

Air Quality Changes and Geospatial Dispersion Modeling in the Dry Season in Port Harcourt and its Environs, Niger Delta, Nigeria

Antai, Raphael Eduk¹; Osuji, Leo C. ²; Obafemi, Andrew A.³and Onojake, Mudiaga C.⁴

¹Institute of Natural Resources, Environment and Sustainable Development, University of Port Harcourt, Choba, Nigeria.

¹Inter - Environments Limited, Rumuodara, Port Harcourt, Nigeria.

^{2,4}Department of Pure and Industrial Chemistry, University of Port Harcourt, Choba, Nigeria.

³Department of Geography and Environmental Management, University of Port Harcourt, Choba, Nigeria.

Corresponding Author: e-mail: rantai_ralph@yahoo.com. Phone no: +2348037419259, +2349035225368

Abstract— This work is a geospatial analysis of air dispersion for the purpose of establishing the concentration trend of air pollutants within the study area. Pollutants of consideration are SO₂, NO₂, CO, H₂S, NH₃, VOCs, CH₄, PM_{2.5}, PM₁₀, TSP, while area of interest are Port Harcourt, Obio/Akpor, Eleme, Oyigbo, Etche and Ikwerre Local Government Areas. This is an approach to identify the hotspots and how they are dispersed to impact on other parts of the region. This is an attempt to predict future pollution trends, but an approach to gain understanding of the general scenarios of air quality status and how they impact on receptor areas some kilometers away from the hotspot. Pollution hotspots are locations where emissions from specific sources such as water or air pollution may expose local populations to elevated health risks and environment degradation. It indicates areas with strong pollution sources and high industrial activities of adverse effect

Keywords— Air Quality Changes, Dry Season, Geospatial, IPPC, Hotspots, Modeling.

I. INTRODUCTION

Pollution is defined by the European Union 1996 Council Directive on Integrated Pollution Prevention and Control (IPPC) as “the direct or indirect introduction as a result of human activity, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment”. Inorganic and organic air pollutants cause negative health and environmental effects such as respiratory ailments, premature

deaths. Air pollution-related deaths worldwide are estimated to be up to 2 million per annum.

Other environmental consequences of air pollution include acidification of soil and water and loss of plant and animal life. Air quality assessment studies in Nigeria have focused mainly on urban centres where industrial processes, domestic activities and traffic congestion constitute major sources of air pollution.

Most of these studies are independent as there are no systematic measurements of air quality public agencies. Meteorological parameters influence aids to drive the air pollutants from the pollutant hotspots to non-sources areas (Antai *et al.*, 2017, Everitt, 1992 and Esplin, 1995). This is the trend that has put man in alert in his own environment since the air has no boundary or barrier from one man to another.

The aim of this research is to assess changes in existing physical and chemical characteristic of the air quality and to determine the hotspots and assess the level of concentration of air pollutants dispersion trends in the study area. Results of geospatial analysis and generalized additive models revealed that sources of pollutants in the study areas are both localized in the up-land area and the region around the coastal area.

Description of the Study Area

Location

Port Harcourt metropolis is located between latitudes 4⁰35' and 5⁰30' North and between longitudes 6⁰54' and 7⁰08' East. It covers an estimated area of 1811.6 square kilometer. Port Harcourt, the capital of Rivers State, was established in 1914 by the British colonial administration under Lord

Lugard to meet the pressing economic needs of the Europe the city, which lies at the heart of the Niger Delta, is one of the world's richest wetlands and is bounded on the south by the Atlantic Ocean, to the North by Imo and Abia States, to the East by Akwa Ibom State and to the West by Bayelsa and

Delta States respectively. The spatial coverage of this study extends through beyond in Port Harcourt and its environs, Port Harcourt, Obio/Akpor, Eleme, Oyibo, Ikwerre and Etche Local Government Areas.

Table.1: Sampling Points Key, Description of Sampling Points, Coordinate and Frequency of Monitoring

Sampling Point Code:	Description of Sampling Points	Coordinates	Frequency of Monitoring/Hourly
SP 1	Onne Roundabout by FLT and FOT Signboard	N 04 ⁰ 43'. 207'' E 007 ⁰ 09'. 478''	Morning, Afternoon and Evening
SP 2	Notore Road by Notore Garden Camp, Onne	N 04 ⁰ 44'. 147'' E 007 ⁰ 08'. 526''	Morning, Afternoon and Evening
SP 3	Onne (Trailer park) Junction by East-West Road	N 04 ⁰ 45'. 510'' E 007 ⁰ 09'. 516''	Morning, Afternoon and Evening
SP 4	Port Harcourt Refinery Junction by East-West Road, Alesa	N 04 ⁰ 47'. 066'' E 007 ⁰ 07'. 001''	Morning, Afternoon and Evening
SP 5	Agbonchia by Zina Motel Junction Eleme	N 04 ⁰ 47'. 867'' E 007 ⁰ 07'. 358''	Morning, Afternoon and Evening
SP 6	Eleme Petrochemical (Ndorama gate) Aleto, Eleme	N 04 ⁰ 48'. 744'' E 007 ⁰ 05'. 842''	Morning, Afternoon and Evening
SP 7	Sandfilled Roundabout, Akpajo	N 04 ⁰ 49'. 402'' E 007 ⁰ 05'. 276''	Morning, Afternoon and Evening
SP 8	Okoloma Afam by Afam Power Plant	N 04 ⁰ 51'. 058'' E 007 ⁰ 15'. 088''	Morning, Afternoon and Evening
SP 9	Izuoma Asa by Dominican College	N 04 ⁰ 51'. 458'' E 007 ⁰ 10'. 717''	Morning, Afternoon and Evening
SP 10	Oyigbo by Eke Oyigbo Market	N 04 ⁰ 52'. 561'' E 007 ⁰ 08'. 889''	Morning, Afternoon and Evening
SP 11	Oyigbo Junction by Port Harcourt-Aba Road	N 04 ⁰ 52'. 852'' E 007 ⁰ 07'. 959''	Morning, Afternoon and Evening
SP 12	Shell Flow Station/Location Junction, Umuebulu 4, Etche	N 04 ⁰ 53'. 6107'' E 007 ⁰ 07'. 302''	Morning, Afternoon and Evening
SP 13	Shell Gas Plant, Umuebulu 4, Etche	N 04 ⁰ 53'. 674'' E 007 ⁰ 07'. 129''	Morning, Afternoon and Evening
SP 14	Igbo Etche Junction-Umasikpo, Igbo Etche	N 04 ⁰ 56'. 788'' E 007 ⁰ 04'. 94''	Morning, Afternoon and Evening
SP 15	Eleme Junction by Oilmill Bus Stop	N 04 ⁰ 51'. 267'' E 007 ⁰ 03'. 843''	Morning, Afternoon and Evening
SP 16	Rumukrushi Bus Stop by Rumukrushi Park	N 04 ⁰ 50'. 992'' E 007 ⁰ 03'. 201''	Morning, Afternoon and Evening
SP 17	Rumukrushi Tank by East-West Road	N 04 ⁰ 51'. 859'' E 007 ⁰ 03'. 364''	Morning, Afternoon and Evening
SP18	Eneka Roundabout, Rumu-olukwu, Eneka	N 04 ⁰ 53'. 756'' E 007 ⁰ 02'. 392''	Morning, Afternoon and Evening
SP 19	Artillery Junction by Okporo Road	N 04 ⁰ 50'. 612'' E 007 ⁰ 02'. 298''	Morning, Afternoon and Evening
SP 20	Rumuobiakani Junction by Oginigba/Old Aba	N 04 ⁰ 50'. 208'' E 007 ⁰ 02'. 000''	Morning, Afternoon and Evening

