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Health Risk and Evaluation of Atmospheric Pollutants in Owerri Metropolis and Sub-urban Areas of Imo State, Nigeria, Using Chemometric Models

J.C. Ike[1], U.U. Egereonu[2,*], C.K. Enenebeaku[2], A.U. Nkwoada[3], M.C. Igbomezie[4], M.O. Ezeokoye[5], I.C. Obiagwu[5], U.L. Onu[5], J.C. Egereonu[6], N.J. Okoro[7], C. Onwuka[8], S.K. Egereonu[9]

Abstract

Concern about the health risk from atmospheric pollutants; particulate matter (PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO) prompted atmospheric monitoring and inhalation health risk assessment for residents of Owerri Metropolis and its sub-urban areas. Field measurements were carried out in 35 select locations within Imo State. Monitoring was carried out using chemometric methods such as Matrix Laboratory (MATLAB) and Artificial Neural Network (ANN). According to the experiment results, the pollutants were present year-round. The human health risk assessment methodology of the United States Environmental Protection Agency (USEPA) was utilized to estimate potential health risks resulting from exposure to contaminants. For acute and chronic exposure periods for infants, children, and adults, a scenario assessment technique was used, wherein normal exposure and the worst-case scenario were adopted. The mean concentrations of the pollutants exceeded the WHO 1-hr., 24-hr., and annual mean maximum exposure limits. The 24-hour, annual PM_{10} ambient quality standard for instance was exceeded during the monitoring period. This could explain the chronic (annual) hazard quotient (HQ>1) that our study found, which suggests that there may be some danger associated with long-term PM10 exposure. Therefore, steps should be taken to control the exposure of the public to contaminants and to increase public awareness. Frequent monitoring is advised to lower concentrations because determining whether these pollutants pose health risks as determined by the human health risk assessment framework will help the government, environmental experts, and other pertinent stakeholders take more decisive action to safeguard and extend human life.

***Author for Correspondence**
U. U. Egereonu
E-mail: uegeronu@gmail.com

[1]Assistant Lecturer, Department of Chemistry, Federal University of Technology, Owerri, Nigeria
[2]Professor, Department of Chemistry, Federal University of Technology, Owerri, Nigeria
[3]Lecturer, Department of Chemistry, Federal University, Owerri, Nigeria
[4]Lecture, Department of Chemistry, Federal University of Technology, Owerri, Nigeria
[5]Lecturer, Department of Chemistry, Federal University of Technology, Owerri, Nigeria
[6]Assistant Lecturer, Department of Geosciences, Federal University of Technology, Owerri, Nigeria
[7]Lecturer, Department of Chemistry, University of Agriculture and Environmental Sciences, Umuagwo, Imo State, Nigeria
[8]Lecturer, Department of Chemistry, Rhema University Nigeria, Aba, Nigeria
[9]Assistant Lecturer, Department of Information Technology, Federal University of Technology, Owerri, Nigeria

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Keywords Risk assessment, atmospheric pollutants, hazard quotient, ANN, MATLAB

INTRODUCTION

Air pollution has been identified as a significant environmental issue and public health concern on a global scale [1]. Urban air quality concerns are primarily caused by the growing human population, industrialization, urbanization, modernization, and corresponding increase in automobile emissions and activities. In 2018, Tedros Adhanom Ghebreyesus, the General Director of the WHO, called air pollution “the new tobacco” and a “silent public health emergency” [2] during the first-ever WHO Global Conference on Air Pollution and Health. Air pollution is responsible for over one out of every nine deaths worldwide. It was the fourth most important risk factor for death worldwide in 2019 and is predicted to have contributed to 7 million deaths worldwide. The only factors that had a greater overall impact were tobacco use, dietary hazards, and high blood pressure. It is estimated that approximately 1.28 million people die worldwide each year because of exposure to air pollution during traffic accidents.

Long-term and short-term exposure to air pollution has resulted in increased mortality and reduced life expectancy. There was also a yearly pattern that showed that during the dry season, the average daily concentrations of SO_2, NO_2, and PM10 were greater. However, certain demographic groups are more vulnerable to certain types of air pollution. The most susceptible demographic includes those who are young, old, pregnant, or have multiple medical concerns [3]. Air pollution is responsible for 24% of stroke cases and 43% of lung ailments. According to WHO Health Organization projections, ischemic heart disease and stroke accounted for almost 37% of premature deaths in 2019 associated with outdoor air pollution, followed by chronic obstructive pulmonary disease (18%), acute lower respiratory infections (23%), and respiratory tract cancer (11%). Inhaled particles, known as particulate matter (PM), can enter the respiratory system and lead to cancer and reproductive, cardiovascular, and cerebrovascular disorders, as well as malfunctions of the central nervous system and reproductive organs. Moreover, sulphur dioxide and nitrogen oxide are dangerous air pollutants. The inhalation of large amounts of carbon monoxide has the potential to cause rapid poisoning. Depending on the extent of exposure, heavy metals such as lead can cause either acute poisoning or long-term intoxication when absorbed into the human body. Most respiratory system ailments brought on by the substances listed above include asthma, bronchiolitis, lung cancer, cardiovascular events, abnormalities of the central nervous system, and skin conditions. People who are sensitive or prone to air pollution may have health effects, even on days with moderate levels of pollution. Short-term exposure to air pollution is closely linked to wheezing, asthma, respiratory disorders, shortness of breath, cough, and high hospitalization rates (a measure of morbidity). The long-term effects of air pollution include cardiovascular disease, pulmonary insufficiency, chronic asthma, and cardiovascular death. A Swedish cohort study suggested that prolonged exposure to air pollution may cause diabetes [4]. Furthermore, it appears that early life exposure to air pollution causes a range of harmful health outcomes, including respiratory, cardiovascular, mental, and perinatal illnesses, that can result in chronic disease in adulthood or infant death [5]. It is interesting to note that industrialized and high-income nations have a greater prevalence of cardiovascular disorders than developing, low-income nations that are heavily exposed to air pollution [6]. The number of deaths in December 1952 in London and New York City in 1963 (400 deaths) increased as a result of air pollution, especially sulphur dioxide and smoke, which accumulated to 1,500 mg/m^3 [7]. The concentrations of fine, inhalable, and sulfate particles appeared to be more closely associated with mortality in all cases than the levels of aerosol acidity, nitrogen dioxide, sulphur dioxide, or total particulate pollution.

Therefore, it is crucial to monitor atmospheric changes to ascertain the extent of population exposure to air pollutants that can have a range of unfavorable effects. Owing to the lack of air quality reporting, industrialization, urbanization, and population growth, the impacts of pollution are mostly dependent on the type of pollutant, its amount, duration, and frequency of exposure, as well as its toxicity [8]. Models that integrate new observations into coherent theoretical frameworks were employed to test this understanding by providing results that could be compared with independent data, as would be observed in the monitoring locations in both the dry and rainy seasons for the study duration. Air pollutant mappings produced using these models could be used as an information source to boost the health of the inhabitants of Imo State and would also help relevant agencies make valid decisions necessary and strategic for better pollution policies, control, and management. The gap in Nigerian air quality policies exists because relevant authorities do not use proactive predictive approaches to develop effective air quality planning strategies [9–13]. However, more predictive, and proactive approaches, such as GIS (IDW method) and MATLAB (polynomial linear regression), are being used in this research to present the spatial variation of air pollutant concentrations in the study area and interpret the experimental/actual data.

MATERIALS AND METHODS

Materials

Gasman Air-Monitor-Crowcon, Hazdust Particulate Monitor–Model EPAM 5000, MATLAB 2015 (polynomial linear regression), and ANN.

Study Area

Imo is a state in southeastern Nigeria that is one of the 36 states in the country. Created on the 3rd of February 1976, under the regime of the late military Head of State, Gen. Murtala Muhammad is located in an area of approximately 5,100 square kilometers and is between latitudes 4°45′N and 7°15′N and longitudes 6°50′E and 7°25′E. According to the 2006 census, the state has a population of approximately 3.9 million, a projected population of 5,408,800 is predominantly Igbo, and English is the official language. Christianity is the predominant religion. Twenty-seven [14] local Government Areas comprise Imo State: Ikeduru, Isiala Mbano, Isu, Mbaitoli, Ngor-Okpala, Njaba, Nkwerre, Nwangele, Obowo, Oguta, Ohaji/Egbema, Okigwe, Onuimo, Orlu, Orsu, Oru East, Oru West, Owerri Municipal, Owerri North, and Owerri West. Situated between the upper and middle Imo River and the lower Niger River sits the state capital Owerri. Imo State shares borders with the following states: River State to the south, Anambra State to the north, River Niger and Delta State to the west, and Abia State to the east. The Köppen–Geiger classification assigns a tropical wet climate. With a brief dry season, most of the year is rainy.

The rainy season, which spans from April to October, experiences an annual rainfall of between 1,500 and 2,200 mm (60–80 inches). Relative humidity rises to 75% with an annual temperature above 20°C (68°F) and reaches 90% during the rainy season. During the dry season, harmattan lasts for two months, from late December to late February. According to www.igbofocus.co.uk, January–March is the hottest month. The three Local Government Areas of Owerri Municipal, Owerri North, and Owerri West comprise Owerri, the state's main capital. The only local government in the state with an autonomous community called Owerri Nchi-Ise and just one town, Owerri Municipal Town, is Owerri Municipal. Its headquarters is located in the city of Owerri. Situated at the intersection of routes from Port-Harcourt, Onitsha, Aba, Orlu, Okigwe, and Umuahia, Owerri Municipality has an area of 58 km² and a population of 125,337, as of the 2006 census. Known collectively as Owerri Nchi-ise, Umuororonjo, Amawom, Umuonyeche, Umuodu, and Umuoyima are the five villages that comprise Owerri Town and often spelled Owerri. Owerri Town served as the administrative center for the Owerri Division and, subsequently, the former Owerri Province due to British colonialism and influence in the early 1900s. Owerri City was selected as the capital of the Imo State upon its creation on February 3, 1976. Owerri became a municipal City on December 15, 1996. (Figure 1) Other Local Government Areas in the state included in the study include Ehime Mbano and Mbaitoli (Table 1). Geological map of study area Imo State is shown in Figure 1, and a brief description of sampling locations given in Table 1

Air Quality Sampling

Gas pollutant concentrations were collected from the distributed sampling stations across the study area, and coordinate values of locations were captured using a Global Positioning System (GPS) device. To ensure adequate representation, sites for conducting air quality measurements were chosen using stratified random sampling. Stratification was performed based on the Australian Standard AS2922. Sampling frequency for the criteria air pollutants (SO_2, CO, NO_2, and PM_{10}) was carried out twice weekly for 14 weeks in both the dry and rainy seasons in the 35 selected air monitoring locations for 2 years. The gaseous pollutants were determined using the Crowcon Gas Monitor, while the dust concentration was measured using the HAZ-DUST EPAM 5000 Particulate Monitor (Table 2).

