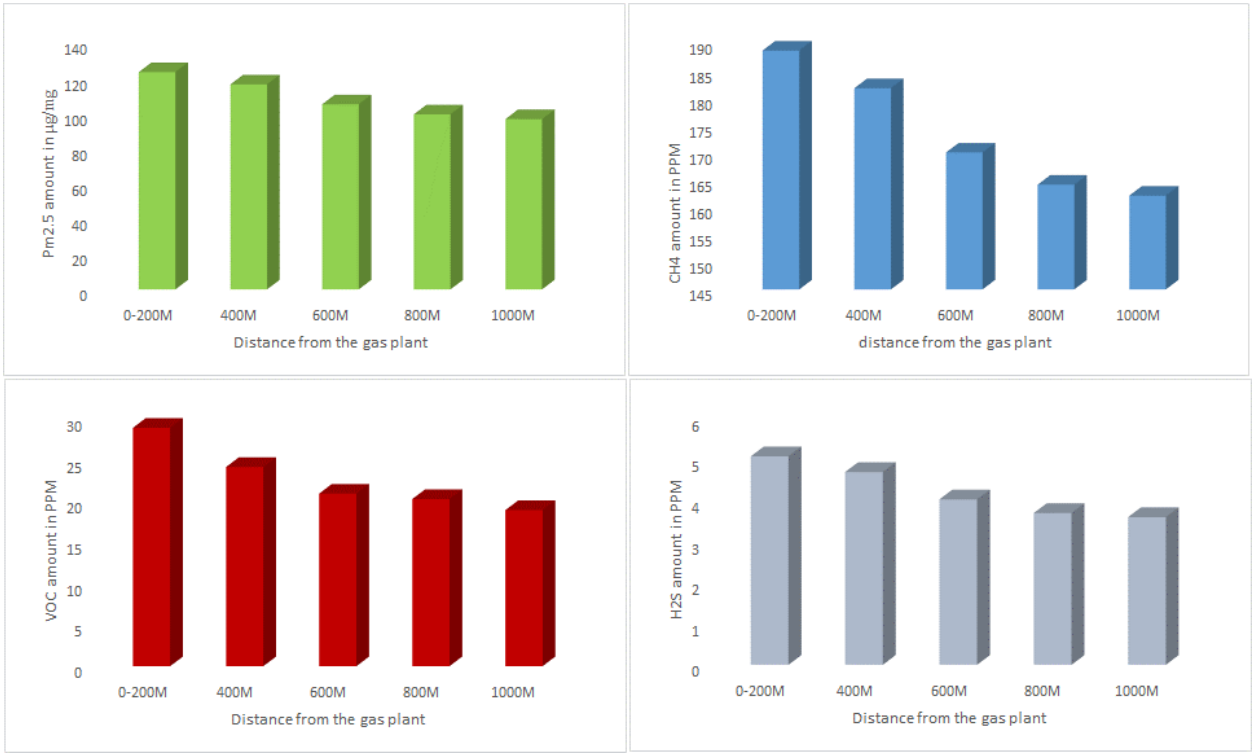


Figure 4: Spatial distribution of Pollutants in the Vicinity of Gas Plants Yenagoa