	Road	066''		Evening
SP 21	Rumuomasi in- Between Aba Road Rumuomasi Junction and Old Aba Road	N 04 ⁰ 50'. 236''	E 007 ⁰ 01' 548''	Morning, Afternoon and Evening
SP 22	Rumuodara Junction by East-West Road	N 04 ⁰ 51'. 622''	E 007 ⁰ 01' 776''	Morning, Afternoon and Evening
SP 23	Eliozu Flyover Junction	N 04 ⁰ 51'. 570''	E 007 ⁰ 01'. 307''	Morning, Afternoon and Evening
SP24	Rukpokwu Roundabout	N 04 ⁰ 53'. 447''	E 007 ⁰ 00'. 140''	Morning, Afternoon and Evening
SP 25	Igwuruta Roundabout by Air Port Road	N 04 ⁰ 57'. 400''	E 007 ⁰ 00'. 690''	Morning, Afternoon and Evening
SP 26	Port Harcourt International Air Port Junction/Roundabout Omagwa	N 04 ⁰ 58'. 858''	E 006 ⁰ 56'. 989''	Morning, Afternoon and Evening
SP 27	Greater Port Harcourt in-Between Air Port and Obirikwere Road by H and H Engineering Ltd	N 04 ⁰ 57'. 421''	E 006 ⁰ 56'. 965''	Morning, Afternoon and Evening
SP 28	Aluu Roundabout, Aluu	N 04 ⁰ 56'. 019''	E 006 ⁰ 56'. 547''	Morning, Afternoon and Evening
SP 29	Choba Junction, By Uniport East-West Road	N 04 ⁰ 53'. 917''	E 006 ⁰ 54'. 400''	Morning, Afternoon and Evening
SP 30	Rumuosi Junction by East-West Road	N 04 ⁰ 52'. 951''	E 006 ⁰ 56'. 461''	Morning, Afternoon and Evening
SP 31	Nkpolu Junction by East-West Road	N 04 ⁰ 52'. 158''	E 006 ⁰ 58'. 862''	Morning, Afternoon and Evening
SP 32	Rumuokoro Junction/Roundabout	N 04 ⁰ 52'. 612''	E 006 ⁰ 59'. 855''	Morning, Afternoon and Evening
SP 33	Wimpy Junction by Ikwere Road	N 04 ⁰ 49'. 835''	E 006 ⁰ 58'. 924''	Morning, Afternoon and Evening
SP 34	Location Junction by NTA and Ada George Road	N 04 ⁰ 51'. 137''	E 006 ⁰ 58'. 516''	Morning, Afternoon and Evening
SP 35	Rumuokuta Junction/ Roundabout	N 04 ⁰ 50'. 271''	E 006 ⁰ 59'. 308''	Morning, Afternoon and Evening
SP 36	Rumuigbo by Obiwali Junction	N 04 ⁰ 50'. 843''	E 006 ⁰ 59'. 421''	Morning, Afternoon and Evening
SP 37	Akar Base, Saipem Gate, Rumuolumeni	N 04 ⁰ 46'. 550''	E 006 ⁰ 58'. 013''	Morning, Afternoon and Evening
SP38	University of Education's Gate, Rumuolumeni	N 04 ⁰ 48'. 420''	E 006 ⁰ 56'. 061''	Morning, Afternoon and Evening
SP 39	Eagle Island Gate by Illoabuchi T Junction	N 04 ⁰ 47'. 164''	E 006 ⁰ 58'. 806''	Morning, Afternoon and Evening
SP40	Agip Junction by Agip Flyover	N 04 ⁰ 48'. 825''	E 006 ⁰ 59'. 018''	Morning, Afternoon and Evening
SP41	Mile 3 by Mile 3 Park	N 04 ⁰ 48'. 158''	E 006 ⁰ 59'. 409''	Morning, Afternoon and Evening
SP 42	Illoabuchi by Ukuoto Street, Mile 2	N 04 ⁰ 47'. 451''	E 006 ⁰ 59'. 279''	Morning, Afternoon and Evening
SP 43	Ikoku by Eko Bank	N 04 ⁰ 48'. 043''	E 006 ⁰ 59'. 698''	Morning, Afternoon and Evening
SP 44	Waterline Junction by Olu Obansanjo/Port Harcourt Aba Road	N 04 ⁰ 49'. 016''	E 007 ⁰ 00'. 562''	Morning, Afternoon and Evening

SP 45	Garrison Junction by Ogunabali/Port Harcourt Aba Road	N 04 ⁰ 48' 335'' E 007 ⁰ 00'. 566''	Morning, Afternoon and Evening
SP 46	Rumuola Junction/Flyover by Port Harcourt Aba Road	N 04 ⁰ 49'. 945'' E 007 ⁰ 00'. 315''	Morning, Afternoon and Evening
SP 47	Woji by Woji Town Hall	N 04 ⁰ 49'. 820'' E 007 ⁰ 03'' 018''	Morning, Afternoon and Evening
SP 48	YKC Junction, Woji	N 04 ⁰ 49'. 338'' E 007 ⁰ 03'. 228''	Morning, Afternoon and Evening
SP 49	Elelenwo by Woji T-Junction/Health Center	N 04 ⁰ 49'. 807'' E 007 ⁰ 04'. 279''	Morning, Afternoon and Evening
SP 50	Trans-amadi by Slaughter Junction/ Roundabout	N 04 ⁰ 48'. 760'' E 007 ⁰ 02' 688''	Morning, Afternoon and Evening
SP 51	Gbalajam	N 04 ⁰ 48'. 713'' E 007 ⁰ 04'. 208''	Morning, Afternoon and Evening
SP 52	Mothercat Junction, Trans-amadi	N 04 ⁰ 48'. 304'' E 007 ⁰ 01'. 683''	Morning, Afternoon and Evening
SP53	Trans-amadi Gas Turbine by Total E & P Back Gate	N 04 ⁰ 49'. 003'' E 007 ⁰ 01'. 834''	Morning, Afternoon and Evening
SP 54	Abuloma Jetty Road by Okuru Link Road, Abuloma	N 04 ⁰ 46'. 930'' E 007 ⁰ 03'. 277''	Morning, Afternoon and Evening
SP55	Sansung Roundabout/Junction by Peter Odilli Road	N 04 ⁰ 47'. 728'' E 007 ⁰ 02'. 316''	Morning, Afternoon and Evening
SP 56	Nkpogu Junction, Trans-amadi	N 04 ⁰ 48' 570'' E 007 ⁰ 00'. 994''	Morning, Afternoon and Evening
SP 57	Eastern By Pass Roundabout/Junction	N 04 ⁰ 47'. 583'' E 007 ⁰ 00'. 948''	Morning, Afternoon and Evening
SP 58	Abonnema Jetty by Shell Kidney Island	N 04 ⁰ 46'. 583'' E 007 ⁰ 00'. 315''	Morning, Afternoon and Evening
SP 59	Tombia Extension by Prof Abowie GRA Phase II	N 04 ⁰ 49'. 509'' E 006 ⁰ 59'. 454''	Morning, Afternoon and Evening
SP 60	King Perekule Junction by Evo street GRA Phase II	N 04 ⁰ 49'. 171'' E 007 ⁰ 00'. 070''	Morning, Afternoon and Evening
SP 61	Mile 1 Opposite Isaac Boro Park	N 04 ⁰ 47'. 237'' E 007 ⁰ 00'. 229''	Morning, Afternoon and Evening
SP 62	Rumuibekwe by Gram Diagnostic Laboratory	N 04 ⁰ 50'. 375'' E 007 ⁰ 03'. 003''	Morning, Afternoon and Evening
SP 63	Stadium Road by Mummy B Junction	N 04 ⁰ 49'. 615'' E 007 ⁰ 00'. 930''	Morning, Afternoon and Evening
SP 64	BMSH Junction Old GRA	N 04 ⁰ 46'. 817'' E 007 ⁰ 00'. 905''	Morning, Afternoon and Evening
SP 65	Moscow Road by NNPC/House of Assembly Complex	N 04 ⁰ 46'. 159'' E 007 ⁰ 01'. 166''	Morning, Afternoon and Evening
SP66	Lagos Bus Stop, Town, Port Harcourt	N 04 ⁰ 45'. 697'' E 007 ⁰ 01'. 132''	Morning, Afternoon and Evening
SP 67	UPE Junction, Borokiri, Port Harcourt	N 04 ⁰ 44'. 930'' E 007 ⁰ 02'. 489''	Morning, Afternoon and Evening

SP 68	Nembe Water Side, Port Harcourt	N 0 ⁰ 45'. 500''	E 0007 ⁰ 01'. 361''	Morning, Afternoon and Evening
SP 69	Ibeto Cement Gate, Bundu Ama Estate, Port Harcourt	N 04 ⁰ 44'. 879''	E 007 ⁰ 00'. 379''	Morning, Afternoon and Evening
SP70	Makobar Area, Town, Port Harcourt	N 04 ⁰ 45'. 509''	E 007 ⁰ 00'. 533''	Morning, Afternoon and Evening
SP 71	Agudama Avenue Junction D/Line, Port Harcourt	N 04 ⁰ 48'. 367''	E 007 ⁰ 00'. 166''	Morning, Afternoon and Evening

II. METHODOLOGY

A total number of seventy one (71) sampling points (Table 1) were selected in Port Harcourt and its environs using WHO's (2005) guideline for site selection studies for population density, topography, industrial clusters, and heavy traffic.

All the sampling points selected were geo-referenced using GPS model 76Cx Garmin Global positioning system.

Field observations were carried out visually and recorded in the field notebook. Camera was used to take photographs to show evidence of important features and activities that may be the primary sources of the air pollutants.

Validity/Reliability of Instrument

All the portable in-situ meters for the field air quality and meteorological parameters including noise level measurement were certified calibrated by the manufacturer prior to mobilization to the field data gathering. Quality assurance and control measures were carried out accurately as per the equipment manufacturer's directive and battery were fully charged.

Pollutant Mapping

Concentration levels at each location were mapped out using ArcGIS 10.2 software. The software integrated the spatial air pollutants data from the sampling points within the Port Harcourt and its environs and analyzed them as input variables for graphical presentation to produce curves or contours of air pollutants levels.

III. RESULTS AND INTERPRETATION

Distribution of SO₂ in Study Area in the Dry Season

In the dry season, SO₂ hotspot is visible within Eleme with the highest concentration within 1.10 to 1.18ppm (Figure 1). It occupies an aerial coverage of about 3,725meters radius. It has a larger influence on Port Harcourt, followed by Obio/Akpor and Oyigbo while its minor influence is in Ikwerre as shown in Figure 1. Its least influence is on Etche area. It is predicted that the hotspot will contribute about 0.035ppm to 0.080ppm to the background concentration of SO₂ in parts of Port Harcourt, Obio/Akpor, Oyigbo, Etche and Ikwerre Local Government Areas respectively.