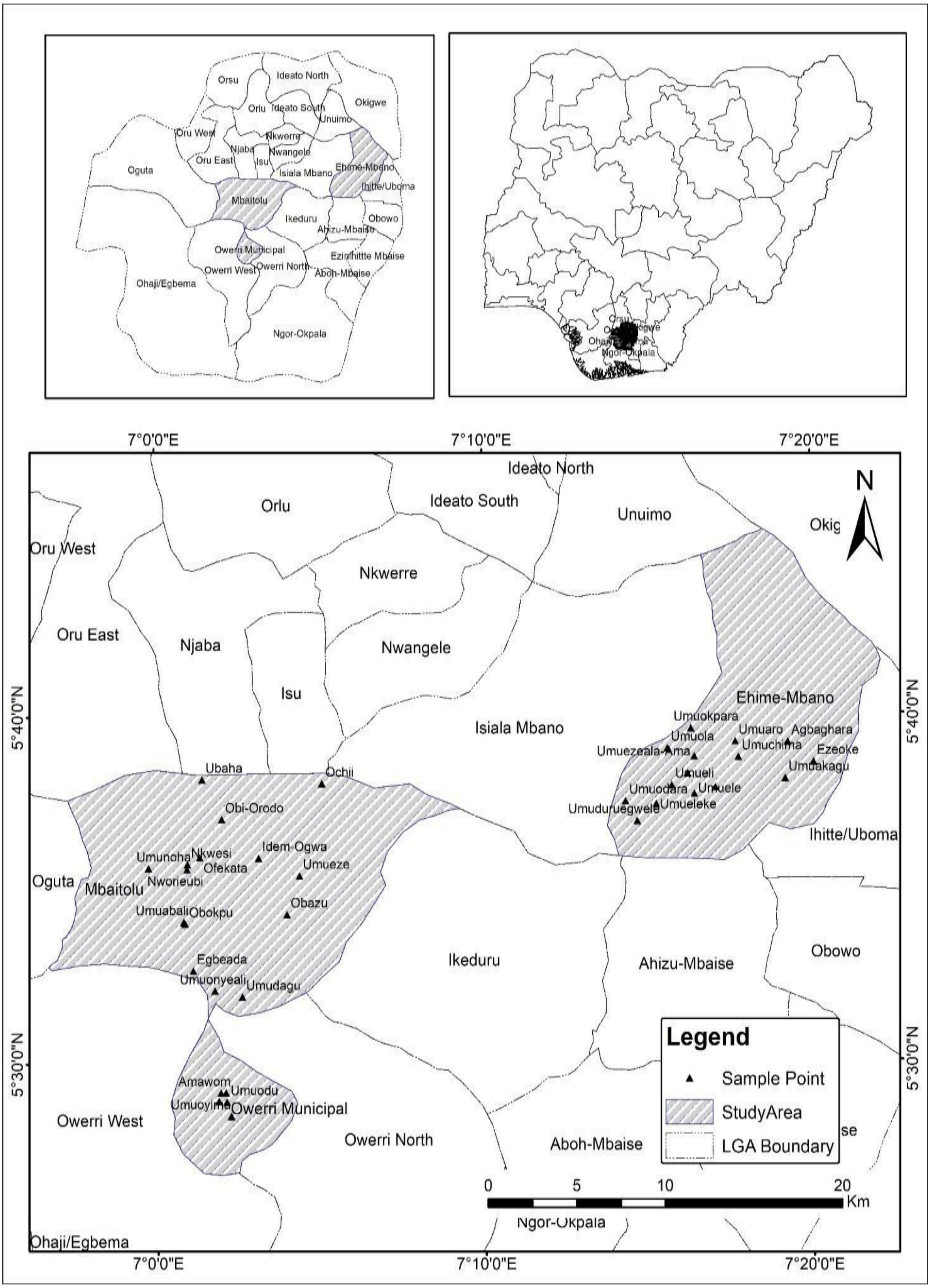


Figure 1. GIS map of the study area showing sampling locations.

Table 1. GPS and description of each sampling location.

S/N	Sampling area	Co-ordinates (longitude/latitude)	Sampling site	Description
Owerri Municipal L.G.A.				
1.	Amawom	5.48570, 7.03221	Ekeonunwa Street, Owerri.	Commercial, Residential
2.	Umuodu	5.48141, 7.03523	Ihugba Street, Owerri	Commercial, Residential
3.	Umuonyeche	5.48166, 7.03113	Rotobi Street, Owerri.	Commercial,
				Residential
4.	Umuoyima	5.47454, 7.03747	Oyima Street, Owerri.	Commercial, Residential
5.	Umuororonjo	5.48585, 7.03473	Oha-Owerre Hall	Commercial, Residential
Ehime Mbano L.G.A.				
Umuezeala				
6.	Umuezeala-Ama	5.64607, 7.27366	Umuezeala-Ama Secondary School.	Residential
7.	Umuezeala-Owerre	5.63123, 7.28432	Mercy girls Sec. Sch., Umuezeala, Owerre.	Commercial, Residential
8.	Umuopara	5.63804, 7.27029	Lutheran Church, Umuopara, Ogboama, Umuezeala.	Residential
Umueze II				
9.	Umueleke	5.62340, 7.25425	St. Michael’s Catholic Church, Umueleke.	Residential
10.	Umuodara	5.62479, 7.23861	Emmanuel Anglican Church, Umuodara.	Residential
11.	Umuduruegwele	5.61529, 7.24459	Umuduruegwele Health Center, Umueze II.	Residential
Umunakanu				
12.	Umuele	5.62821, 7.27366	Oil Mill, Umuele.	Commercial, Residential
13.	Umueli	5.63233, 7.26211	St. Barnabas Ang. Church, Umueli, Umunakanu.	Residential
14.	Umuola	5.65517, 7.25774	St. Mathias Anglian Church, Umuola, Umunakanu.	Residential
Umunumo				
15.	Umuaro	5.65312, 7.29449	Nkwo-Umunumo.	Commercial, Residential
16.	Umuokpara	5.65957, 7.27201	Ibeafor Sec. Sch., Umunumo.	Residential
17.	Umuchima	5.64561, 7.29604	St. Charles Catholic Parish, Umuchima, Umunumo.	Residential
Nsu				
18.	Agbaghara	5.65281, 7.32121	St. Columbus Catholic Church, Agbaghara, Nsu.	Residential
19.	Ezeoke	5.64312, 7.33425	St. Paul’s Cathedral, Ezeoke, Nsu.	Residential
20.	Umuakagu	5.63528, 7.31985	St. Mark’s Anglican Church, Umuakagu.	Commercial, Residential
Mbaitoli L.G.A.				
Mbieri				
21.	Obazu	5.57121, 7.06627	Obazu Girls Sec. Sch., Oba zu, Mbieri.	Commercial, Residential
22.	Umuonyeali	5.53472, 7.02946	Industrial Market, Umuonyeali, Mbieri.	Commercial, Residential

S/N	Sampling area	Co-ordinates (longitude/latitude)	Sampling site	Description
23.	Umudagu	5.53176, 7.04340	Ukwu-Uko, Umudagu, Mbieri.	Commercial, Residential
Ogwa				
24.	Idem-Ogwa	5.59841, 7.05204	St. Marks Church, Idem-Ogwa.	Residential
25.	Ochii	6.65454, 7.08435	St. James Ang. Church, Ochii, Ogwa.	Residential
26.	Umueze-Ogwa	5.64068, 7.06507	Ang. Church, Umueze, Ogwa.	Residential
Ubomiri				
27.	Egbeada	5.54443, 7.01844	Holy Family Table Water, Egbeada, Ubommiri.	Commercial, Residential
28.	Obokpu	5.56700, 7.01453	Nkwo-Ubommiri Market.	Commercial, Residential
29	Umuabali	5.56789, 7.01385	St. Mary’s Catholic Church, Umuabali, Ubommiri.	Residential
Orodo				
30.	Obi-Orodo	5.61708, 7.03330	Primary Health Center, Obi-Orodo.	Residential
31.	Ofekata	5.59882, 7.02211	Shammah Int’l Sch., Ofekata, Orodo.	Residential
32.	Ubaha	5.63619, 7.02343	St. Paul’s Ang. Church, Ubaha, Orodo.	Residential
Ifakala				
33.	Umunoha	5.59381, 6.99607	Holy Trinty Anglican Church, Ifakala, Umunoha.	Residential
34.	Nworieubi	5.59312, 7.01563	UBA, Nworieubi.	Commercial, Residential
35.	Nkwesi	5.59548, 7.01586	Nkwesi Town Hall.	Residential

Table 2. Dry season (year 1) mean value data for gases and PM_{10}.

S/N	Sampling area	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} mg/m^3)
Owerri Municipal L.G.A.					
1.	Amawom	40	0.55	0.82	10.35
2.	Umuodu	40	0.54	0.82	10.54
3.	Umuonyeche	40	0.53	0.85	10.54
4.	Umuoyima	41	0.54	0.82	10.44
5.	Umuororonjo	39	0.55	0.85	10.54
Ehime Mbano L.G.A.					
Umuezeala					
6.	Umuezeala-Ama	48	0.63	0.51	12.34
7.	Umuezeala-Owerre	48	0.64	0.53	12.39
8.	Umuopara	48	0.65	0.53	12.10
Umueze II					
9.	Umueleke	47	0.62	0.53	12.17
10	Umuodara	47	0.62	0.52	12.16
11.	Umuduruegwele	47	0.64	0.56	12.24
Umunakanu					
12.	Umuele	46	0.64	0.52	12.30
13.	Umueli	47	0.64	0.55	12.37

S/N	**Sampling area**	**CO (ppm)**	**NO$_2$ (ppm)**	**SO$_2$ (ppm)**	**PM$_{10}$ mg/m^3)**
14.	Umuola	48	0.63	0.52	12.20
Umunumo					
15.	Umuaro	46	0.60	0.50	12.15
16.	Umuokpara	46	0.65	0.54	12.30
17.	Umuchima	47	0.63	0.53	12.30
Nsu					
18.	Agbaghara	49	0.68	0.56	12.30
19.	Ezeoke	50	0.65	0.55	12.12
20.	Umuakagu	48	0.63	0.55	12.11
Mbaitoli L.G.A.					
Mbieri					
21.	Obazu	43	0.65	0.60	10.12
22.	Umuonyeali	44	0.63	0.62	10.21
23.	Umudagu	44	0.62	0.62	10.33
Ogwa					
24.	Idem-Ogwa	43	0.62	0.62	10.23
25.	Ochii	43	0.65	0.65	10.38
26.	Umueze	43	0.63	0.61	10.33
Ubomiri					
27.	Egbeada	46	0.69	0.65	11.70
28.	Obokpu	46	0.70	0.64	11.45
29	Umuabali	45	0.68	0.62	11.55
	Orodo				
30.	Obi-Orodo	46	0.69	0.64	11.50
31.	Ofekata	47	0.69	0.63	11.56
32.	Ubaha	45	0.70	0.62	11.63
Ifakala					
33.	Umunoha	45	0.72	0.60	11.47
34.	Nworieubi	47	0.74	0.67	11.69
35.	Nkwesi	46	0.71	0.64	11.46

RESULTS

The results obtained from the analysis of atmospheric pollutant concentrations at 35 selected locations within Imo State in both the dry (November D_1, January D_2, February D_3) and rainy seasons (June R_1, July R_2, and August R_3) for a 2-year analytical period using standard instrumental methods are shown in Tables 3–5.

Table 3. Rainy season (year 1) mean value data for gases and PM$_{10}$.

S/N	**Sampling area**	**CO (ppm)**	**NO$_2$ (ppm)**	**SO$_2$ (ppm)**	**PM$_{10}$ (mg/m^3)**
Owerri Municipal L.G.A.					
1.	Amawom	51	0.58	0.67	7.36
2.	Umuodu	52	0.58	0.68	7.52
3.	Umuonyeche	52	0.60	0.67	7.55
4.	Umuoyima	53	0.58	0.67	7.50
5.	Umuororonjo	52	0.59	0.68	7.53
Ehime Mbano L.G.A.					
Umuezeala					
6.	Umuezeala-Ama	62	0.66	0.42	8.77

S/N	Sampling area	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (mg/m^3)
7.	Umuezeala-Owerre	62	0.65	0.45	8.65
8.	Umuopara	62	0.68	0.45	8.70
Umueze II					
9.	Umueleke	61	0.65	0.43	8.54
10	Umuodara	62	0.65	0.43	8.57
11.	Umuduruegwele	62	0.66	0.45	8.54
Umunakanu					
12.	Umuele	60	0.68	0.43	8.60
13.	Umueli	60	0.68	0.45	8.61
14.	Umuola	60	0.67	0.47	8.63
Umunumo					
15.	Umuaro	62	0.64	0.43	8.55
16.	Umuokpara	61	0.67	0.44	8.56
17.	Umuchima	62	0.66	0.45	8.58
Nsu					
18.	Agbaghara	63	0.70	0.46	8.65
19.	Ezeoke	64	0.68	0.45	8.63
20.	Umuakagu	64	0.65	0.45	8.60
Mbaitoli L.G.A.					
Mbieri					
21.	Obazu	55	0.65	0.50	7.32
22.	Umuonyeali	56	0.68	0.51	7.34
23.	Umudagu	57	0.67	0.52	7.35
Ogwa					
24.	Idem-Ogwa	56	0.65	0.54	7.25
25.	Ochii	56	0.68	0.55	7.21
26.	Umueze	57	0.67	0.52	7.24
Ubomiri					
27.	Egbeada	58	0.71	0.55	8.18
28.	Obokpu	58	0.73	0.54	8.20
29	Umuabali	57	0.71	0.53	8.21
Orodo					
30.	Obi-Orodo	59	0.73	0.54	8.05
31.	Ofekata	58	0.74	0.54	8.06
32.	Ubaha	59	0.73	0.53	8.04
Ifakala					
33.	Umunoha	58	0.75	0.50	8.24
34.	Nworieubi	59	0.77	0.54	8.35
35.	Nkwesi	57	0.75	0.54	8.31

Table 4 Dry season (Year 2) mean value data for gases and PM_{10}.