The concentration of pollutant across different distance intervals from the gas plants in Yenagoa is shown in figure 4. The concentration of CO at 0 – 200m show the concentration of 300ppm, 250ppm at 400m, and less than 250ppm at the interval of 600m, 800m and 1000m. The concentration of NO_2 show that the zone from 0 – 200m recorded 250ppm, 200ppm at 400m, and the area from 600m to 1000 recorded less than 200ppm of SO_2. The spread of ozone at different intervals show visible variation in the concentration of ozone, the area between 0 – 200m recorded 200ppm which slightly reduced at 400m with 190ppm. The reduction was more abrupt at 600m, 800m and 1000m where less than 170ppm was recorded. The concentration of SO_2 is similar to previous reports in this study where the spread is even `with 0.1ppm. The data presented in figure 4.8 show the variation in the concentration of pollutant across different intervals in Yenagoa. The concentration of $PM_{2.5}$ show slight and gradual reduction with distance from the source. For example, the area between 0 – 200m show the concentration of 120ppm which reduced slightly at the interval of 400m. The interval between 600m to 1000m showed significant reduction in the concentration of $PM_{2.5}$. This trend is replicated for methane where the area closer to the gas plant which is between 0 – 200m recorded the concentration of 190ppm of CH_4, but a significant reduction is seen at 1000m where less than 165ppm is recorded. The case for VOCs is not also different; the area close to the gas plant had more retention of VOCs with 30ppm, but the case at the interval of 1000m was different at less than 20ppm. The case of the concentration of H_2S show more concentration close to the gas plant with slightly above 5ppm, but there is a visible reduction at the intervals of 400m, 600m, 800m and 1000m.