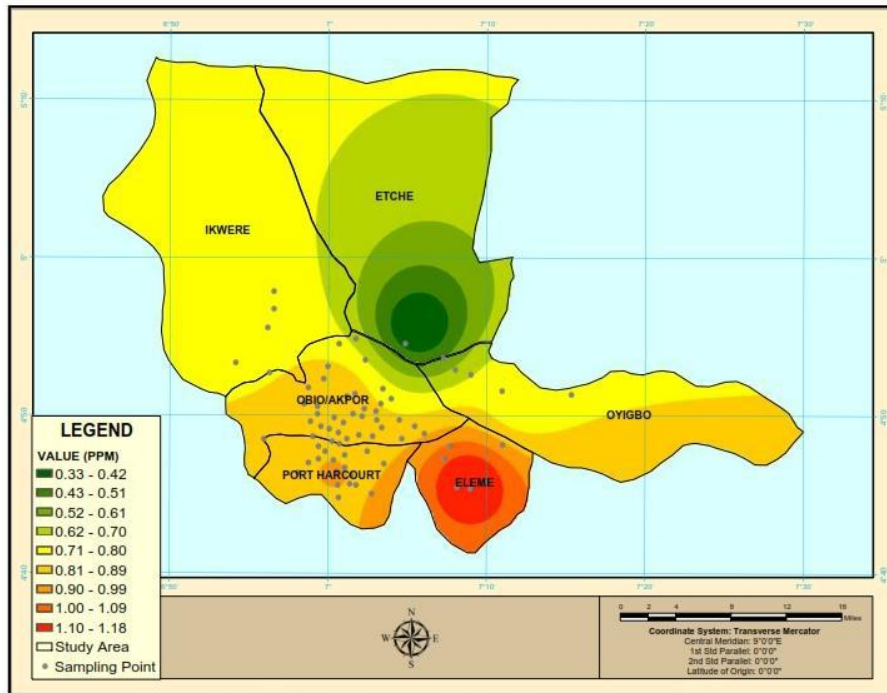


Fig.1: Distribution in SO₂ of the Study Area in the Dry Season

Distribution of NO₂ in the Study Area in the Dry Season

In the dry season, NO₂ hotspots are visible within Eleme and part of Oyiibo with the highest concentration within 0.82 to 0.88ppm (Figure 2). It occupies elongated area coverage of about 17670meters. It showed moderate influence in Obio/Akpor and Ikwerre. It has a larger influence on Oyiibo

followed by Etche with the least influence in Port Harcourt area as shown in Figure 2. It is predicted that these hotspots will contribute about 0.05 to 0.070ppm to the background concentration of NO₂ in parts of Oyiibo, Etche, Obio/Akpor, Port Harcourt and Ikwerre.

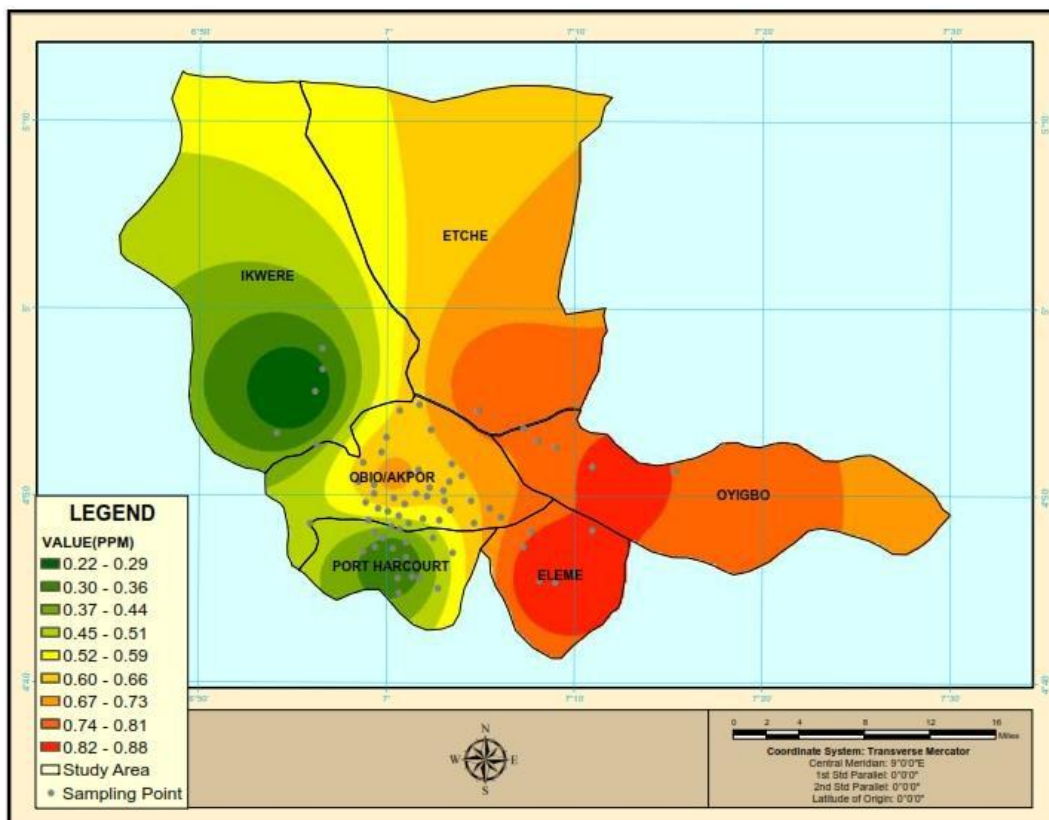


Fig.2: Distribution of NO_2 in the Study Area in the Dry Season

Distribution of H_2S in the Study Area in the Dry Season

In the dry season, H_2S hotspot is visible within Eleme with the highest concentration within 1.70 to 1.87ppm as shown in Figure 3. It occupies an aerial coverage with a 2670meters radius and has a moderate influence on Oyigbo and its least

influence is in Port Harcourt, Obio/Akpor and Etche. It is predicted that this hotspot will contribute additional 0.05 to 0.1ppm to the background concentration of H_2S in parts of Port Harcourt, Oyigbo, Obio/Akpor and Etche.

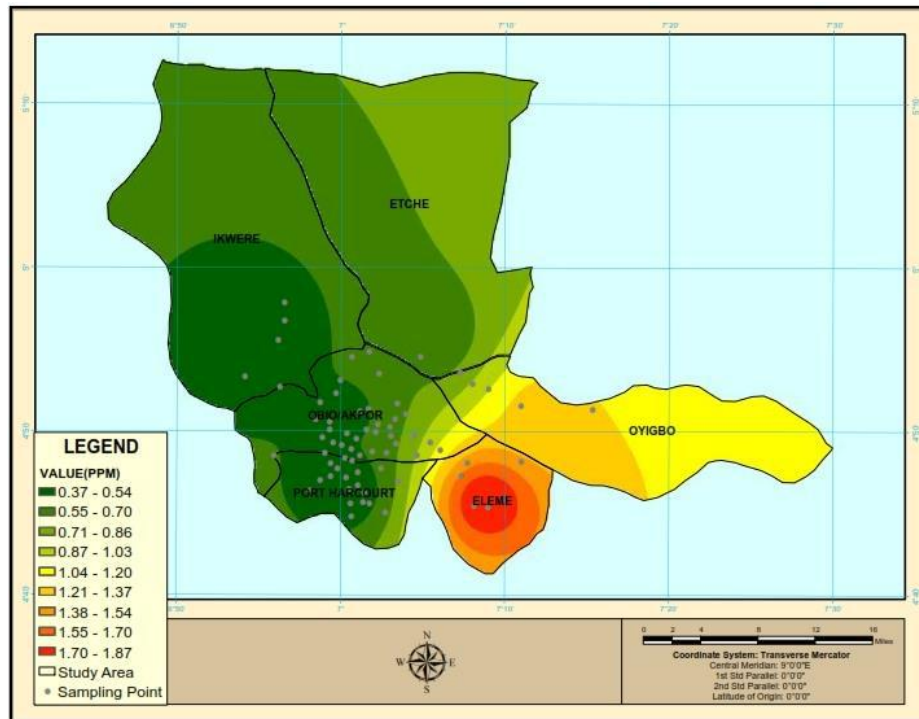


Fig.3: Distribution of H_2S in the Study Area in the Dry Season

Distribution of VOCs in the Study Area in the Dry Season

In the dry season, VOCs hotspot is visible within Eleme with the highest concentration within 6.26 to 6.82ppm as shown in Figure 4. It occupies an aerial coverage of about 3,850meters

radius. It has a larger influence on Obio/Akpor. It has least influence on Port Harcourt, followed by Oyigbo, Etche and Ikwerre LGAs. It is estimated that this hotspot will contribute additional 0.25ppm to 0.41ppm to the background concentration of VOCs.