S/N	Sampling area	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (mg/m^3)
Owerri Municipal L.G.A.					
1.	Amawom	44	0.62	0.90	11.05
2.	Umuodu	43	0.58	0.88	11.08
3.	Umuonyeche	43	0.56	0.88	11.16
4.	Umuoyima	45	0.57	0.87	11.15
5.	Umuororonjo	42	0.56	0.86	11.00

S/N	Sampling area	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (mg/m^3)
Ehime Mbano L.G.A.					
Umuezeala					
6.	Umuezeala-Ama	51	0.65	0.55	12.88
7.	Umuezeala-Owerre	50	0.65	0.58	12.82
8.	Umuopara	50	0.66	0.56	12.80
Umueze II					
9.	Umueleke	50	0.63	0.55	12.80
10	Umuodara	49	0.65	0.54	12.84
11.	Umuduruegwele	51	0.64	0.58	12.82
Umunakanu					
12.	Umuele	49	0.68	0.55	12.86
13.	Umueli	50	0.65	0.57	12.87
14.	Umuola	51	0.66	0.56	12.80
Umunumo					
15.	Umuaro	50	0.63	0.53	12.75
16.	Umuokpara	49	0.68	0.57	12.83
17.	Umuchima	48	0.65	0.56	12.70
Nsu					
18.	Agbaghara	49	0.70	0.58	12.74
19.	Ezeoke	52	0.68	0.57	12.72
20.	Umuakagu	50	0.65	0.58	12.80
Mbaitoli L.G.A.					
Mbieri					
21.	Obazu	46	0.67	0.63	10.78
22.	Umuonyeali	47	0.65	0.64	10.21
23.	Umudagu	46	0.63	0.64	10.33
Ogwa					
24.	Idem-Ogwa	45	0.64	0.65	10.87
25.	Ochii	46	0.68	0.65	10.88
26.	Umueze	46	0.65	0.65	10.93
Ubomiri					
27.	Egbeada	48	0.70	0.67	12.20
28.	Obokpu	48	0.72	0.68	11.91
29	Umuabali	45	0.70	0.66	12.15
Orodo					
30.	Obi-Orodo	47	0.70	0.67	11.95
31.	Ofekata	48	0.71	0.65	11.96
32.	Ubaha	45	0.72	0.65	11.95
Ifakala					
33.	Umunoha	47	0.72	0.63	11.93
34.	Nworieubi	50	0.76	0.65	12.04
35.	Nkwesi	50	0.74	0.64	12.01

Table 5 Rainy season (year 2) mean value data for gases and PM_{10}.

S/N	Sampling area	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (mg/m^3)
Owerri Municipal L.G.A.					
1.	Amawom	56	0.78	0.75	7.70
2.	Umuodu	54	0.78	0.78	7.69
3.	Umuonyeche	56	0.77	0.76	7.72

S/N	Sampling area	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (mg/m^3)
4.	Umuoyima	56	0.75	0.78	7.71
5.	Umuororonjo	55	0.76	0.77	7.68
Ehime Mbano L.G.A.					
Umuezeala					
6.	Umuezeala-Ama	66	0.84	0.51	9.01
7.	Umuezeala-Owerre	65	0.85	0.50	8.86
8.	Umuopara	66	0.84	0.51	8.85
Umueze II					
9.	Umueleke	65	0.85	0.48	8.85
10	Umuodara	67	0.86	0.51	8.90
11.	Umuduruegwele	65	0.87	0.50	8.92
Umunakanu					
12.	Umuele	67	0.83	0.52	8.85
13.	Umueli	64	0.85	0.50	8.85
14.	Umuola	65	0.84	0.48	8.78
Umunumo					
15.	Umuaro	65	0.83	0.49	8.86
16.	Umuokpara	65	0.85	0.50	8.95
17.	Umuchima	68	0.85	0.50	8.84
Nsu					
18.	Agbaghara	65	0.80	0.50	8.94
19.	Ezeoke	66	0.83	0.52	9.02
20.	Umuakagu	65	0.85	0.50	8.95
Mbaitoli L.G.A.					
Mbieri					
21.	Obazu	58	0.87	0.51	8.42
22.	Umuonyeali	57	0.86	0.52	8.46
23.	Umudagu	57	0.87	0.51	8.45
Ogwa					
24.	Idem-Ogwa	56	0.91	0.53	8.52
25.	Ochii	58	0.92	0.51	8.53
26.	Umueze	57	0.93	0.54	8.55
Ubomiri					
27.	Egbeada	58	0.90	0.56	8.68
28.	Obokpu	56	0.91	0.50	8.65
29	Umuabali	58	0.86	0.53	8.70
Orodo					
30.	Obi-Orodo	62	0.93	0.53	8.85
31.	Ofekata	61	0.90	0.54	8.76
32.	Ubaha	61	0.86	0.55	8.75
Ifakala					
33.	Umunoha	58	0.87	0.53	8.81
34.	Nworieubi	62	0.93	0.55	8.85
35.	Nkwesi	61	0.86	0.54	8.80

HUMAN HEALTH RISK ASSESSMENT

A comprehensive process for characterizing the negative effects of human exposure to hazardous chemicals is a health risk assessment. The human health risk assessment (HHRA) measures the health impacts of human exposure to a specific pollutant using exposure data that are currently available and predictive [15]. Numerous epidemiological studies have discovered a link between poor air quality and a range of harmful health effects, highlighting the major contribution of air pollution to the disease burden in the general population, which can range from subclinical effects to early mortality. At the individual, societal, and preventative health and disease levels, the health risk assessment of air quality is extremely important. Air Pollution Health Risk Assessment (AP-HRA) is a crucial tool for informing public policy decisions because it projects the anticipated health effects of measures affecting air quality under different policy, environmental, and socioeconomic scenarios (Table 6–8)

Table 6 Mean values for CO (ppm) for both years.

S/N	Sampling area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Owerri Municipal L.G.A.							
1.	Amawom	40	44	42	51	56	54
2.	Umuodu	40	43	42	52	54	53
3.	Umuonyeche	40	43	42	52	56	54
4.	Umuoyima	41	45	43	53	56	55
5.	Umuororonjo	39	42	41	52	55	54
Ehime Mbano L.G.A.							
Umuezeala							
6.	Umuezeala-Ama	48	51	50	62	66	64
7.	Umuezeala-Owerre	48	50	49	62	65	64
8.	Umuopara	48	50	49	62	66	64
Umueze II							
9.	Umueleke	47	50	49	61	65	63
10.	Umuodara	47	49	48	62	67	65
11.	Umuduruegwele	47	51	49	62	65	64
Umunakanu							
12.	Umuele	46	49	48	60	67	64
13.	Umueli	47	50	49	60	64	62
14.	Umuola	48	51	50	60	65	63
Umunumo							
15.	Umuaro	46	50	48	62	65	64
16.	Umuokpara	46	49	48	61	65	63
17.	Umuchima	47	48	48	62	68	65
Nsu							
18.	Agbaghara	49	49	49	63	65	64
19.	Ezeoke	50	52	51	64	66	65
20.	Umuakagu	48	50	49	64	65	65
Mbaitoli L.G.A.							
Mbieri							
21.	Obazu	43	46	45	55	58	57
22.	Umuonyeali	44	47	46	56	57	57
23.	Umudagu	44	46	45	57	57	57
Ogwa							
24.	Idem-Ogwa	43	45	44	56	56	56
25.	Ochii	43	46	45	56	58	57
26.	Umueze	43	46	45	57	57	57
Ubomiri							
27.	Egbeada	46	48	47	58	58	58
28.	Obokpu	46	48	47	58	56	57
29.	Umuabali	45	45	45	57	58	58

S/N	Sampling area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Orodo							
30.	Obi-Orodo	46	47	47	59	62	61
31.	Ofekata	47	48	48	58	61	60
32.	Ubaha	45	45	45	59	61	60
Ifakala							
33.	Umunoha	45	47	46	58	58	58
34.	Nworieubi	47	50	49	59	62	61
35.	Nkwesi	46	50	48	57	61	59

Table 7. Carbon monoxide ANOVA table.

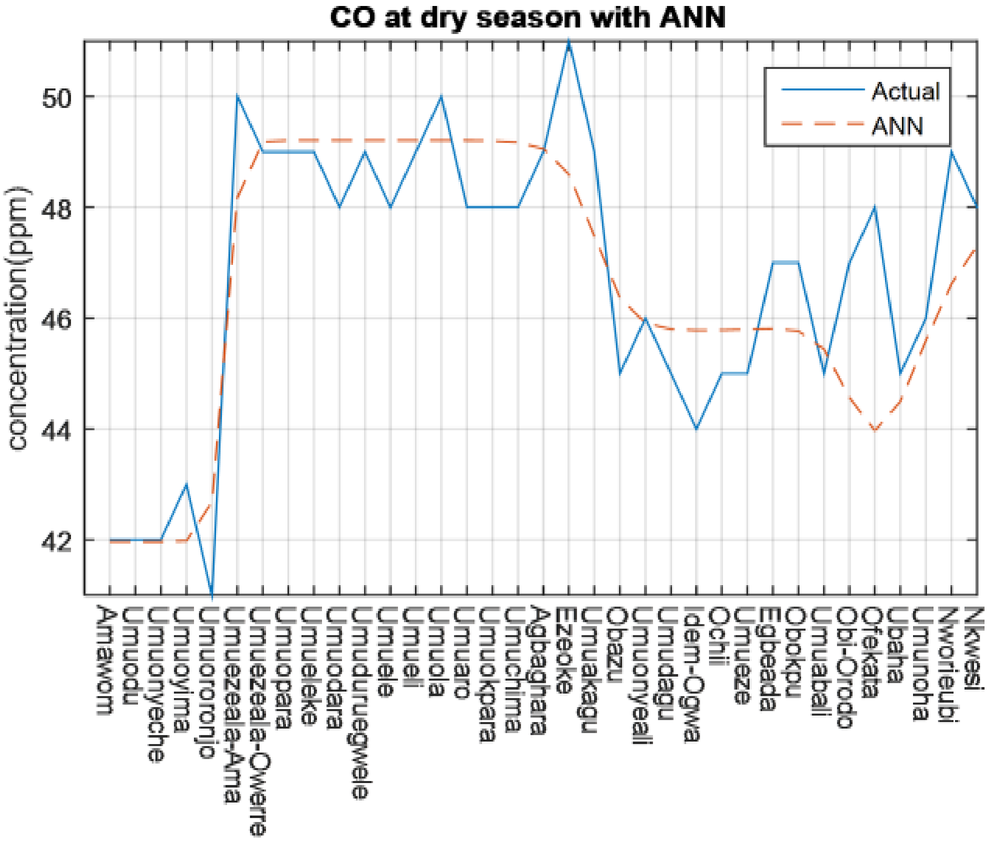
Source	SS	df	MS	F	Prob>F
Columns	3102.23	1	3102.23	284.08	5.60542-26
Error	742.57	68	10.92		
Total	3844.8	69			

Table 8. Mean values NO_2 (ppm) for both years.