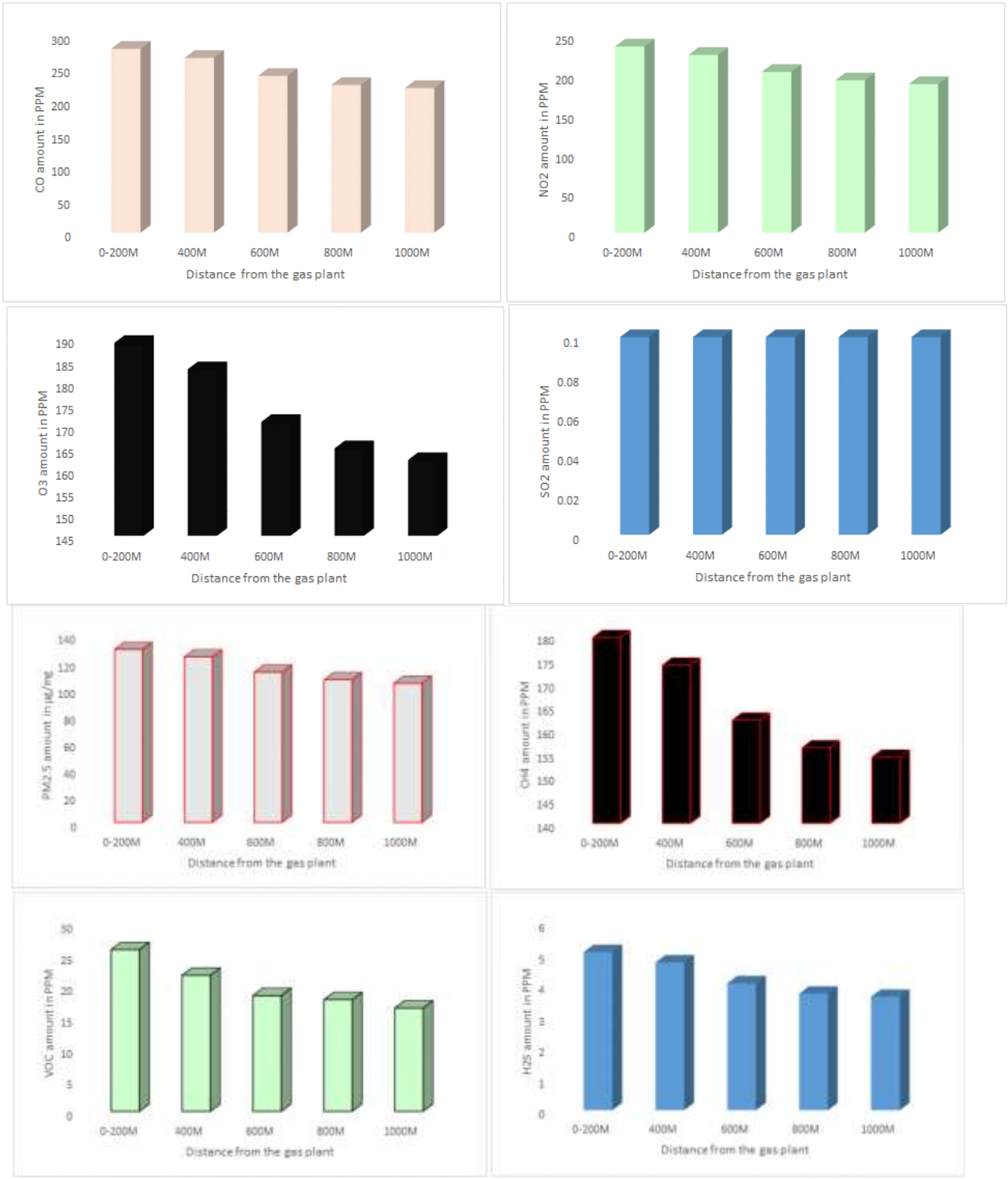


Figure 5: Spatial distribution of Pollutants in the Vicinity in Benin

The data presented in figure 5 show the concentration pollutants from gas power plant in Benin. Evidently, there is a reduction in pollutant load with distance from the source. The amount of CO retained in the atmosphere from 0 – 200m is 300ppm, 250ppm at 400m and less than 250ppm at 600m, 800m and 1000m respectively. The same pattern is replicated in the concentration of NO_2 where the areas close to the source recorded more concentration. Ozone concentration between 0 to 200m show 190ppm, 185ppm at 400m, 170ppm at 600m, and less than 165ppm at 800m and 1000m. Curiously, the concentration of SO2 recorded uniform concentration across all the intervals from the gas power plant in Benin City. The concentration of $PM_{2.5}$ show that the area from 0 – 200m recorded 140ppm, less than 140ppm at 400m, 120ppm at 600m, less than 120ppm at 800m and 1000m. This pattern is also replicated for the concentration of methane where the area close to the gas

power plant between 0 – 200m recorded more than 180 ppm, which is slightly different from what was recorded at the interval of 400m. More reduction is seen at the interval of 600m, 800m and 1000m where less than 160ppm is recorded. The concentration of VOCs also show more concentration close to the source given that the area between 0 – 200m recorded more than 25ppm, evidently, figure 5 show that there is a gradual reduction in the concentration of VOCs as distance increases from the source. This pattern is seen in the concentration of H_2S where the area close to the source also recorded the highest concentration.