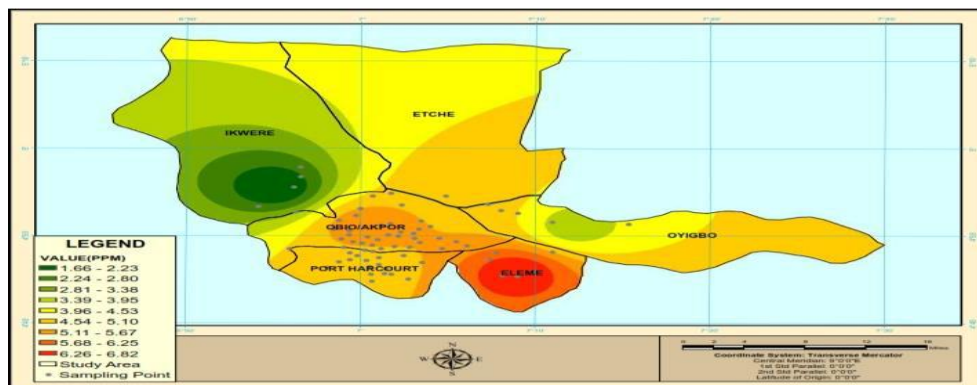


Fig.4: Distribution of VOCs in the Study Area in the Dry Season

Distribution of CO in the Study Area in the Dry Season

In the dry season, Carbon Monoxide (CO) hotspot is visible within Eleme with highest concentration within 25.06 to 27.85ppm as shown in Figure 5. It occupies an aerial coverage with a 4350meters radius. It has a minor influence

on Obio/Akpor, followed by Oyigbo and Port Harcourt. Its least influence is on Ikwerre and Etche areas. It is predicted that this hotspot contributes additional 1.1 to 2.05ppm to the background concentration of carbon monoxide in parts of Obio/Akpor, followed by Oyigbo and Port Harcourt.

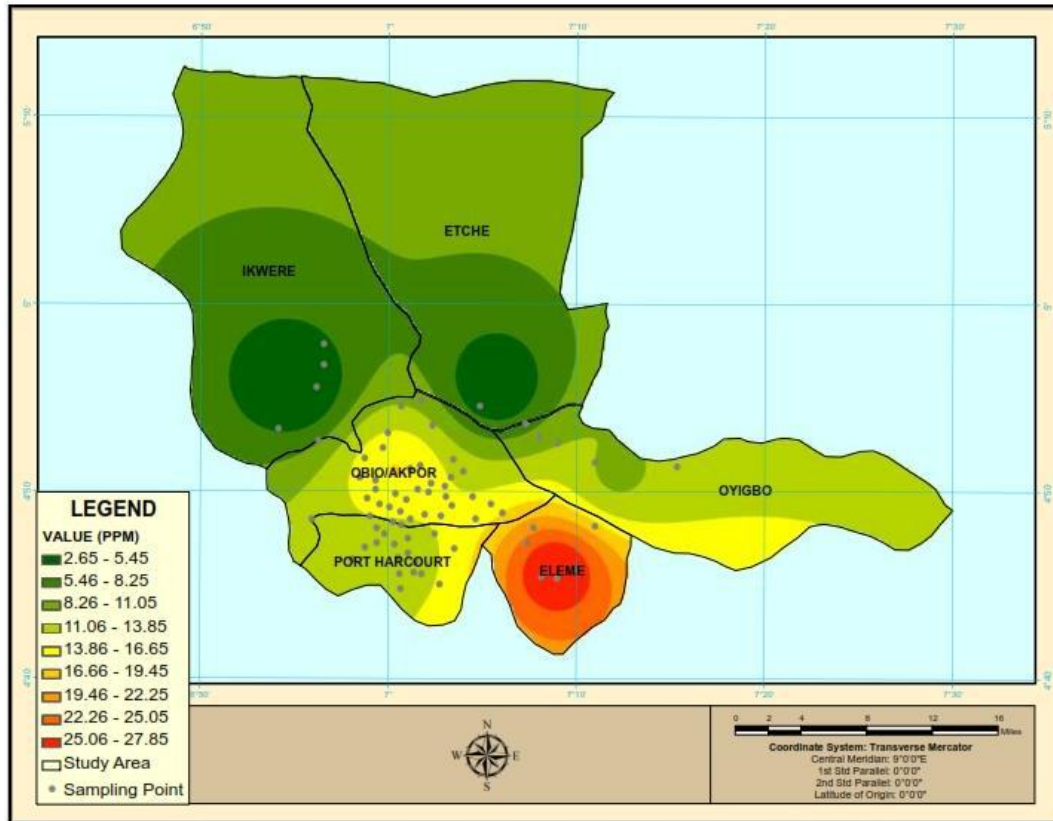


Fig.5: Distribution of CO in the Study Area in the Dry Season

Distribution of NH₃ in the Study Area in the Dry Season

In the dry season, ammonia hotspot is visible within Eleme with highest concentration within 5.32 to 5.98ppm as shown in Figure 6. It occupies an aerial coverage of 3500meters radius. It has a very minor influence on Oyigbo, but less on Obio/Akpor and Port Harcourt. Its least influence is on

Ikwerre and Etche areas. It is predicted that this hotspot will contribute additional 0.15 to 0.2ppm to the background concentration of ammonia in parts of Oyigbo, Obio/Akpor and Port Harcourt.

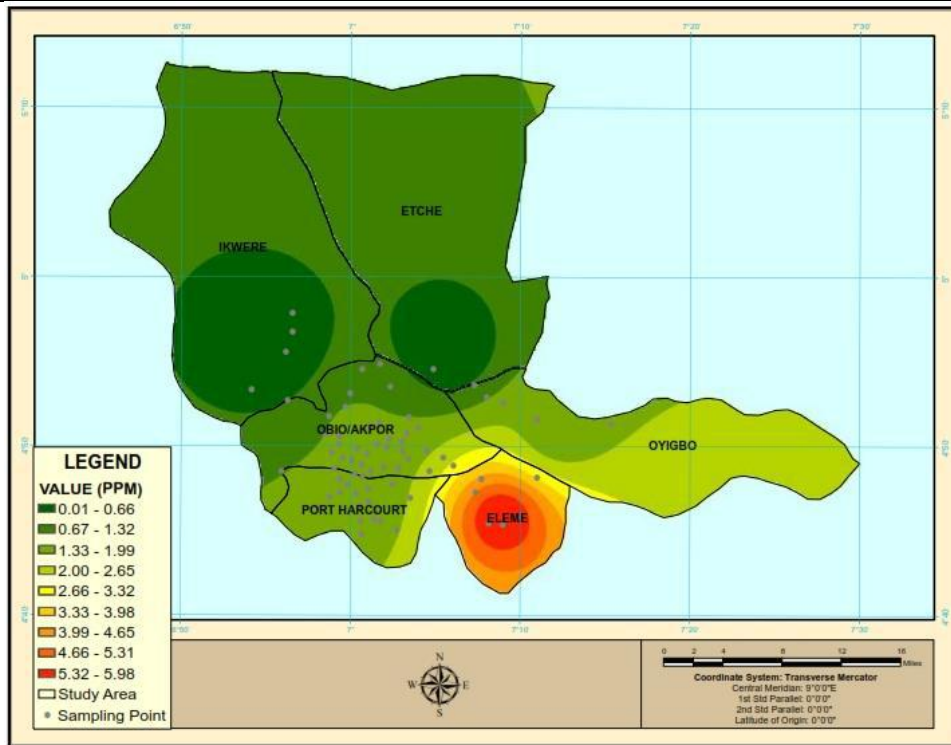
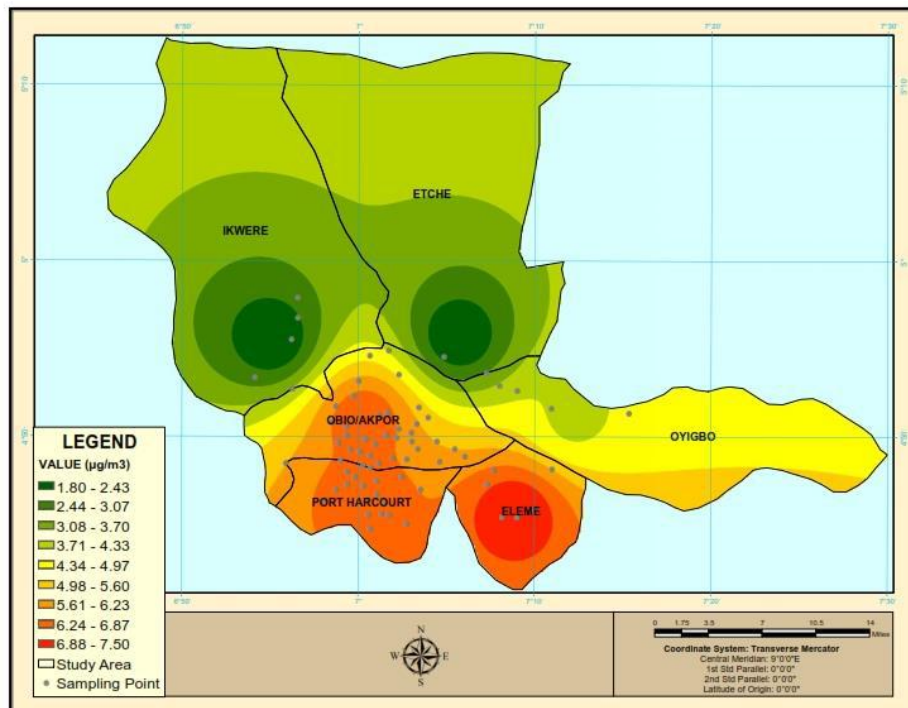


Fig.6: Distribution of NH_3 in the Study Area in the Dry Season

Distribution of CH_4 in the Study Area in the Dry Season

In the dry season, methane hotspots are visible within Eleme followed by Obio/Akpor and Port Harcourt with highest concentration within 6.86 to 7.48ppm as shown in Figure 7. It occupies an aerial coverage of 3750meters radius. It has a

moderate influence on Oyiibo. It has least influence on Ikwere and Etche LGAs. It is predicted that these hotspots contribute about 3.0 to 4.0ppm to the background concentration of methane (CH_4) in parts of Oyiibo, Ikwere and Etche.