S/N	Sampling area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Owerri Municipal L.G.A.							
1.	Amawom	0.55	0.62	0.59	0.58	0.78	0.68
2.	Umuodu	0.54	0.58	0.56	0.58	0.78	0.68
3.	Umuonyeche	0.53	0.56	0.55	0.60	0.77	0.69
4.	Umuoyima	0.54	0.57	0.56	0.58	0.75	0.67
5.	Umuororonjo	0.55	0.56	0.56	0.59	0.76	0.68
Ehime Mbano L.G.A.							
Umuezeala							
6.	Umuezeala-Ama	0.63	0.65	0.64	0.66	0.84	0.75
7.	Umuezeala-Owerre	0.64	0.65	0.65	0.65	0.85	0.76
8.	Umuopara	0.65	0.66	0.66	0.68	0.84	0.76
Umueze II							
9.	Umueleke	0.62	0.63	0.63	0.65	0.85	0.75
10.	Umuodara	0.62	0.65	0.64	0.65	0.86	0.76
11.	Umuduruegwele	0.64	0.64	0.64	0.66	0.87	0.77
Umunakanu							
12.	Umuele	0.64	0.68	0.66	0.68	0.83	0.76
13.	Umueli	0.64	0.65	0.65	0.68	0.85	0.77
14.	Umuola	0.63	0.66	0.65	0.67	0.84	0.76
Umunumo							
15.	Umuaro	0.60	0.63	0.62	0.64	0.83	0.74
16.	Umuokpara	0.65	0.68	0.67	0.67	0.85	0.76
17.	Umuchima	0.63	0.65	0.64	0.66	0.85	0.76
Nsu							
18.	Agbaghara	0.68	0.70	0.69	0.70	0.80	0.75
19.	Ezeoke	0.65	0.68	0.67	0.68	0.83	0.76
20.	Umuakagu	0.63	0.65	0.64	0.65	0.85	0.75
Mbaitoli L.G.A.							
Mbieri							
21.	Obazu	0.65	0.67	0.66	0.65	0.87	0.76
22.	Umuonyeali	0.63	0.65	0.64	0.68	0.86	0.77

S/N	Sampling area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
23.	Umudagu	0.62	0.63	0.63	0.67	0.87	0.77
Ogwa							
24.	Idem-Ogwa	0.62	0.64	0.63	0.65	0.91	0.78
25.	Ochii	0.65	0.68	0.67	0.68	0.92	0.80
26.	Umueze	0.63	0.65	0.64	0.67	0.93	0.80
Ubomiri							
27.	Egbeada	0.69	0.70	0.70	0.71	0.90	0.81
28.	Obokpu	0.70	0.72	0.71	0.73	0.91	0.82
29.	Umuabali	0.68	0.70	0.69	0.71	0.86	0.79
Orodo							
30.	Obi-Orodo	0.69	0.70	0.70	0.73	0.93	0.83
31.	Ofekata	0.69	0.71	0.70	0.74	0.90	0.82
32.	Ubaha	0.70	0.72	0.71	0.73	0.86	0.80
Ifakala							
33.	Umunoha	0.72	0.72	0.72	0.75	0.87	0.81
34.	Nworieubi	0.74	0.76	0.75	0.77	0.93	0.85
35.	Nkwesi	0.71	0.74	0.73	0.75	0.86	0.81

Given that air pollution is currently one of the biggest health risks, there is sufficient scientific evidence to support the creation of methods that integrate epidemiological evaluation into the risks associated with health (Figures 2 and 3). The concept of AP-HRA has been present since the 1950s, but its adoption by the global healthcare system has not happened as swiftly. It is extremely important for disease prevention and health promotion at the individual, community, and global levels (Tables 9 and 10).



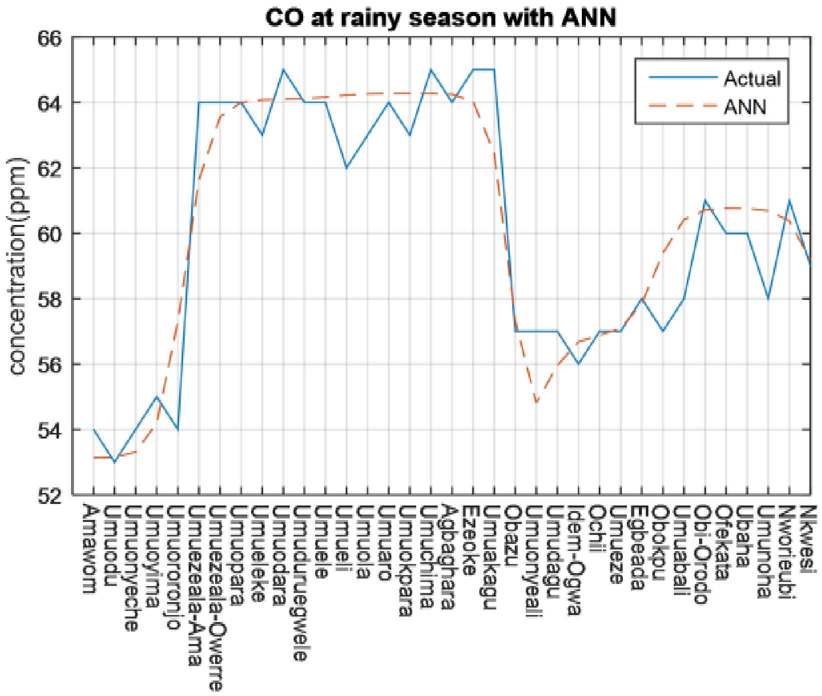


Figure 2. Comparative analysis of actual and ANN predicted CO.

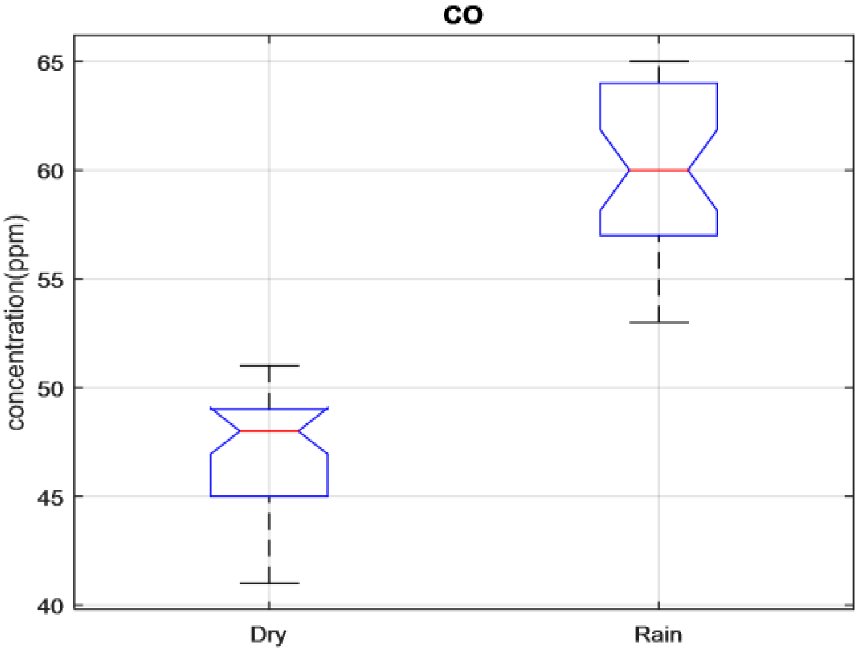


Figure 3. Carbon monoxide Box and Whiskers comparative plot for dry and rainy seasons.

Table 9. Mean values PM_{10} (ppm) for both years.

S/N	Sampling Area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Owerri Municipal L.G.A.							
1.	Amawom	10.35	11.05	10.70	7.36	7.70	7.53
2.	Umuodu	10.54	11.08	10.81	7.52	7.69	7.61
3.	Umuonyeche	10.54	11.16	10.80	7.55	7.72	7.64
4.	Umuoyima	10.44	11.15	10.78	7.50	7.71	7.61
5.	Umuororonjo	10.54	11.00	10.77	7.53	7.68	7.61

S/N	Sampling Area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Ehime Mbano L.G.A.							
Umuezeala							
6.	Umuezeala-Ama	12.34	12.88	12.61	8.77	9.01	8.89
7.	Umuezeala-Owerre	12.39	12.82	12.61	8.65	8.86	8.76
8.	Umuopara	12.10	12.80	12.45	8.70	8.85	8.78
Umueze II							
9.	Umueleke	12.17	12.80	12.49	8.54	8.85	8.70
10.	Umuodara	12.16	12.84	12.51	8.57	8.90	8.74
11.	Umuduruegwele	12.24	12.82	12.53	8.54	8.92	8.73
Umunakanu							
12.	Umuele	12.30	12.86	12.58	8.60	8.85	8.73
13.	Umueli	12.37	12.87	12.62	8.61	8.85	8.73
14.	Umuola	12.20	12.80	12.50	8.63	8.78	8.71
Umunumo							
15.	Umuaro	12.15	12.75	12.45	8.55	8.86	8.71
16.	Umuokpara	12.30	12.83	12.57	8.56	8.95	8.76
17.	Umuchima	12.30	12.70	12.50	8.58	8.84	8.71
Nsu							
18.	Agbaghara	12.30	12.74	12.52	8.65	8.94	8.80
19.	Ezeoke	12.12	12.72	12.42	8.63	9.02	8.83
20.	Umuakagu	12.11	12.80	12.46	8.60	8.95	8.78
Mbaitoli L.G.A.							
Mbieri							
21.	Obazu	10.12	10.78	12.45	7.32	8.42	7.87
22.	Umuonyeali	10.21	10.21	10.21	7.34	8.46	8.10
23.	Umudagu	10.33	10.33	10.33	7.35	8.45	7.90
Ogwa							
24.	Idem-Ogwa	10.23	10.87	10.55	7.25	8.52	7.89
25.	Ochii	10.38	10.88	10.63	7.21	8.53	7.87
26.	Umueze	10.33	10.93	10.63	7.24	8.55	7.90
Ubomiri							
27.	Egbeada	11.70	12.20	11.95	8.18	8.68	8.43
28.	Obokpu	11.45	11.91	11.68	8.20	8.65	8.43
29.	Umuabali	11.55	12.15	11.85	8.21	8.70	8.46
Orodo							
30.	Obi-Orodo	11.50	11.95	11.73	8.05	8.85	8.45
31.	Ofekata	11.56	11.96	11.76	8.06	8.76	8.41
32.	Ubaha	11.63	11.95	11.79	8.04	8.75	8.40
Ifakala							
33.	Umunoha	11.47	11.93	11.70	8.24	8.81	8.53
34.	Nworieubi	11.69	12.04	11.87	8.35	8.85	8.43
35.	Nkwesi	11.46	12.01	11.74	8.31	8.80	8.56

Table 10. Particulate matter ANOVA table.

Source	SS	df	MS	F	Prob>F
Columns	204.208	1	204.208	475.25	2.12638e-32
Error	29.219	68	0.43		
Total	233.427	69			

By weighing the costs and health benefits of climate change mitigation measures, HRA tools can help with policy decision-making (Figure 4, 5).

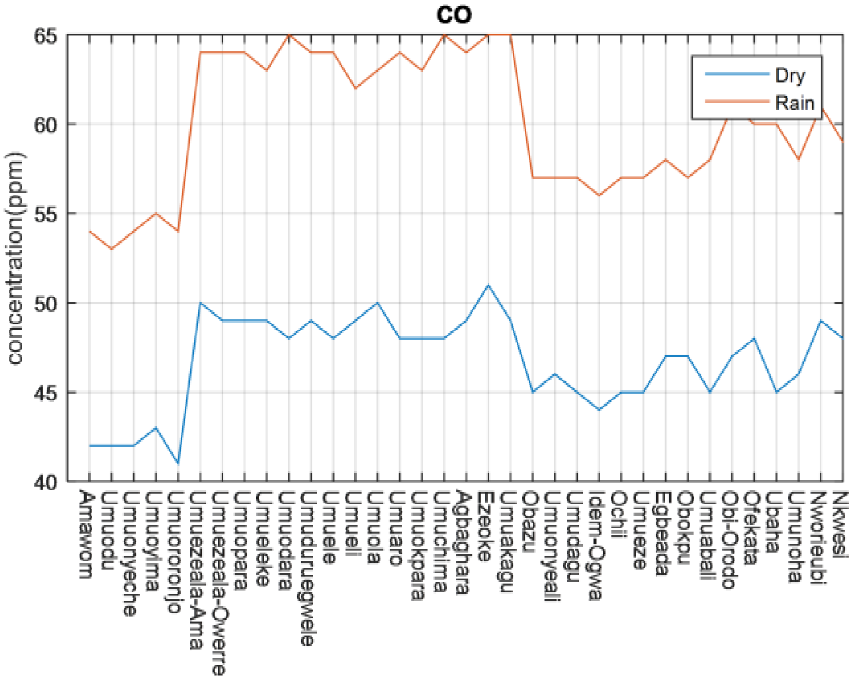


Figure 4. Carbon monoxide MATLAB comparison model.