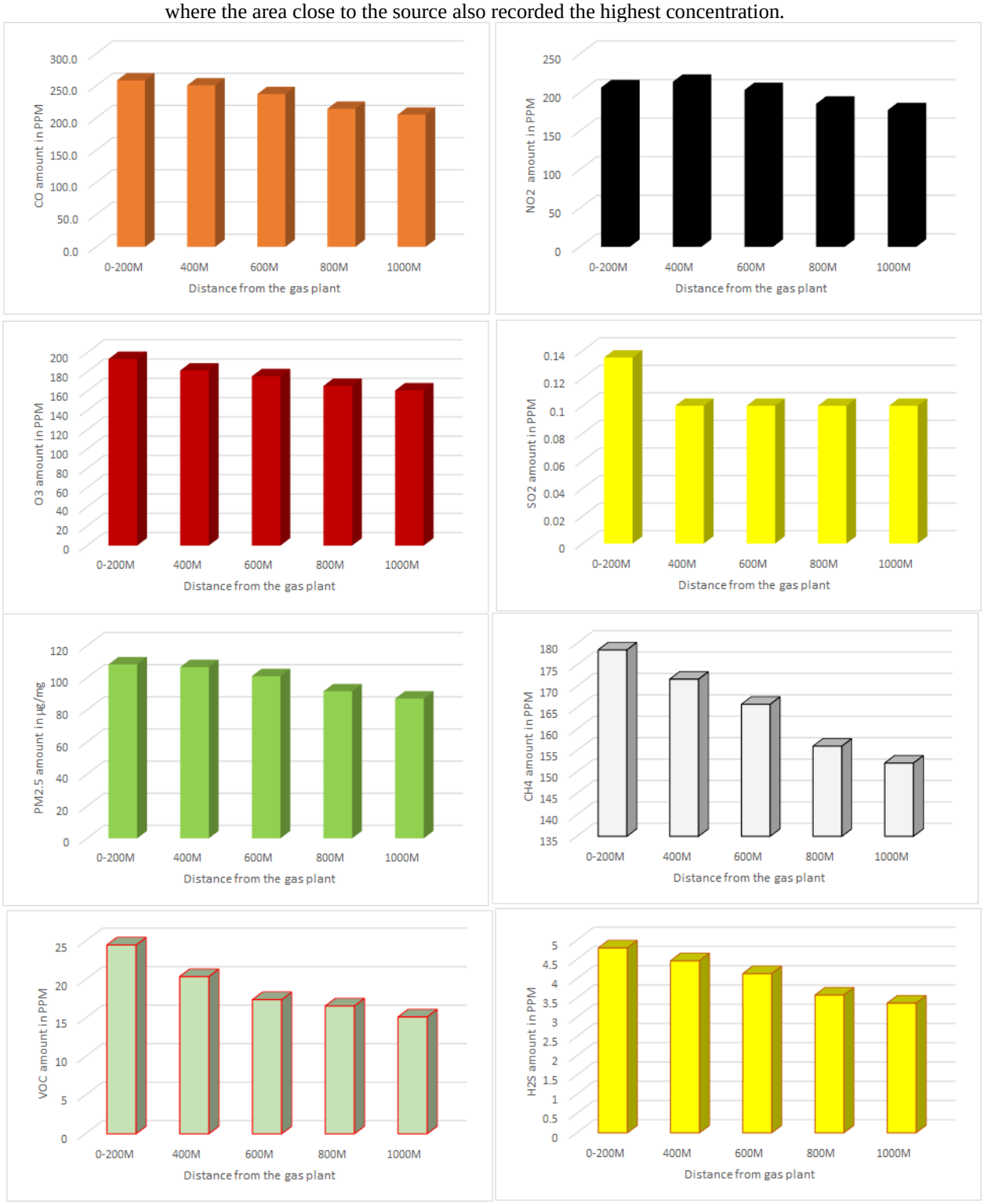


Figure 6: Spatial distribution of Pollutants in the Vicinity in Warri

The data presented in figure 6 show the distribution of pollutants across the different calibrated distance from the gas plant in Warri. The CO concentration between 0 – 200m is slightly above 250ppm and below 250ppm at 400m interval. Evidently, the changes across the different intervals for the concentration of CO is not very significant. The case is the same in the loads of NO_2, and O_3 where the changes is not significant. But the concentration of SO_2 showed marked variation given that the area between 0 – 200m recorded very high load with 0.14ppm, which is conspicuously different from the intervals of 600m, 800m and 1000m that recorded the same amount. It is obvious that the concentration of $PM_{2.5}$ did not show significant change between 0 to 400m, but there is reduction in $PM_{2.5}$ is visible at the interval of 1000m. The case for methane is very conspicuous as there is a marked reduction in concentration across the different distances. For example, the area between 0 – 200m recorded 180ppm while the interval of 1000m recorded less than 150ppm. The distribution of VOCs shows that the area close to the gas plant is more polluted with 25ppm and there is a significant reduction with distance from the power plant. The concentration of H_2S show slight changes in concentration 4.5ppm between 0 – 200m and less than 3.5ppm at 1000m.