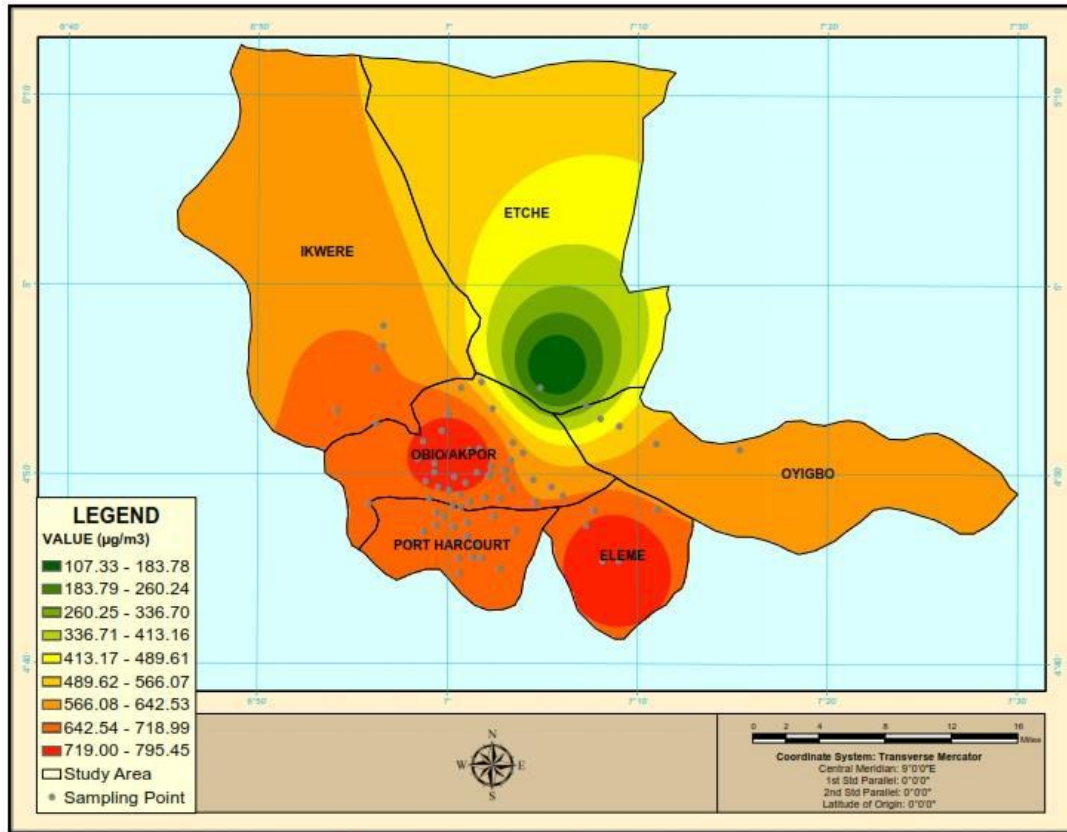
CH4 MAP(Dry Season) OF STUDY AREA

Fig.7: Distribution of CH_4 in the Study Area in the Dry Season

Distribution of TSP in the Study Area in the Dry Season

In the dry season, TSP hotspots are visible within an extended area of Obio/Akpor and Eleme followed by Port Harcourt with highest concentration within $716.27\mu\text{g}/\text{m}^3$ to $792.81\mu\text{g}/\text{m}^3$ as shown in Figure 8. It occupies elongated aerial coverage of 26,466meters length. It has a larger

influence on Ikwerre followed by Oyigbo and showed its moderate influence on Etche area. It is predicted that these hotspots will contribute additional $2.0\mu\text{g}/\text{m}^3$ to $3.4\mu\text{g}/\text{m}^3$ to the background concentration of TSP in parts of Ikwerre, Oyigbo and Etche.



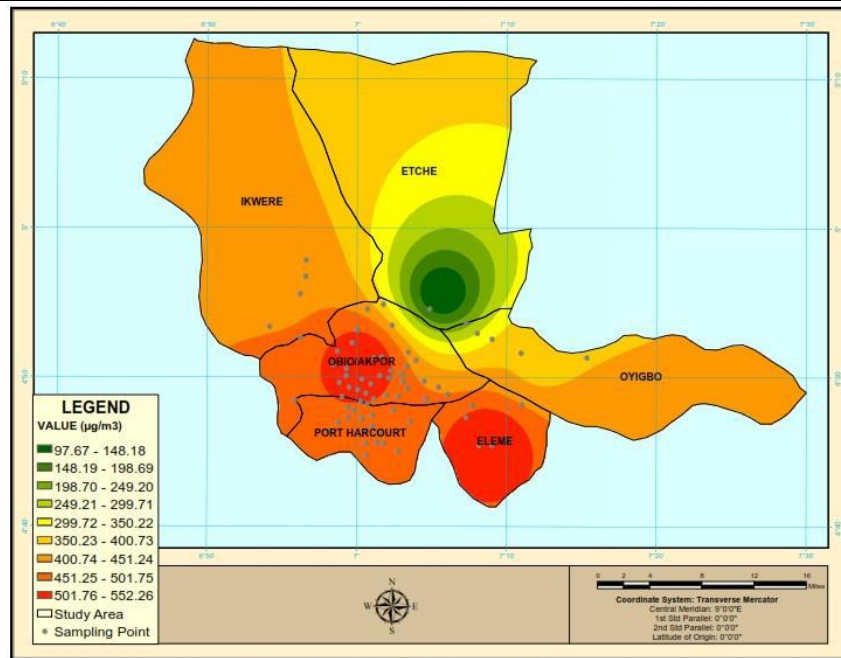
TSP MAP(Dry Season) OF STUDY AREA

Fig.8: Distribution of TSP in the Study Area in the Dry Season

Distribution of PM₁₀ in the Study Area in the Dry Season

In the dry season, PM₁₀ hotspots are visible within an extended area of within Obio/Akpor and Eleme followed by Port Harcourt with highest concentration within $501.39\mu\text{g}/\text{m}^3$ to $554.09\mu\text{g}/\text{m}^3$ as shown in Figure 9. It occupies elongated

aerial coverage of 27200meters length. It has a larger influence on Oyigbo but less on Ikwerre and Etche. It is predicted that these hotspots will contribute about $10\mu\text{g}/\text{m}^3$ to $25\mu\text{g}/\text{m}^3$ to the background concentration of PM₁₀ in parts of Oyigbo, Ikwerre and Etche.



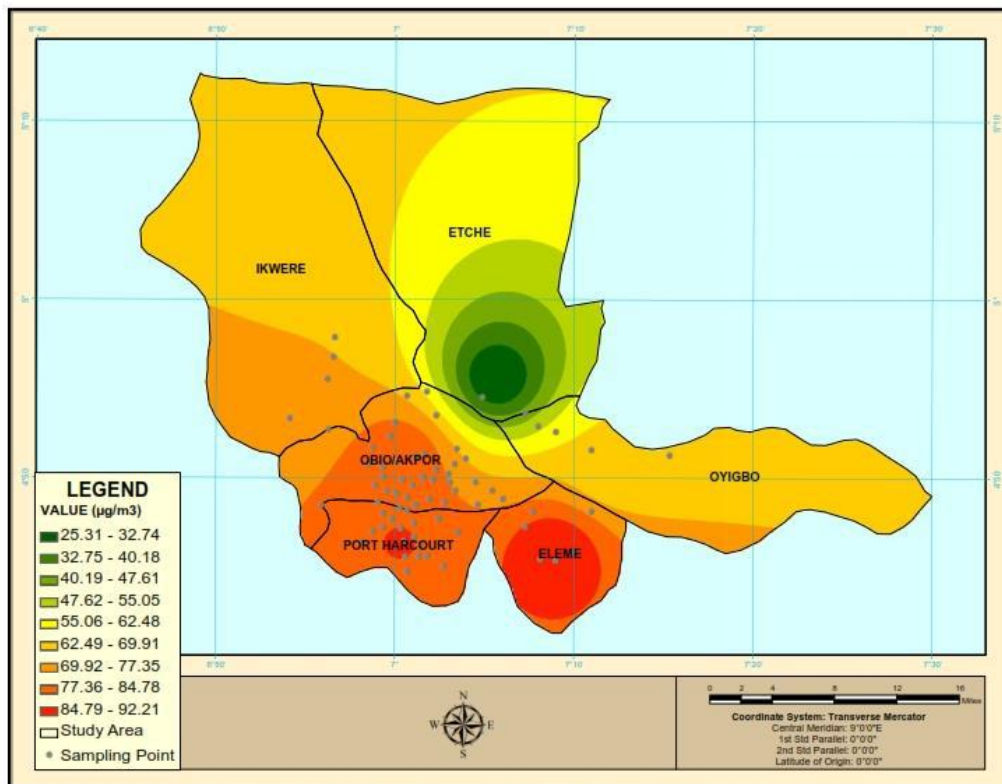
PM10 MAP(Dry Season) OF STUDY AREA

Fig.9: Distribution of PM₁₀ in the Study Area in the Dry Season

Distribution of PM_{2.5} in the Study Area in the Dry Season

In the dry season, PM_{2.5} hotspots are visible within Eleme followed by Port Harcourt and Obio/Akpor with highest concentration within 84.15µg/m³ to 92.19µg/m³ as shown in Figure 10. It occupies an aerial coverage of 4100meters

radius. It has a larger influence on Ikwerre and Oyigbo, but least influence on Etche area. It is predicted that these hotspots contribute about 3.5µg/m³ to 5.5µg/m³ to the background concentration of PM_{2.5} in parts of Ikwerre, Oyigbo and Etche,