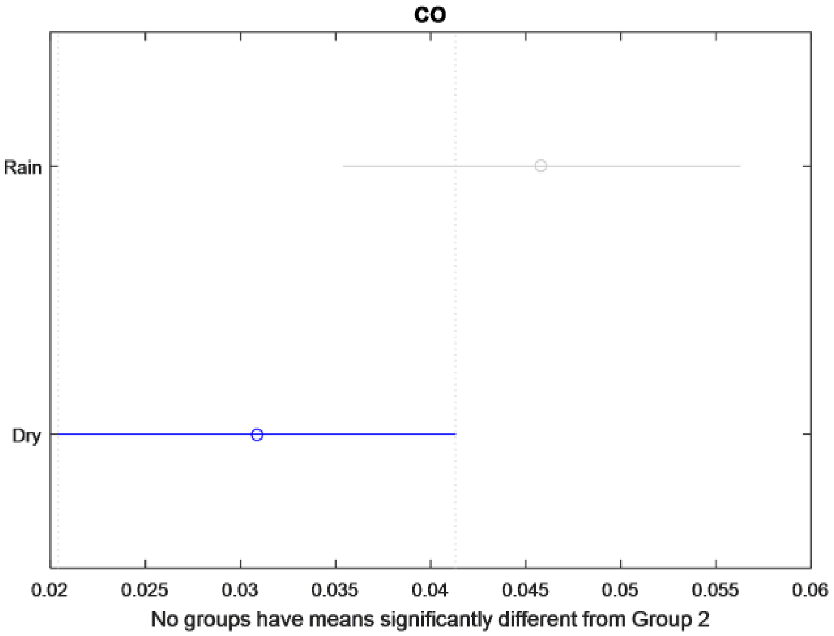


Figure 5. Carbon monoxide mean comparative analysis of dry and rainy seasons.

“AP-HRAs estimate the health impact to be expected from measures that affect air quality, in different socioeconomic, environmental, and policy circumstances,” the World Health Organization states. Consequently, it is an essential tool for directing the creation of public policies.

For regulatory decision-making and public participation, it summarizes data on exposure to air pollution, health effects, and community risk. AP-HRAs have been utilized in numerous studies, such as the WHO’s Global Burden of Illness study, to help comprehend the health benefits that will result from improved air quality. They have switched over the past ten years from primarily qualitative to quantitative methods. HRA tools evaluate the health hazards associated with key pollutants, such as nitrogen and sulphur oxides (NOx and SOx, respectively), ground-level ozone (O_3), and particulate matter (PM2.5), for the population that is exposed to them. Concentration Response Functions (CRFs), use the predicted mortality rates from lung cancer, ischemic heart disease, stroke, and respiratory infections to relate the change in the level of air pollution concentration [15]. This work presents the concept of AP-HRA, provides an outline for conducting AP-HRA properly for various situations, and provides a general explanation of how air pollution-related impacts are assessed, and how health hazards associated with air pollutants and their sources are measured (Figures 6–9).

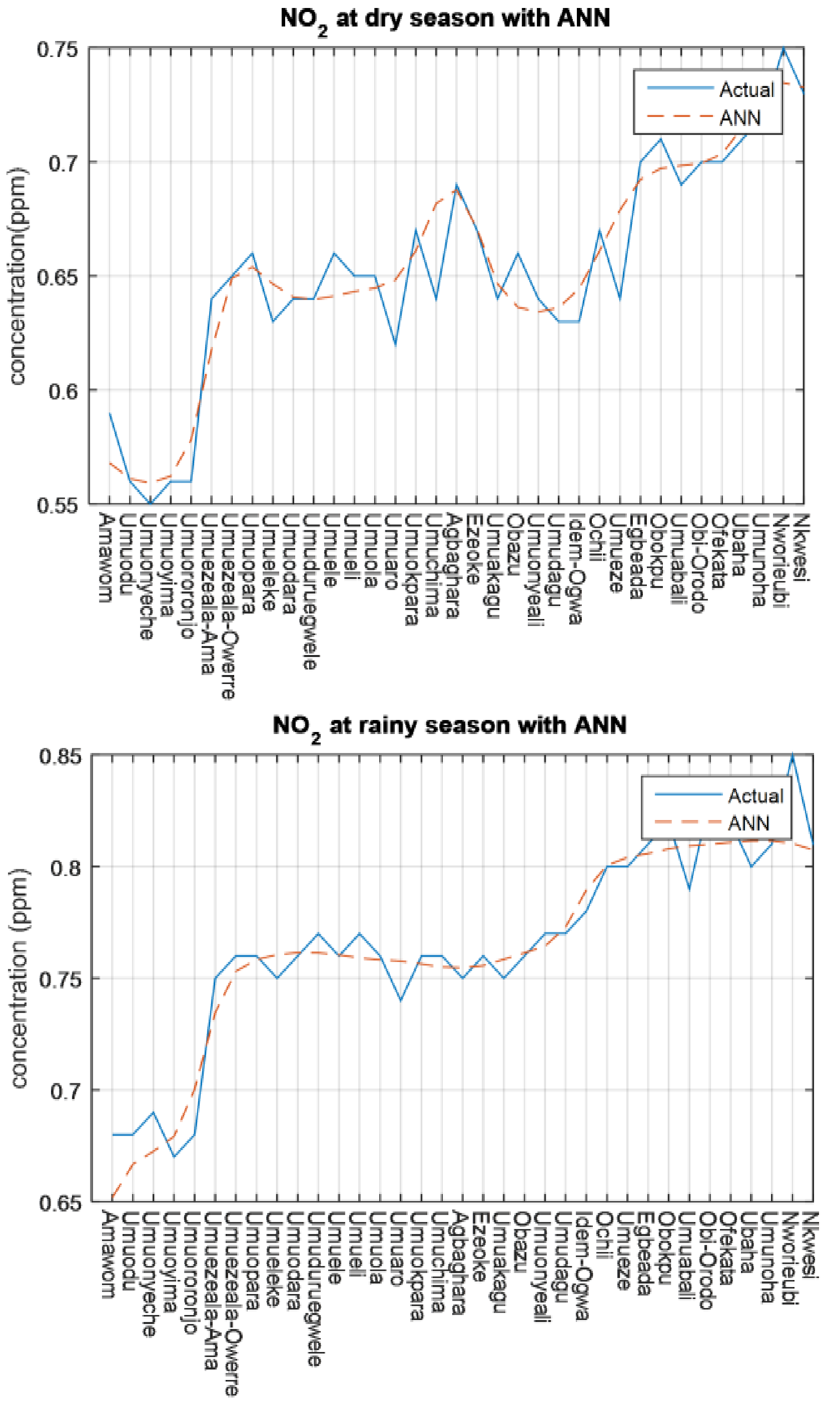


Figure 6. Comparative analysis of actual and ANN predicted NO_2.

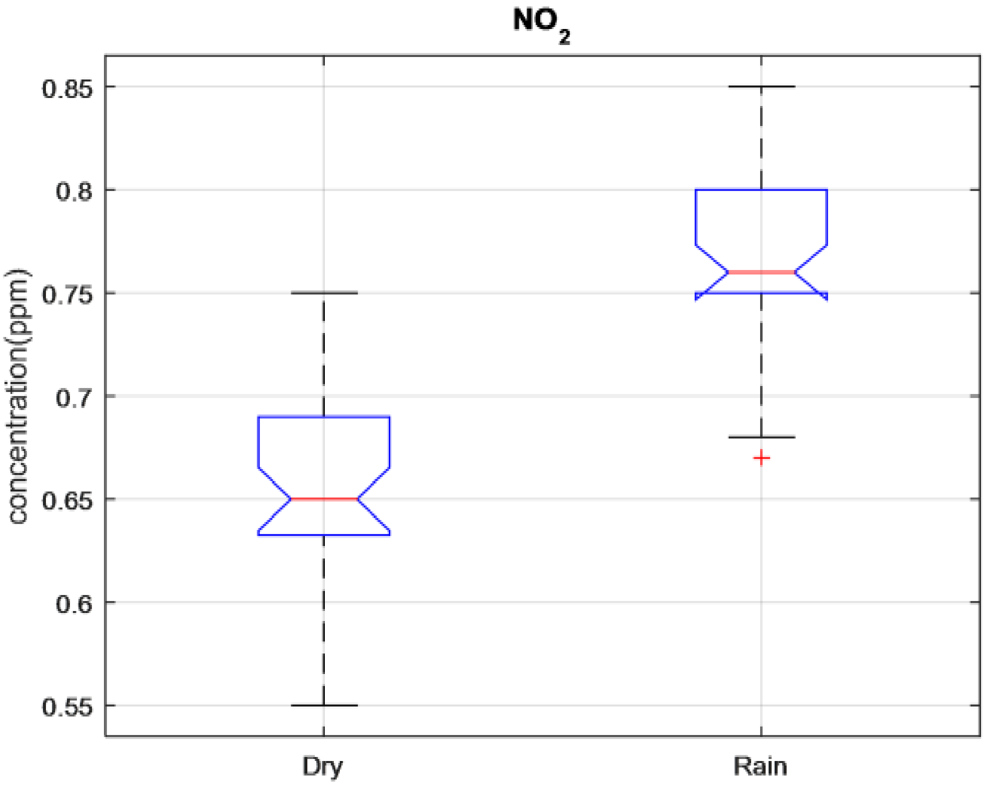


Figure 7. Nitrogen dioxide of Box and Whiskers comparative plot of dry and rainy seasons.

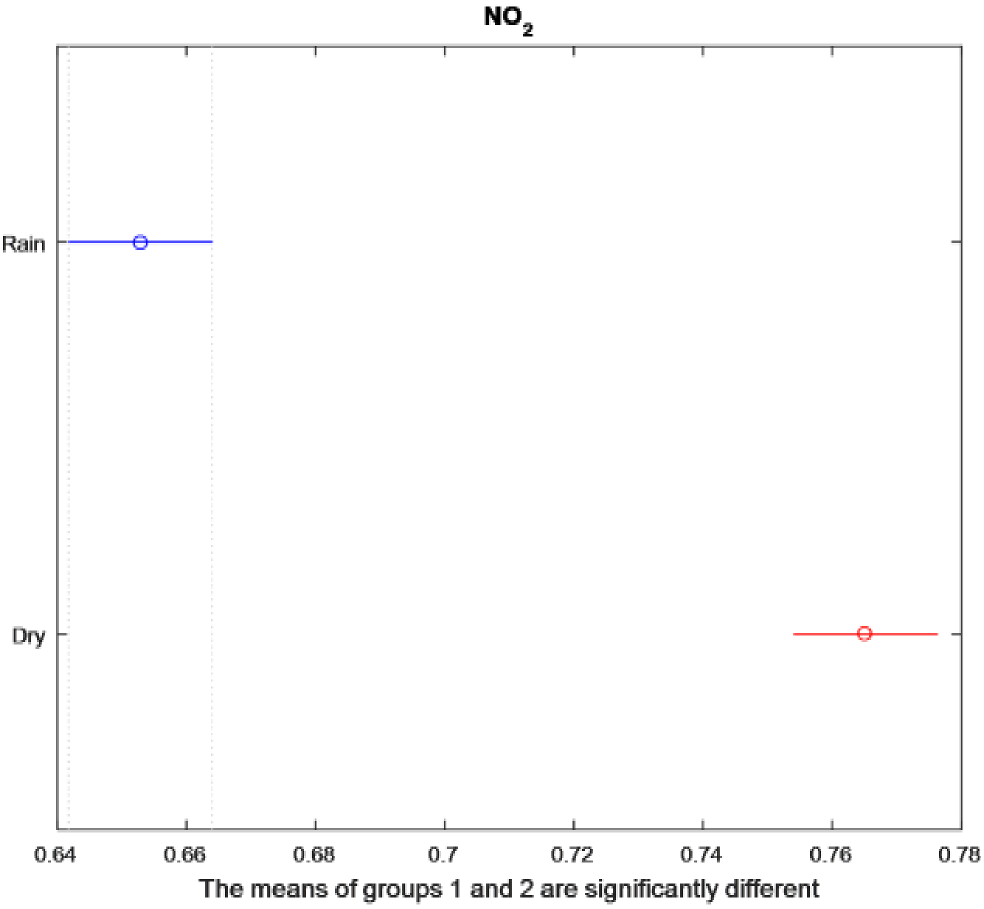


Figure 8. Nitrogen dioxide mean comparative analysis of dry and rainy seasons.