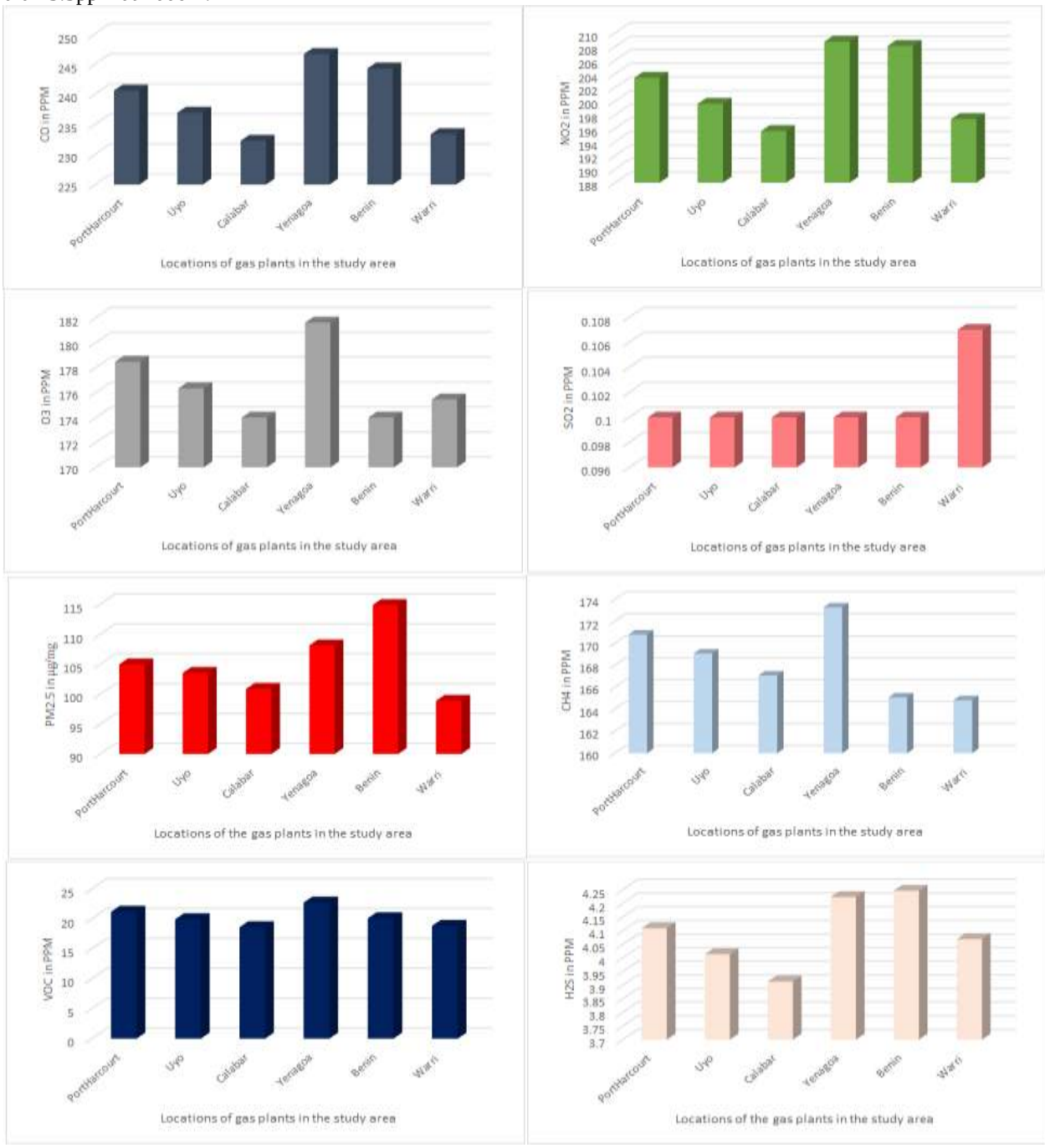


Figure 7: Spatial distribution of pollutants in the study area

In figure 7 the accumulated concentration of pollutants from the location of gas plants in the different cities in the region under investigation are shown. The concentration of CO in Yenagoa is higher in the region with 245ppm which is slightly different from the CO in Benin. Calabar recorded the lowest concentration of CO in the region with less than 235ppm. The concentration of NO_2 in Yenogoa and Benin is also higher than the case in other cities in the region. Like what obtained for CO, Calabar also recorded the lowest concentration of NO_2 with less than 196ppm. The concentration of O_3 is higher in Yenagoa with 182ppm, less than 180ppm in PH. Calabar and Benin recorded the lowest concentration of O_3 in the region. Curiously, Warri recorded the highest concentration of SO_2, but other cities in the region had uniform load of SO_2. $PM_{2.5}$ show the highest concentration in Benin with 115ppm, and slightly below the 110ppm in Yenagoa. The lowest concentration of $PM_{2.5}$ is seen in Warri. The case of CH_4 is different given that Yenagoa recorded the highest concentration at 172ppm, Warri and Benin recorded the lowest concentration of Ch_4. The concentration of VOCs is highest in Yenagoa with over 20ppm, 20ppm in Port Harcourt and less than 20ppm in Warri. Benin recorded the highest concentration of H_2S with 4.2ppm, slightly different from the case of Yenagoa with 4.15ppm. The case in Calabar is lowest with 3.85ppm.

Table 9: ANOVA summary of the spatial variation in atmospheric pollutants across the study area

	Mean values							
Pollutants	**Port Harcourt**	**Uyo**	**Calabar**	**Bayelsa**	**Benin**	**Warri**	**F-values**	**Sig**
CO (PPM)	240.6000	236.9333	232.2667	246.6667	244.2667	233.3644	13.2310	**0.00
NO_2 (PPM)	203.3944	199.5778	195.5778	208.7111	208.0778	197.3389	10.0014	**0.02
O_3 (PPM)	178.4556	176.3222	173.9889	181.5889	173.9889	175.4378	08.2314	**0.05
SO_2 (PPM)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1070	1.0211	0.21
CH_4 (PPM)	170.8200	169.0867	167.0867	173.2867	165.0867	164.8411	06.1321	**0.04
VOC (PPM)	21.1844	19.9344	18.6011	22.7344	20.1011	18.8311	17.2131	**0.00
H_2S	4.1089	4.0133	3.9133	4.2233	4.2467	4.0689	09.3112	**0.01
$PM_{2.5}$ ($\mu g/m^3$)	104.9556	103.5222	100.8556	108.1222	114.8556	98.8900	15.8013	**0.00