PM2.5 MAP(Dry Season) OF STUDY AREA

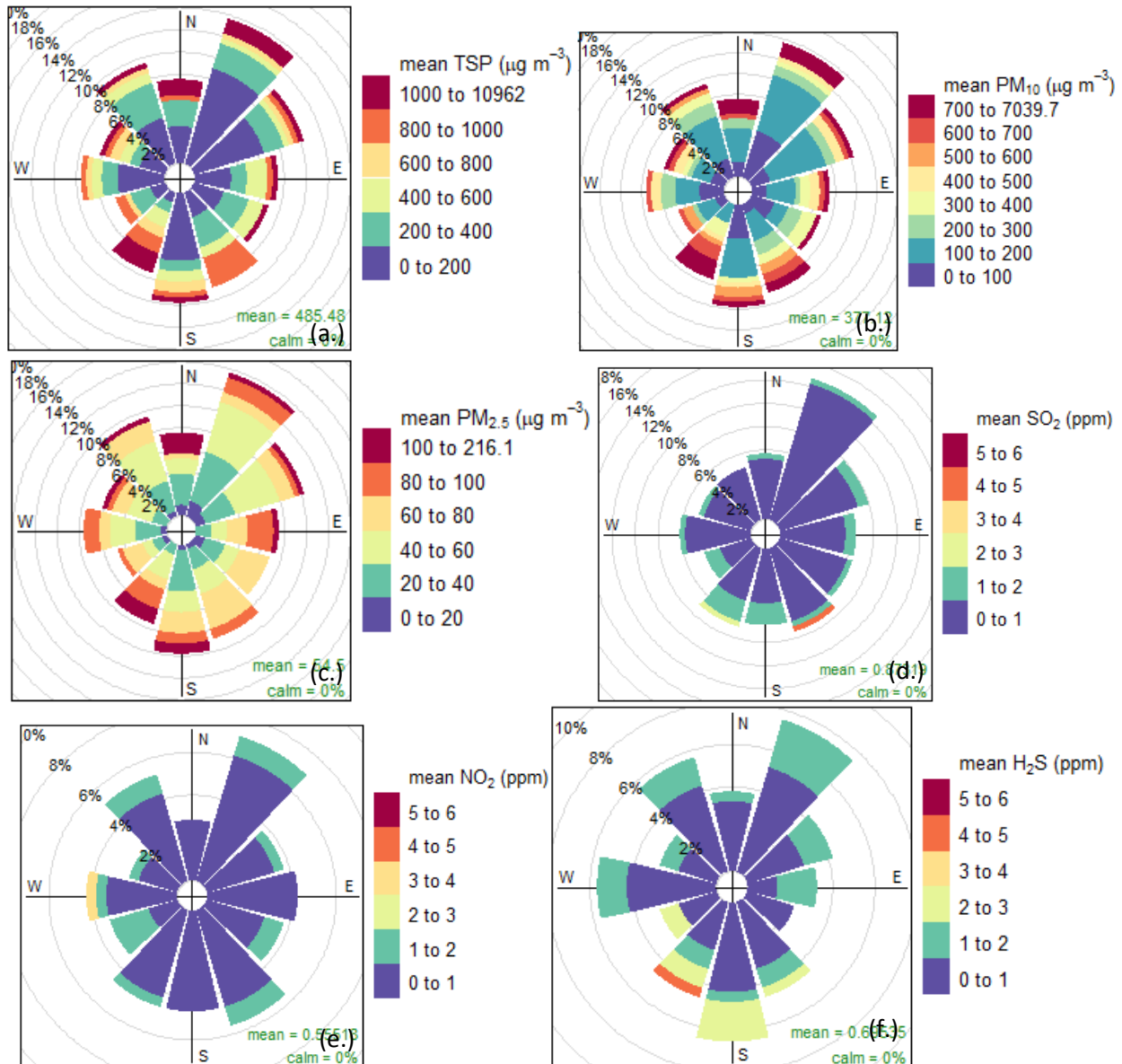
Fig.10: Distribution of PM_{2.5} in the Study Area in the Dry Season

IV. DISCUSSION

Evaluation of Pollutants Dispersion Pattern in the Study Area in the Dry Season

The pollutants dispersion patterns in the study area in the dry season were evaluated with the aid of pollution roses and bivariate polar plots of each pollutant with respect to wind speed and wind direction. The dry season results are presented in Figures 11 (a-j) and 12 (a-j). The pollution roses and polar plots were developed using the mean concentration of each pollutant in different wind speed and percentage

frequency count of wind direction categories (Munir, 2016). They were simulated with the aid of Generalized Additive Model (GAM) smoothing techniques Carslaw, (2015) that depict pollutant concentrations as a continuous surface. Pollution roses (Figure 11 (a-j)) showed that pollutant concentrations increase with increased wind speed. Low concentrations of pollutants were obtained at low wind speed and vice-versa. This implies that wind speed has positive influence on the concentration levels of pollutants in the study area.



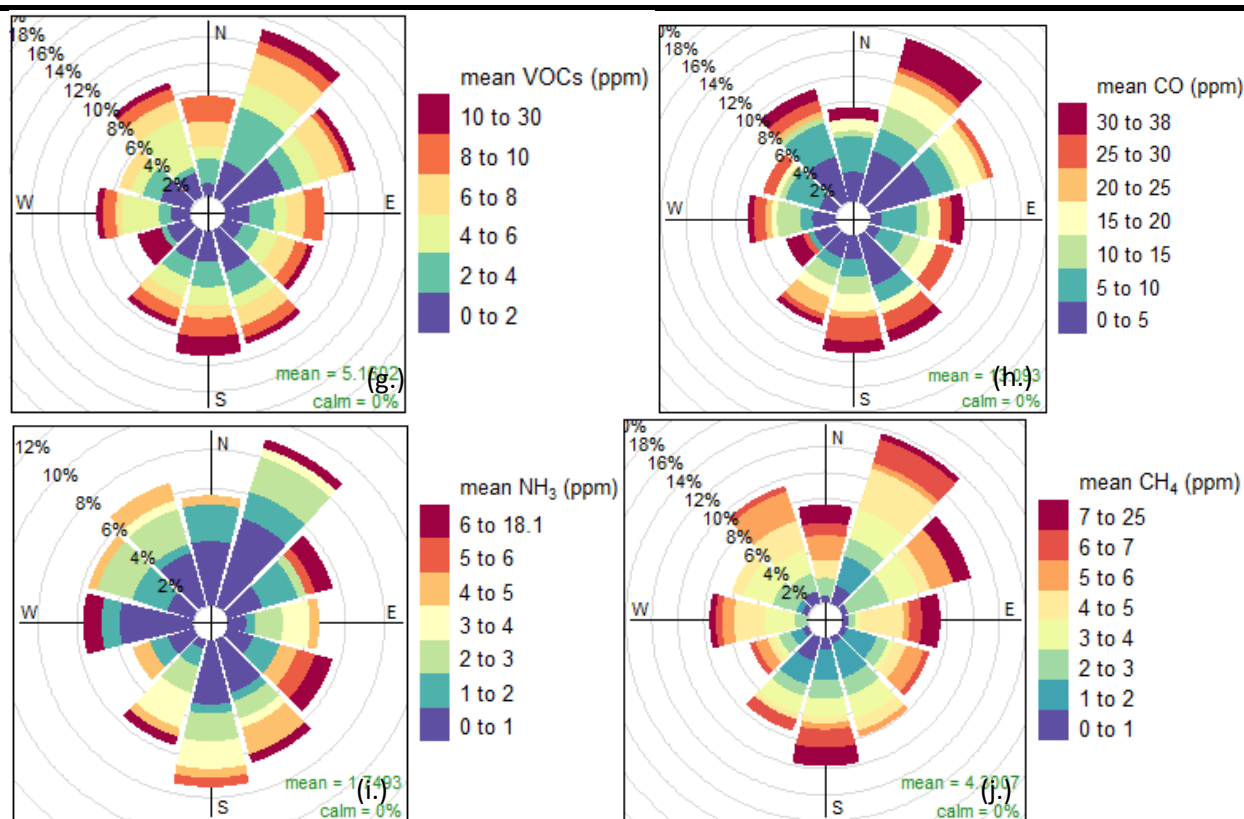


Fig.11(a-j): Pollution Roses of Pollutants in the Study Area in the Dry Season

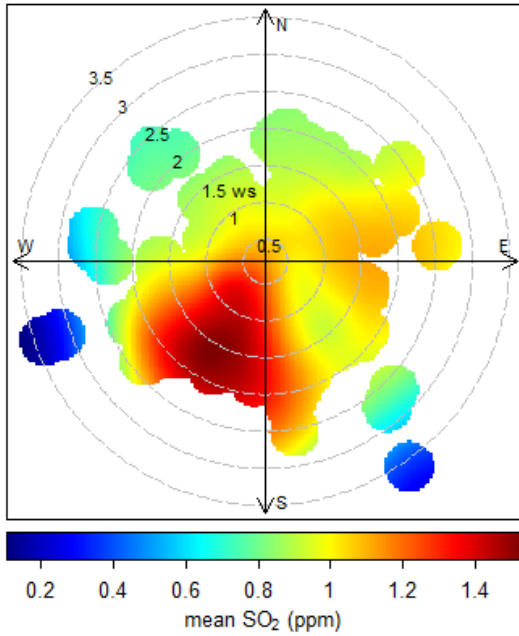
The pollutant polar plots (Figure 12 (a-j)) showed that concentrations of pollutants in the area are associated with wind speed up to 3.5m/s. It is also observed from Figure 12 (a-j) that pollutant concentrations increase with increased wind speed.