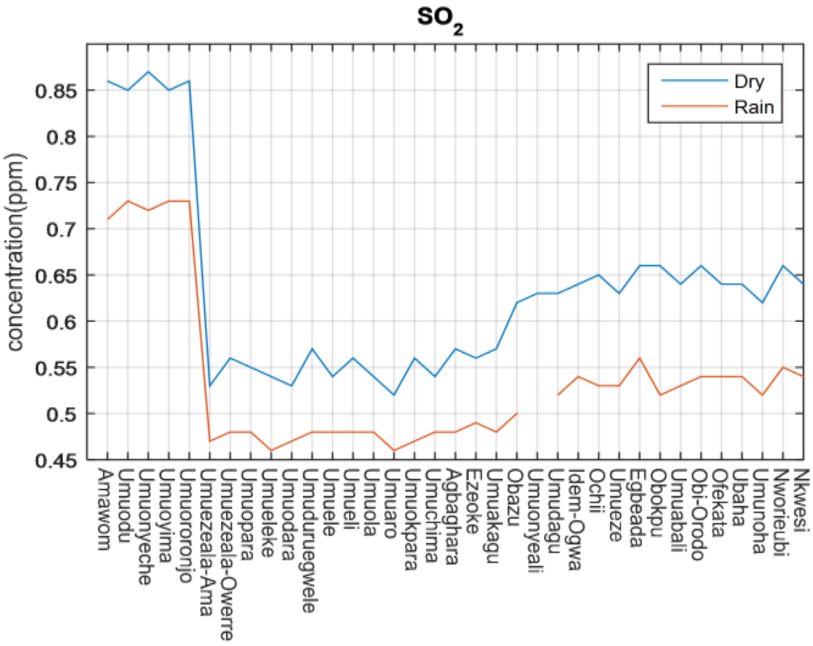
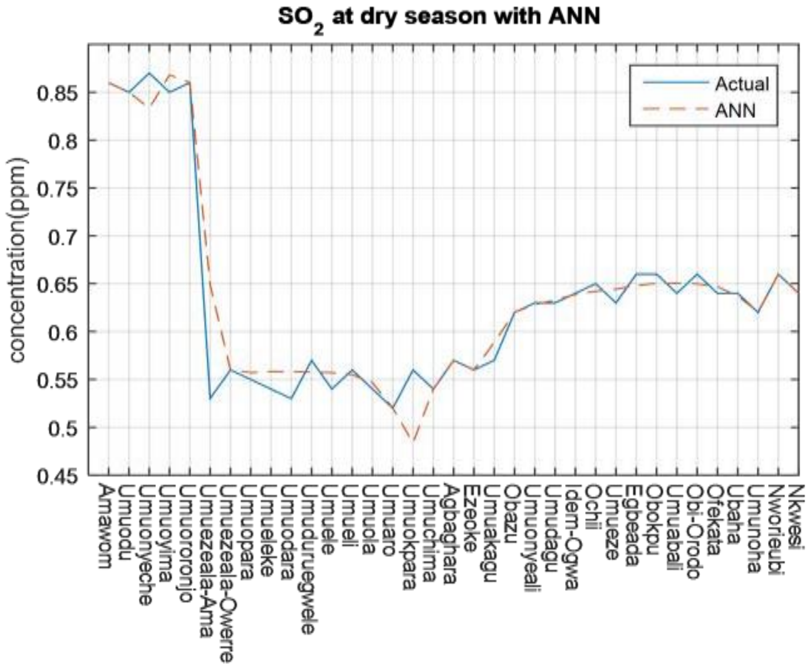


Figure 9. Sulphur dioxide MATLAB comparison model.



The four parts of the HHRA framework are risk characterization, exposure assessment, dose-response assessment, and hazard identification.

Hazard Identification

A literature review was conducted to determine the health concerns associated with PM10, CO, NO_2, and SO_2.

Assessment of Dose-Response

In this case, the quantity of pollutants ingested by the body was calculated based on the exposure duration and concentration (WHO, 1999). This investigation lacked a dose-response evaluation. Instead, we used the National Ambient Air Quality Standard (NAAQS) as the baseline and compared the detected ambient concentrations of the contaminants in the research area.

Evaluation of Exposure

The population exposed to the risk, as well as the level and length of exposure, was determined by exposure assessment. In our analysis, the primary pathway of exposure to the contaminants under observation is believed to be inhalation. A scenario assessment method was employed in this study. The worst-case (continuous exposure) and typical (average exposure) scenarios were computed for both the intermediate (24-hour) and chronic (year) exposure periods. Additionally, typical acute exposure times of one hour were determined. These were ascertained across three age groups: children (6–12 years), adults (19–75 years), and newborns (birth to one year). The acute exposure rate equation for non-carcinogenic pollutants (PM10, CO, NO_2, and SO_2) was as follows:

$$AHD = C \times IR/BW \tag{1}$$

Where;

The average hourly dose for inhalation (µg/kg/h) is known as the AHD. where C is the chemical concentration (µg/m^3).

The term “inhalation rate” (m^3/hour) is IR.
Body weight is expressed as BW (kg) [16]

The exposure equation for the inhalation exposure route for non-carcinogenic pollutants (PM10, CO, NO_2, and SO_2) is.

$$ADD = (C \times IR \times ED)/(BW \times AT) \tag{2}$$

Where;

The ADD is the average daily dose of the chemical of interest (µg/kg/day).

C is the amount of the chemical in ambient air (µg/m^3), and IR is the inhalation rate (m^3/day).

IR is the inhalation rate (m 3 /day)

ED is the exposure duration (days)

BW is the body weight of the exposed group (kg)

AT is the average time (days) (USEPA, 1988)

$$ED \text{ (exposure duration)} = ET \times EF \times DE \tag{3}$$

Where;

ET is the exposure time (hour/day)

EF is the exposure frequency (days/year)

DE is the duration of exposure (year).

Table 11 illustrates the assumptions that underpin the requirements for each age group (USEPA, 1997). The EF value is determined by assuming that an individual is absent from their residence (study area) for 14 days each year [17]. For infants, children, and adults, DE was determined at 1, 12, and 30 years of age, respectively (Figure 10). The estimated AT was calculated by multiplying the exposure time by 365 d per year. The estimated ET values for acute, intermediate, and chronic exposure durations based on average and continuous scenarios are presented in Table 12 for each population group [17]. The default values for IR and BW (USEPA, 1997) for each exposure group are listed in Table 13.

Table 11. Exposure frequency, exposure duration, and averaging time for different exposure groups.

Exposed group	**EF (days/year))**	**DE (year))**	**AT (days)**
Infant (birth–1 year)	350	1	365 (1×365)
Child (6–12 years)	350	12	4,380 (12×365)
Adult (19–75 years)	350	30	10,950 (30×365)

Source: Adapted from Matooane and Diab and US Environmental Protection Agency. AT, averaging time; DE, duration of exposure; EF, exposure frequency.

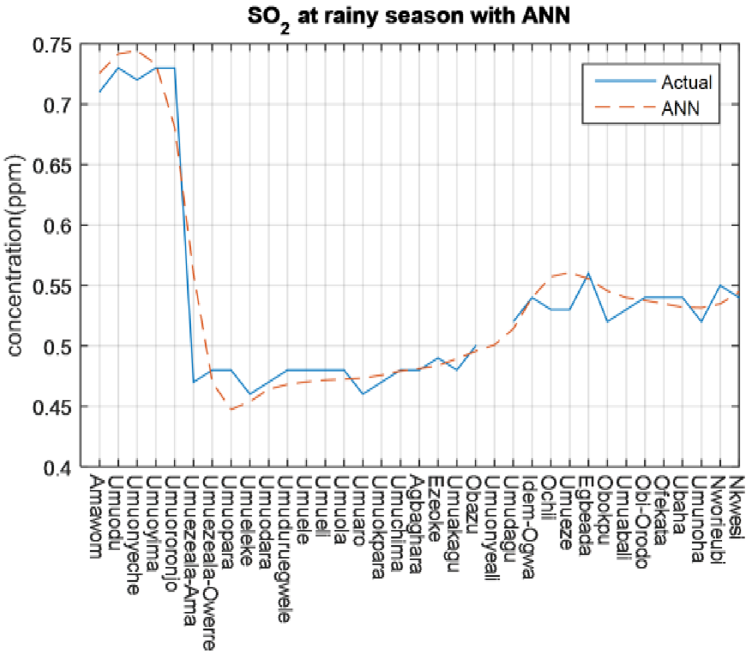


Figure 10. Comparative analysis of actual and ANN predicted SO_2.

Table 12. Exposure time (hours) for normal and worst-case scenarios for acute, intermediate, and chronic exposures.

Exposed group	**Exposure time (hours)**				
	Intermediate			***Chronic***	
	Acute	*Normal*	*Worst case*	*Normal*	*Worst case*
Infant (birth–1 year)	1	1	24	14.6((350/24) ×1)	365(1×350)
Child (6–12 years)	1	6	24	1,050((4,200/24) ×6)	4,200(12×350)
Adult (19–75 years)	1	3	24	1,312.5((10,500/24) ×3)	10,500(30×350)

Source: Adapted from Matooane and Diab and US Environmental Protection Agency.

Table 13. Average inhalation rates and body weights of the exposed population.

Exposed group	**Mean inhalation rate (m^3/hour)**		
	Acute exposure	***Chronic exposure***	***Mean body weight (kg)***
Infant (birth–1 year)	0.3	6.8	11.3
Child (6–12 years)	1.2	13.5	45.3
Adult (19–75 years)	1.2	13.3	71.8

Source: Adapted from Matooane and Diab and US Environmental Protection Agency.

Characterization of Risk

The quantitative assessment of the health risks associated with pollutant exposure is known as risk characterization. The possible non-carcinogenic effects of exposure to a known pollutant were measured using the hazard quotient (HQ) [17]. This shows the likelihood that someone healthy and/or sensitive will experience negative health consequences. For both acute and chronic exposure scenarios, non-cancer hazards were computed as follows:

$$HQ = ADD/REL \text{ (chronic exposure)} \quad (4)$$
$$HQ = AHD/REL \text{ (acute exposure)} \quad (5)$$

Where;

REL is the dosage at which the exposed groups experience noticeably worse health outcomes than the unexposed group. We used the term "Reference Exposure Level" (REL), which was developed by the Office of the Environmental Health Hazard Assessment (OEHHA), in this inquiry. Table 14 lists the RELs used. The standard for safety was an HQ of 1.0. A 1.0 HQ suggests that there could be dangers associated with exposure for those who are easily offended.

Table 14. Reference exposure levels for different pollutants.

Pollutant	1 hr. (μg/m^3)	8hr. (μg/m^3)	24 hr. (μg/m^3)	Annual mean (μg/m^3)
PM_{10}	-		50′	20′
NO_2	200*		80†	40*
SO_2	350*		125*	50*
CO	87,500‡	22,500‡	-	-

*Note: *, EU Standard); ′, WHO Standard; †, NAAQS Air Quality Guideline; ‡, Default value was converted from ppm to μg/m^3. CO, carbon monoxide; NO_2, nitrogen dioxide; PM_{10}, particulate matter; SO_2, Sulphur dioxide.*
Source: Department of Environmental Affairs.

RESULTS

PM_{10} Concentration

Table 9 shows the annual mean range of PM_{10} in the dry seasons was 10.21–12.62 mg/m^3 which was higher than that of the rainy seasons 7.53–8.89 mg/m^3. The highest reading (12.62 mg/m^3) occurred in the dry season. PM_{10} was present throughout the year, with the dry season being more polluted. PM_{10} concentrations were higher than the FEPA and NAAQS standards. ANOVA analysis in Table 10, affirmed by the Box and Whiskers plot in Figure 11, and the multi-comparative graph in Figure 12 interprets the concentration values of the pollutant in the dry seasons as varying significantly from that of the rainy seasons, indicating that the particulate matter concentration of the atmosphere was affected by seasonal change.