****significant at 5% alpha level, n=182**

Table 9 presents the analysis of variance results which was computed to unfurl the differences in the concentration of pollutant loads from gas power plant in different cities in South-South, Nigeria. The mean difference for the concentration of CO in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri are significant at $P<0.05$ level. F= 13.2310, sig = 0.00, since the significant value is 0.00 which is below 0.05 *(p* value), it indicates that there is a statistically significant difference in the spatial variation of carbon monoxide in the cities under investigation. The mean difference for the concentration of NO_2 in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri) is significant at $P<0.05$ level. F= 10.0014, sig = 0.02. The mean difference for the concentration of O_3 in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri) is significant at $P<0.05$ level. F= 08.2314, sig = 0.05. The mean difference for the concentration of SO_2 in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri is significant at $P>0.05$ level. F= 1.0211, sig = 0.21. The mean difference for the concentration of CH_4 in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri) is significant at $P<0.05$ level. F= 06.1321, sig = 0.04. The mean difference for the concentration of VOC in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri) is significant at $P<0.05$ level. F= 17.2131, sig = 0.00. The mean difference for the concentration of H_2S in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri is significant at $P<0.05$ level. F= 09.3112, sig = 0.01. The mean difference for the concentration of PM2.5 in the six cities (Port Harcourt, Uyo, Calabar, Bayelsa, Benin and Warri) is significant at $P<0.05$ level. F= 15.8013, sig = 0.00. The result of the analysis revealed that a significant difference exists in the spatial variation of CO, NO_2, O_3, CH_4, VOC, H_2S and $PM_{2.5}$ across the cities whereas no significant difference in the spatial variation of $SO_2$was observed in the cities under investigation. There is overwhelming consensus in the literature that the production of electricity from gas powered plant emits toxic pollutants into the atmosphere in developed and developing countries. This study has reported the quantum of pollutant loads within the vicinity of the gas power plant in the southern part of Nigeria. Evaluation of air pollutants within the vicinity of gas power plant in the southern region of Nigeria show concentration above the permissible limit of the World Health Organization (WHO). Data reported in Port Harcourt, Uyo, Calabar, Yenagoa, Benin and Warri show that the area around gas power plants are heavily polluted, but the pollution vary across different intervals from the source. The reports of the WHO show that power plants have the potential to emit 200 tons of fine particulate matter, over 300 tons of nitrogen oxides, and 100 tons of VOCs annually which is consistent with the results of this study. Similar reports by Sillman (2000) show that there is less information and documentation about the quantum of ozone that is