Surface polar plots of pollutants concentrations in the study area revealed that high concentrations of SO₂, NO₂, NH₃, H₂S and VOCs are associated with the south-west and south-east directions and are dispersed toward the north-east and north-west directions. This may imply that sources of these pollutants are in the southern part, which is the coastal region of the study area. Industrial activities, especially in Eleme area (refineries, petrochemical company, fertilizer companies, industrial waste management facilities, civil construction, gas flaring, and vehicular movement) and the release of black carbon (black soot) due to illegal refineries in the coastal area may be the sources of these pollutants (Above, 2006, Akpan *et al.*, 2014 and Antai *et al.*, (2016)).

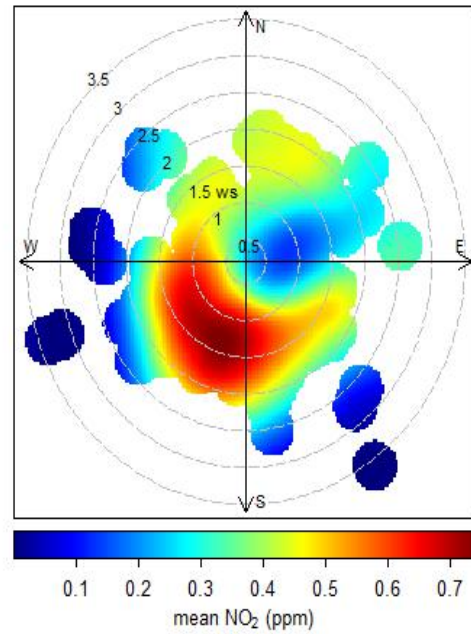
Figure 12 (a-j) also indicate that concentrations of CO is associated with south-west, south-east and north-east

directions and are dispersed toward the north-west directions. This may imply that sources of this pollutant are both in the southern and northern parts, which are the coastal and up-land areas. Industrial activities, vehicular exhaust emissions, gas flaring and oil and gas exploitation in Eleme, Port Harcourt, Obio/Akpor and Etche areas might be the sources of these pollutant (Bhatia, 2011, Bleta *et al.*, 2017, Efe, 2005 and Emmanuel *et al.*, 2009).

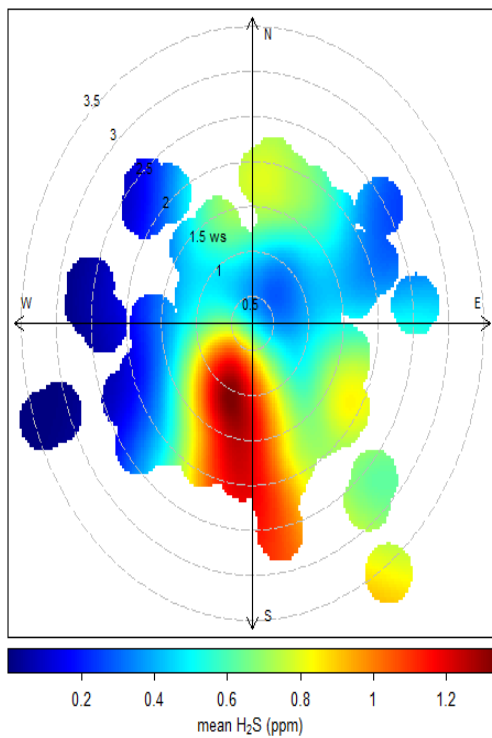
Similarly, concentrations of Methane (CH₄) and Particulate matter (TSP, PM₁₀ and PM_{2.5}) are associated with both northern and southern directions. This showed that activities in the both the coastal and up-land areas are responsible for the release of these pollutants into the environment. In other words, industrial activities, vehicular exhaust emissions, civil construction, the released of black carbon (black soot) due to illegal refineries in the coastal area, gas flaring and oil and gas exploitation in Eleme, Port Harcourt, Obio/Akpor, Etche and Ikwerre areas may be the sources of CH₄ and Particulate matter in the air environment of the study area in the dry season period.



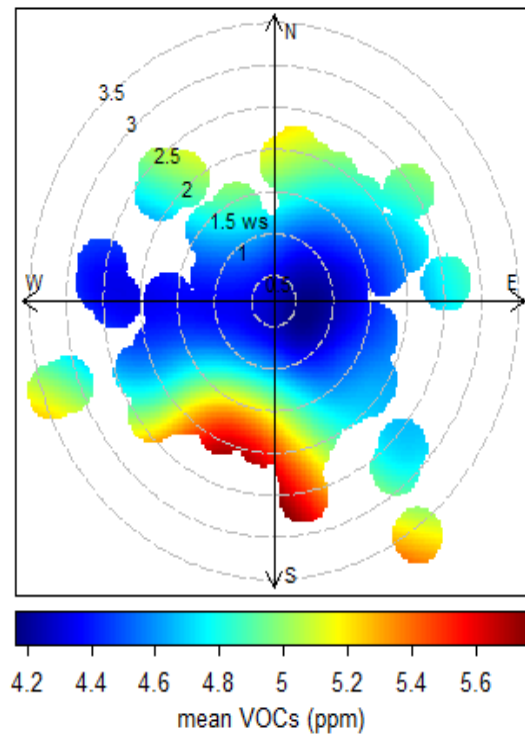
(a.)



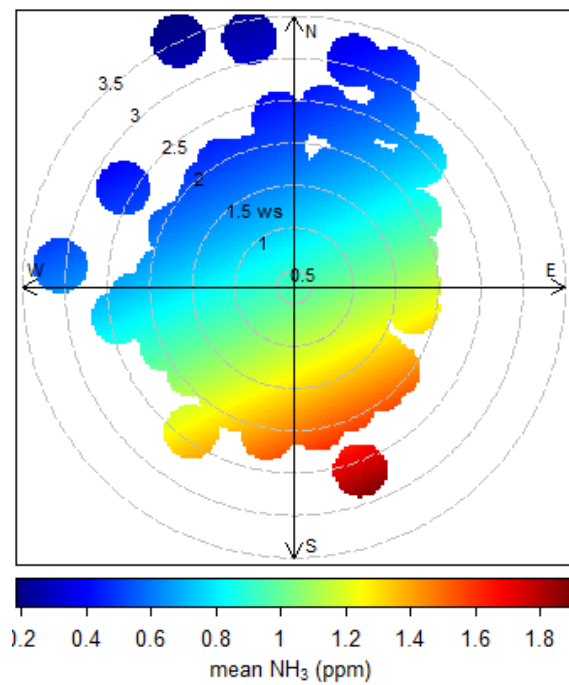
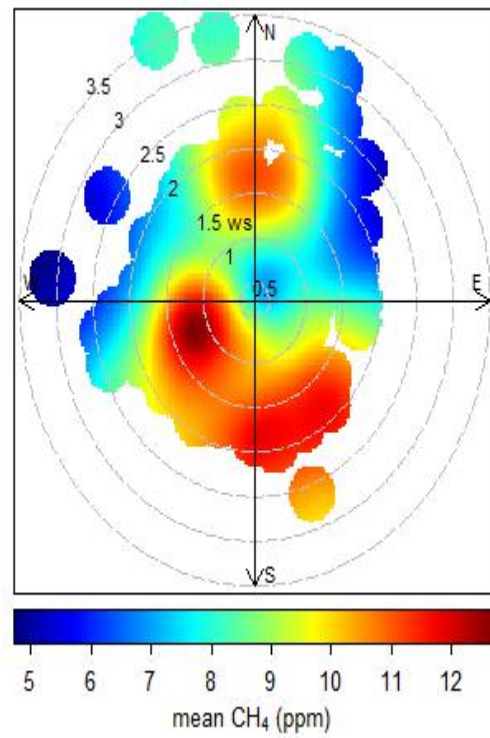
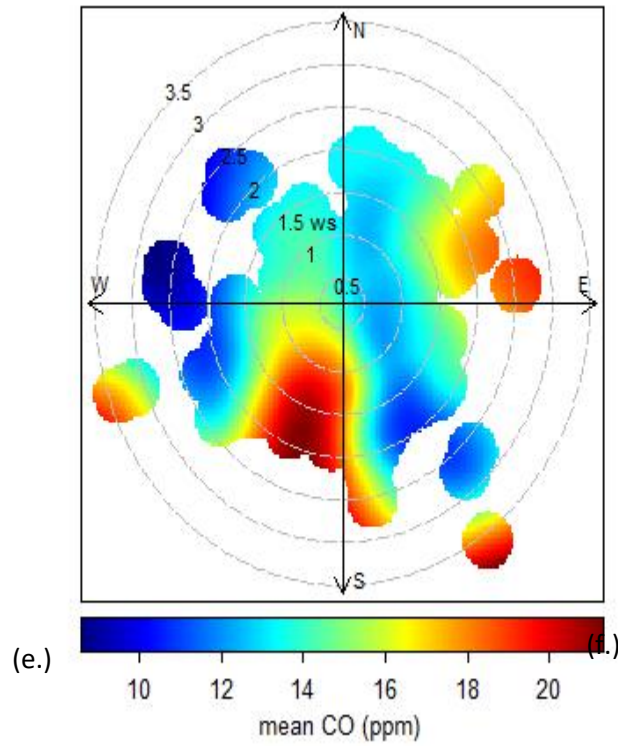
(b.)