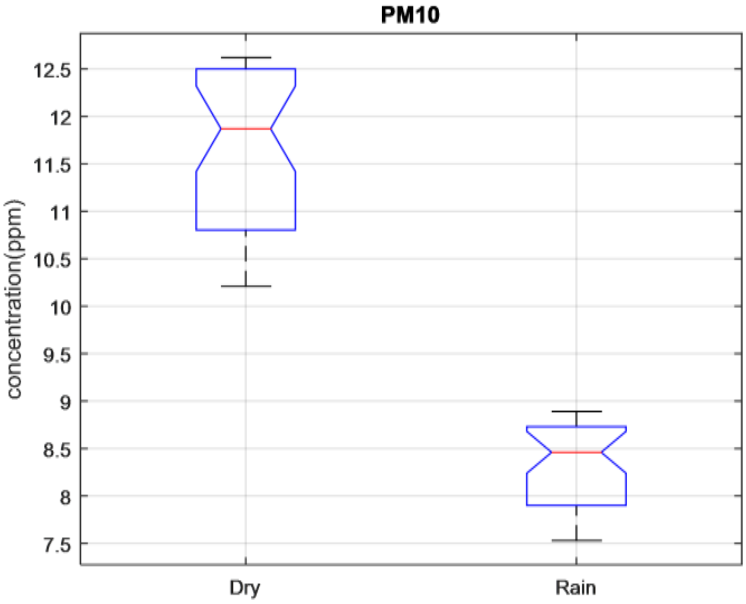


Figure 11. Particulate matter by Box and Whiskers comparative plot of dry and rainy seasons.

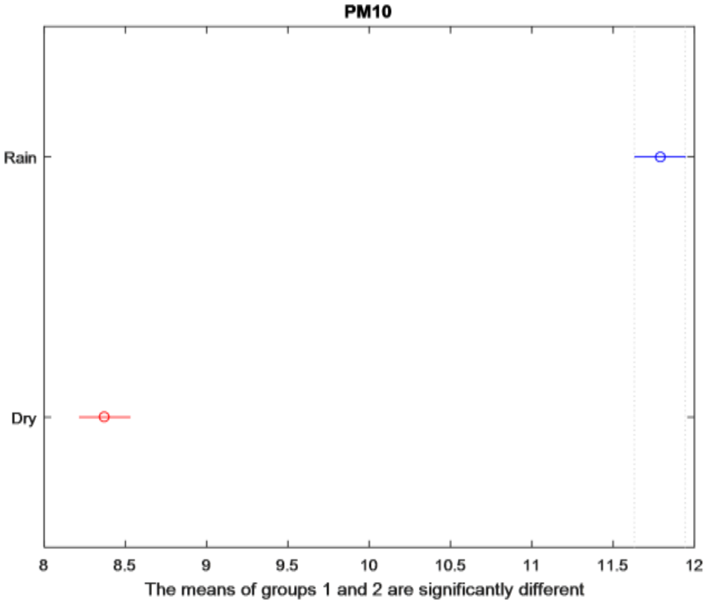


Figure 12. Particulate matter mean comparative analysis of dry and rainy seasons.

The mean hourly, daily, and annual concentrations of PM_{10} in the study area are 14,121 (14.12 mg/m^3), 10,841 (10.84 mg/m^3), and 10,060 µg/m^3 (10.06 mg/m^3) respectively (Table 15). The NAAQS recommended a mean limit of 20 µg/m^3 annually, and the daily (24-hour) guideline limit of 50 µg/m^3 was surpassed. Because a 1-hour REL value for PM10 could not be located in the literature, the 1-hour (acute) scenario was disregarded. Table 16 provides the HQ from the health risk categorization resulting from PM10 exposure. The results demonstrated that the exposed population had a high (HQ>1) probability of experiencing health-related problems under the typical and worst-case scenarios for average and continuous exposure, respectively. This is because HQ>1.0, suggests that PM10 is likely to have a negative impact on health. However, in the typical and worst-case scenarios, for intermediate exposure, children (3.3 × 101 vs. 1.3 × 102) and babies (55.0 × 10-1 vs. 1.3 × 102) are likely to be affected by exposure to PM10 compared with adults (1.0 × 101 vs. 8.3 × 101). For normal and worst-case exposures in the chronic (annual) exposure scenario, HQ>1.0 for adults, children, and newborns. These findings suggest that long-term exposure to PM10 may expose a vulnerable population to health issues. In the best-case scenario, adults will be more harmed than children and infants; however, under normal chronic exposure, children are more likely to be affected than adults and infants.

Table 15. Summary statistics of ambient concentrations of pollutants.

Averaging period	**PM_{10} (µg/m^3) mean**	**NO_2 (µg/m^3) mean**	**SO_2 (µg/m^3) mean**	**CO (µg/m^3) mean**
1 hour	14,121	2,692	2,300	309,145
8 hours				132,500
24 hours	10,841	2,027	1,667	
Annual	10,060	1,775	1,450	

CO, carbon monoxide; NO_2, nitrogen dioxide; PM_{10}, particulate matter; SO_2, Sulphur dioxide.

Table 16. Hazard quotients for normal and worst-case exposure scenarios to particulate matter (PM_{10}).

Exposed group	**Exposure**			
	Intermediate		***Chronic***	
	Normal	*Worst case*	*Normal*	*Normal*
Infant (birth–1 year)	55 × 10^{-1}	1.3 × 10^2	4.2 × 10^3	1.0 × 10^5
Child (6–12 years)	3.3 × 10^1	1.3 × 10^2	1.5 × 10^5	6.0 × 10^5
Adult (19–75 years)	1.0 × 10^1	8.1 × 10^1	1.2 × 10^5	9.4 × 10^5

The 1-hour (acute) scenario was not considered since a 1-hour reference exposure level value for PM_{10} was not found in the literature.

SO$_2$ Concentration

The mean range SO$_2$ readings recorded for the dry seasons was 0.54–0.87 ppm and for the rainy seasons 0.46–0.73 ppm as shown in Table 17. However, these concentration levels for both seasons exceeded the NAAQS Standard (0.5 ppm but fell within the FEPA Standard of 26 ppm for SO$_2$ in the atmosphere. Figure 13 interprets the data as having a slight variation in the air SO$_2$ concentration levels in both seasons. Values obtained from SO$_2$ ANOVA analysis in Table 18, which is affirmed by Figure 14, SO$_2$ Box and Whiskers plot, and Figure 15, SO$_2$ multi-comparative plot showed that datasets were significantly different, indicating that atmospheric SO$_2$ concentration was affected by seasonal changes.

Table 17. Mean values SO$_2$ (ppm) for both years.

S/N	Sampling area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Owerri Municipal L.G.A.							
1.	Amawom	0.82	0.90	0.86	0.67	0.75	0.71
2.	Umuodu	0.82	0.88	0.85	0.68	0.78	0.73
3.	Umuonyeche	0.85	0.88	0.87	0.67	0.76	0.72
4.	Umuoyima	0.82	0.87	0.85	0.67	0.78	0.73
5.	Umuororonjo	0.85	0.86	0.86	0.68	0.77	0.73
Ehime Mbano L.G.A.							
Umuezeala							
6.	Umuezeala-Ama	0.51	0.55	0.53	0.42	0.51	0.47
7.	Umuezeala-Owerre	0.53	0.58	0.56	0.45	0.50	0.48
8.	Umuopara	0.53	0.56	0.55	0.45	0.51	0.48
Umueze II							
9.	Umueleke	0.53	0.55	0.54	0.43	0.48	0.46
10.	Umuodara	0.52	0.54	0.53	0.43	0.51	0.47
11.	Umuduruegwele	0.56	0.58	0.57	0.45	0.50	0.48
Umunakanu							
12.	Umuele	0.52	0.55	0.54	0.43	0.52	0.48
13.	Umueli	0.55	0.57	0.56	0.45	0.50	0.48
14.	Umuola	0.52	0.56	0.54	0.47	0.48	0.48
Umunumo							
15.	Umuaro	0.50	0.53	0.52	0.43	0.49	0.46
16.	Umuokpara	0.54	0.57	0.56	0.44	0.50	0.47
17.	Umuchima	0.53	0.56	0.54	0.45	0.50	0.48
Nsu							
18.	Agbaghara	0.56	0.58	0.57	0.46	0.50	0.48
19.	Ezeoke	0.55	0.57	0.56	0.45	0.52	0.49
20.	Umuakagu	0.55	0.58	0.57	0.45	0.50	0.48
Mbaitoli L.G.A.							
Mbieri							
21.	Obazu	0.60	0.63	0.62	0.50	0.51	0.50
22.	Umuonyeali	0.62	0.64	0.63	0.51	0.52	o.52
23.	Umudagu	0.62	0.64	0.63	0.52	0.51	0.52
Ogwa							
24.	Idem-Ogwa	0.62	0.65	0.64	0.54	0.53	0.54
25.	Ochii	0.65	0.65	0.65	0.55	0.51	0.53
26.	Umueze	0.61	0.65	0.63	0.52	0.54	0.53
Ubomiri							
27.	Egbeada	0.65	0.67	0.66	0.55	0.56	0.56
28.	Obokpu	0.64	0.68	0.66	0.54	0.50	0.52
29.	Umuabali	0.62	0.66	0.64	0.53	0.53	0.53

S/N	Sampling area	YR1 dry	YR2 dry	Dry mean	YR1 rainy	YR2 rainy	Rainy mean
Orodo							
30.	Obi-Orodo	0.64	0.67	0.66	0.54	0.53	0.54
31.	Ofekata	0.63	0.65	0.64	0.54	0.54	0.54
32.	Ubaha	0.62	0.65	0.64	0.53	0.55	0.54
Ifakala							
33.	Umunoha	0.60	0.63	0.62	0.50	0.53	0.52
34.	Nworieubi	0.67	0.65	0.66	0.54	0.55	0.55
35.	Nkwesi	0.64	0.64	0.64	0.54	0.54	0.54

Table 18. Sulphur dioxide ANOVA table.

Source	SS	df	MS	F	Prob>F
Groups	0.16219	1	0.16219	18.08	6.70735-05
Error	0.60094	67	0.00897		
Total	0.76312	68			

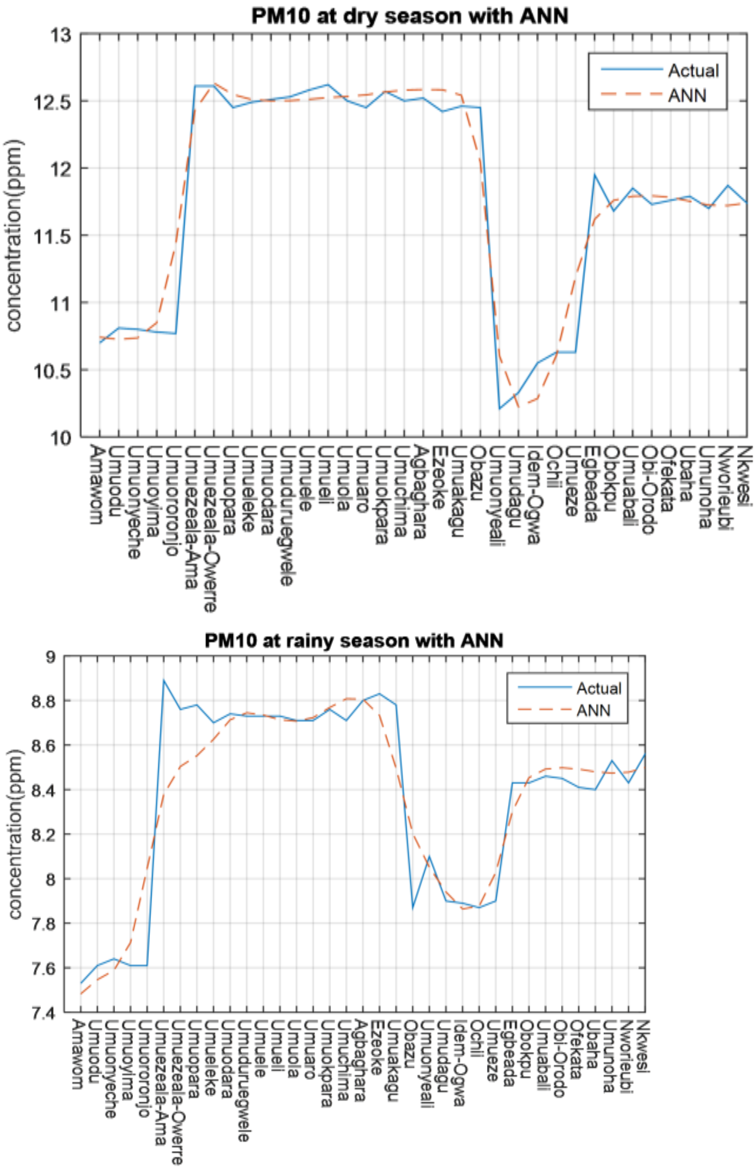


Figure 13. Comparative analysis of actual and ANN predicted PM_{10}.