generated around coal and gas power plant in air pollution literature given that the emissions from coal power plants and gas power plants are erroneously generalized in many studies. The study conducted by Sillman (2000) reported the use of series of aircraft-based measurements of O_3, NOx and SO_2 within the vicinity of gas power plants during different meteorological conditions favourable for the formation of O_3. The study found that O_3 production efficiency per NOx associated with large power plants as much higher than O_3 in urban and small point sources. Gouw *et al*. (2021) reported that 32% of the U.S. natural gas consumption in 2011 was for electric power, 34% for industrial, 13% for commercial and 20% for residential use which indicates that a significant amount of gas is invested to generate electric with attendant consequences for the environment and public health. It is reported that the concentration of methane, carbon monoxide, ozone, nitrogen and sulphur oxide, and $PM_{2.5}$ are high and portends severe public health consequences. Gouw *et al*. (2021) contend that the use of natural gas power plant has increased over the last two decades, but estimation of the public risk is still not sufficiently documented in developed and developing countries. The authors recognized emission of CO_2, NOx and SO_2 beyond the limits of the WHO. Gouw *et al*. (2021) contend that the switch from coal to natural gas has reduced the emissions from power generation plants, but the emission from gas power plants is also pervasive. Gas power plants in Nigeria are disproportionately located across different states in the southern part of Nigeria due to the availability of natural gas. The pollution reported from the gas power plants in this study could have public health impacts over wider regional areas beyond the vicinity of the plants. This study reported variation in the amount of gas power plants across different cities in the southern part of Nigeria. The reports on the dispersion and distribution of pollutants across different intervals from the gas power plants and across different states is consistent with extant literature. This study revealed that the areas close to the gas power plant between 0 – 200m is more exposed to pollutants from the plant, and there is a gradual but significant reduction in the amount of pollutant concentration in the atmosphere with increase in distance from the gas power plant. However, the results of the study suggest that the concentration of pollutants at 1000m from the gas location is also above the permissible limits of the WHO, which exposes the flora fauna and the residents involved in different occupational activity in the zone between 0 – 1000m to risk. Previous studies have reported that the health impacts of the emissions from gas power plants could extend to hundreds of miles from the power plant stack (Gouw *et al*., 2021). Some of the health risks that have been reported are pre-term births and respiratory diseases. Transition from coal to gas has seen 49% of the in-state electricity generation from natural gas in California in 2016 but burning natural gas emits nitrogen oxides, which can contribute to the formation of ozone and particulate matter.

IV. CONCLUSION AND RECOMMENDATIONS

This study aligns with overwhelming scientific consensus that gas power plant is a major source of pollution with significant pollutant loads within the vicinity of gas power plants. It concludes that there is a conspicuous variation in the concentration of pollutant across different calibrated distances from the gas plant location showing that distance is a critical factor in the dispersion of pollutant. All the pollutants evaluated showed that the areas closer to the gas plant (0 – 200m) have higher concentration of pollutants. Also, significant difference in the concentration of pollutant was reported between 200m and 1000m across all the cities. The pollutant loads within the vicinity of the gas power plant varies across different months, and also varies at different calibrated distances. It is very clear from the reports of this investigation that the pollutant concentration is very dynamic. But the concentration of SO_2 was observed to be constant throughout all the months and in all the cities under investigation. From the findings of this study, it was recommended that the National electricity regulation commission (NERC) should institutionalize the conduct of environmental impact assessment; periodic environmental auditing for tracking of pollutant loads should be prioritized and investment in alternative energy sources.

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