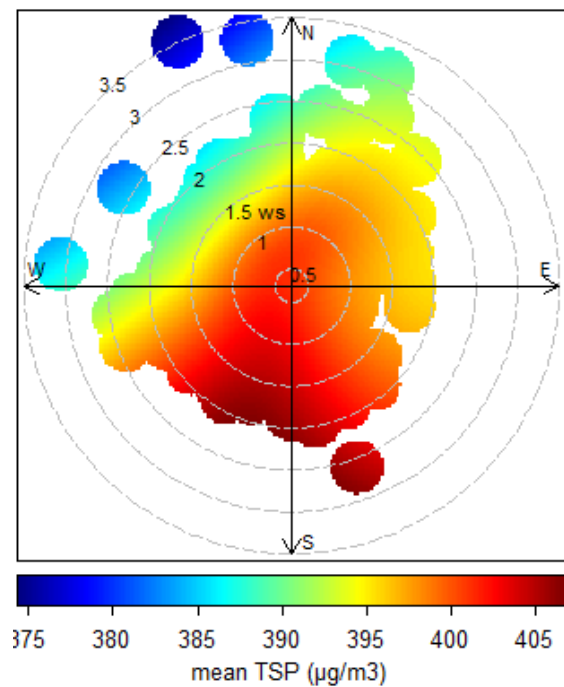
(c.)



(d.)



(g.)



(h.)

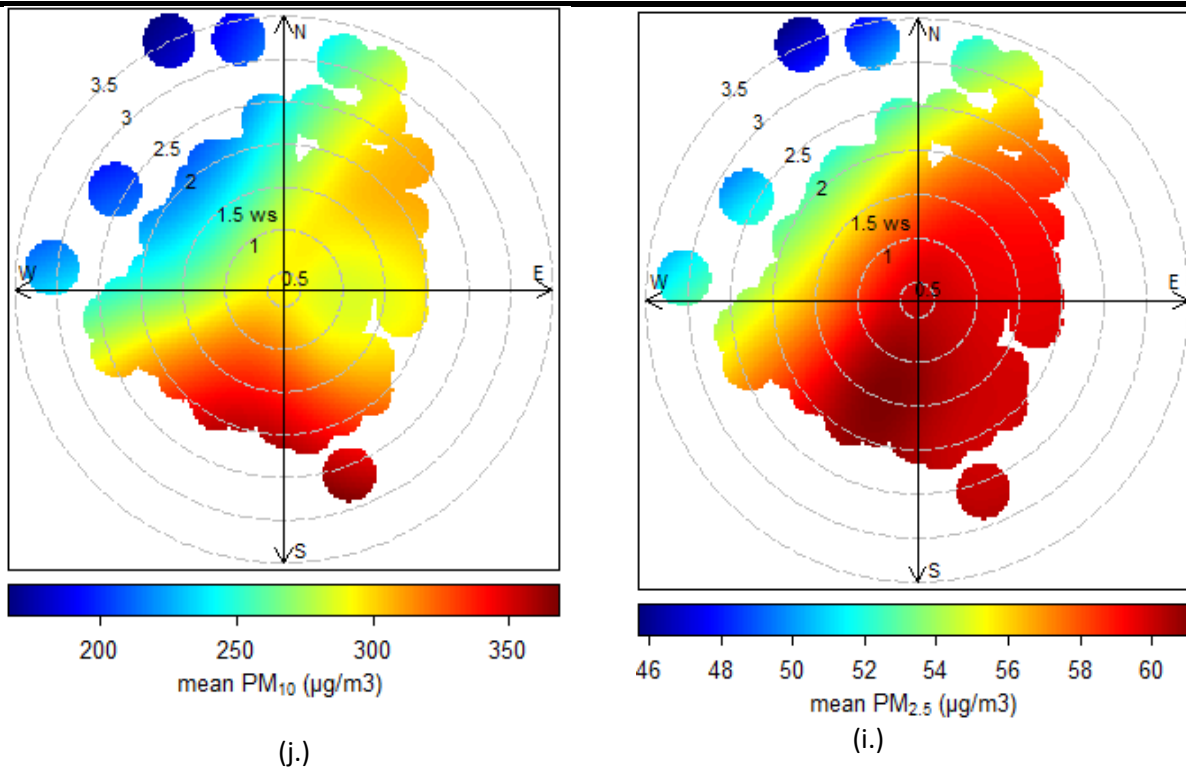


Fig.12 (a-j): Polar Plots of Pollutants in the Study Area in the Dry Season

Determination of Particulate Ratio (TSP: PM₁₀:PM_{2.5}) in the Dry season

Particulate mass concentration ratios PM₁₀/TSP and PM_{2.5}/PM₁₀ in the dry season were determined in the modeling process. Result (Figure 13 (a-b)) indicates that the mean mass concentration ratio of PM₁₀/TSP was 0.84, while the mean mass concentration ratio of PM_{2.5}/PM₁₀ was 0.30. This reveals that PM₁₀ constitutes 84% of the concentration of total suspended particulate (TSP) measured in the study

area, out of which 30.0% is composed of PM_{2.5}. The PM_{2.5}/PM₁₀ ratio obtained in the dry season is below the range (0.5-0.8) found in urban areas of developing countries by World Health Organization (WHO, 2006). This PM_{2.5}/PM₁₀ ratio could be considered hazardous to human health. It revealed that black smoke emanating mostly from the combustion of hydrocarbon fossil fuel is concentrated in this fine fraction of particulate.

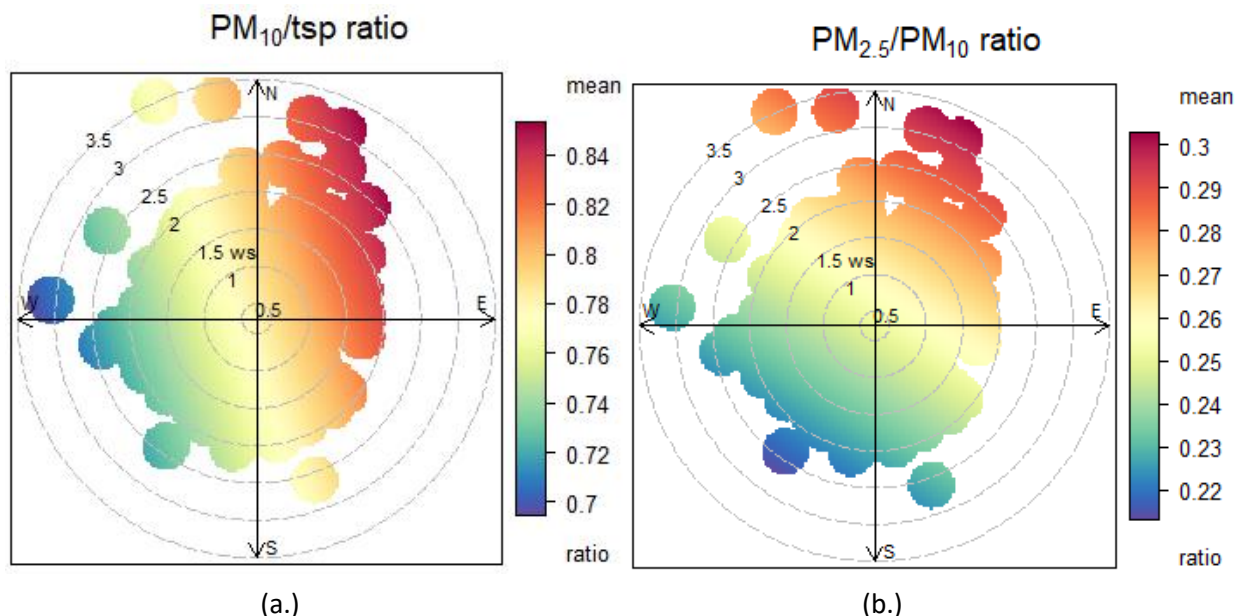


Fig.13(a-b): Particulate Ratio in the Study Area in the Dry Season

V. CONCLUSION

There were relatively high concentrations of air pollutants especially dominated in southern area in the dry season. Results of geospatial analysis and generalized additive models revealed that sources of pollutants in the study area are localized in the up-land area and region around the coastal area and dispersed towards the southern and northern parts of the study area in the dry season.

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