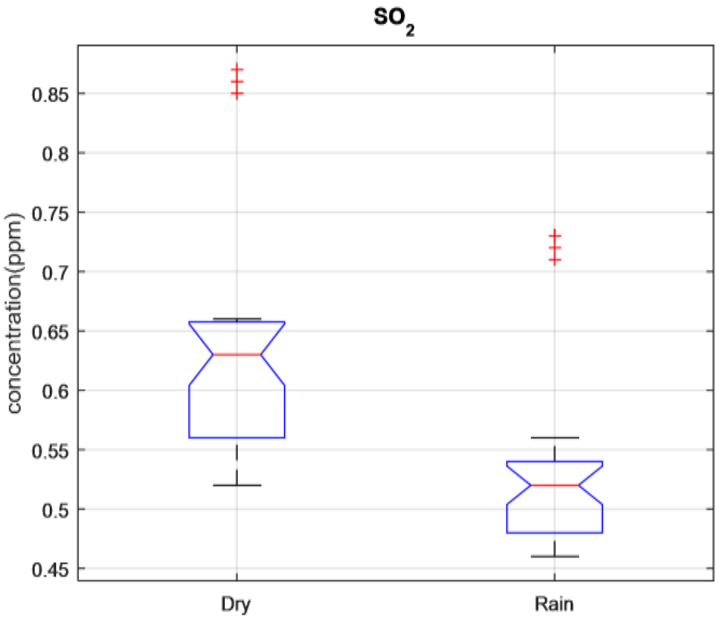


Figure 14. Sulphur dioxide Box and Whiskers comparative Plot dry and rainy seasons.

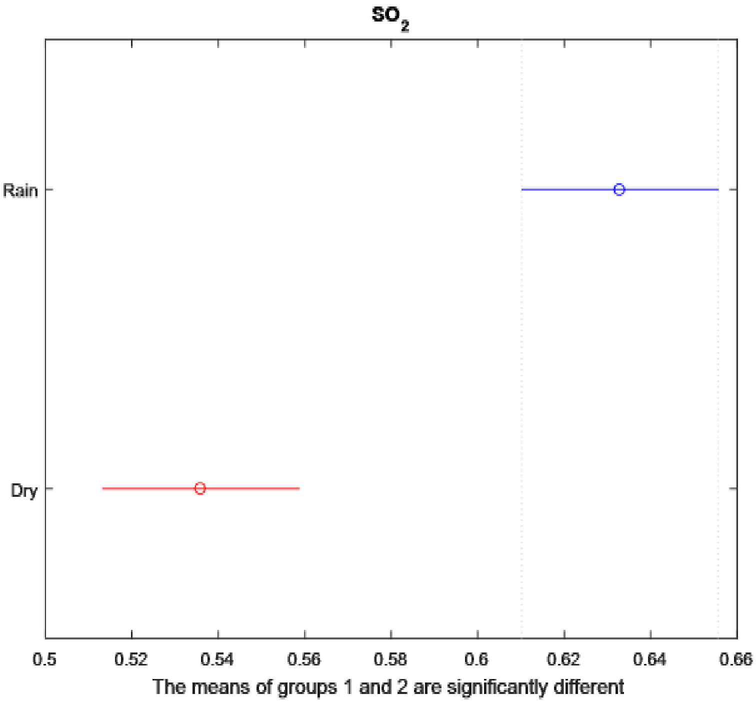


Figure 15. Sulphur dioxide mean comparative analysis dry and rainy seasons.

The measured average concentrations of SO_2 for 1-hr., 24-hr., and the annual averages in the study area were 2,300 (0.92 ppm), 1,667 (0.67ppm), and 1,450 µg/m^3 (0.58 ppm), respectively (Table 15). The NAAQS recommended maximum values for one-hour, 24-hour, and annual averages of 350, 125, and 50 µg/m^3, respectively, which were much lower than these results (Table 14). For both adults and infants, the estimated risk of acute and intermediate (normal) exposure to SO_2 was found to be HQ<1.0 (Table 19). This suggests a very small risk even for the most delicate person. HQ>1 for infants, children, and adults exposed to SO_2 for the intermediate worst-case, and HQ>1 for children's exposure to SO_2 for the intermediate normal-case. Compared to adults (1.1 × 10-1), babies and children (1.7 × 10-1) are expected to be affected by acute exposure to SO_2 in a similar fashion. Under both the best- and worst-case scenarios for chronic exposure, HQ>1 for the whole research population. This suggests that exposure to SO_2 poses certain dangers to susceptible individuals. The age groups were exposed to varying degrees of harshness.

Table 19. Hazard quotients for normal and worst-case exposure scenarios to sulphur dioxide (SO_2) at different levels of exposure.

Exposed group	**Exposure**				
	Intermediate			***Chronic***	
	Acute	*Normal*	*Worst case*	*Normal*	*Worst case*
Infant (birth–1 year)	1.7×10^{-1}	3.4×10^{-1}	81.0×10^{-1}	2.4×10^{2}	5.9×10^{3}
Child (6–12 years)	1.7×10^{-1}	20.3×10^{-1}	81.0×10^{-1}	8.7×10^{3}	3.5×10^{4}
Adult (19–75 years)	1.1×10^{-1}	6.4×10^{-1}	51.0×10^{-1}	6.7×10^{3}	5.4×10^{4}

NO_2 Concentration

For the study period, the average range concentration for the dry seasons of NO_2 was 0.55–0.75 ppm while the rainy seasons were 0.68–0.85 ppm. A peak reading of 0.85 ppm was noted during the rainy season. The FEPA (Stationary sources) and NAAQS (Ambient limit) NO_2 values for Nigeria [18] are 0.06 ppm and 0.1 ppm respectively (FEPA, 1991) thus, the NO_2 levels at all sampling points exceed both FEPA and NAAQS limit for nitrogen dioxide in the atmosphere. In Figure 16, the NO_2 MATLAB comparison model shows that both seasons have similar concentration level distributions, with the rainy season experiencing higher variation in concentration levels. The values from the NO_2 ANOVA analysis in Table 20 show that the datasets were significantly different. This is affirmed by Figure 17, the NO_2 Box and Whiskers plot (since the tip of the boxes is not at the same level), and Figure 13, the NO_2 multi-comparative graph (the two lines of the graph have different colors—Blue and Red), implying that NO_2 concentration in the atmosphere was affected by seasonal change.

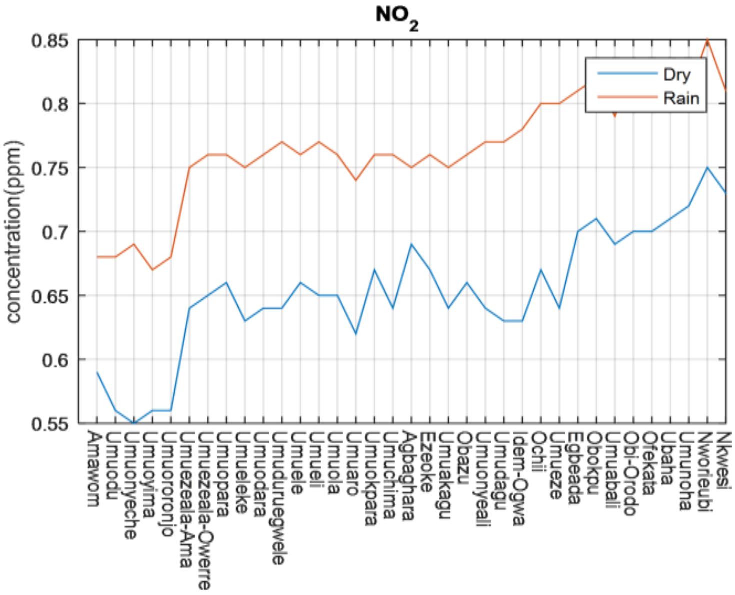


Figure 16. Nitrogen dioxide MATLAB comparison model.

Table 20. Nitrogen dioxide ANOVA table.

ANOVA Table					
Source	***SS***	***df***	***MS***	***F***	***Prob>F***
Columns	0.22064	1	0.22064	101.8	3.79205e-15
Error	0.14739	68	0.00217		
Total	0.36803	69			

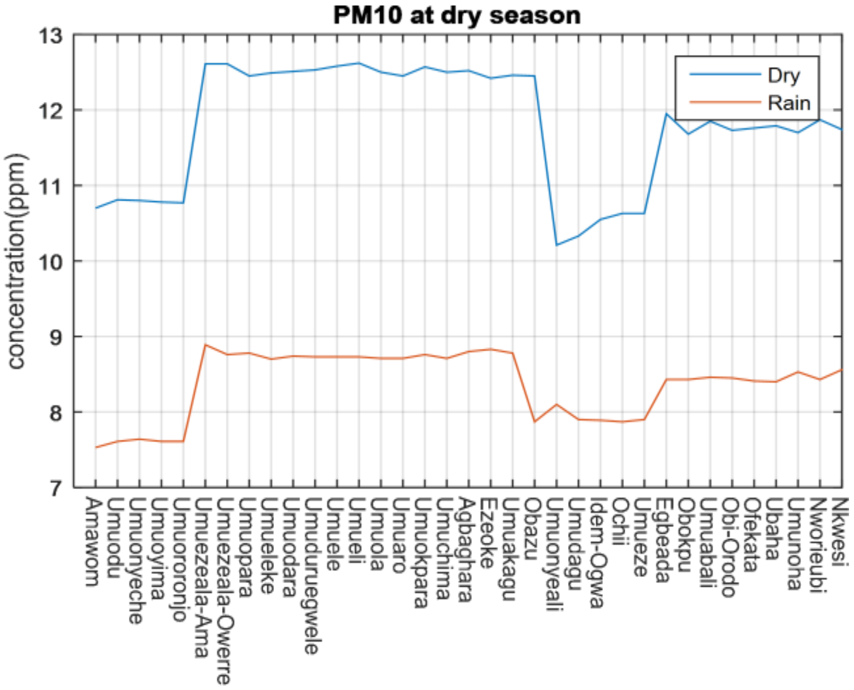


Figure 17. Particulate matter MATLAB comparison model.

The monitored 1-hour, 24-hour, and annual concentrations of NO_2 shown in Table 15 were 2,692 (1.077 ppm), 2,027 (0.81 ppm), and 1,775 $\mu g/m^3$ (0.71 ppm), respectively. The research region surpassed the 1-hour, 24-hour, and yearly standards of the NAAQS, which are 200, 80, and 40 $\mu g/m^3$, respectively (Table 14). In Table 21, HQ calculations for each acute NO_2 exposure level indicated that there was no chance of negative health effects for infants, children, and adults at this level of exposure (HQ<1.0), the same for infants in the intermediate (normal) scenario, and otherwise (HQ>1) for all age groups in the intermediate (worst-case), children, and adult scenarios. In contrast, adults (8.3 × 104) are more likely to be impacted by worst-case chronic exposure, whereas children (1.3 × 104) appear to be more likely to be harmed by typical chronic exposure than babies (3.7 × 102) and adults (1.0 × 104).

Table 21. Hazard quotients for normal and worst-case exposure scenarios to nitrogen dioxide (NO_2) at different levels of exposure.

Exposed group	**Exposure**				
	Intermediate			***Chronic***	
	Acute	*Normal*	*Worst case*	*Normal*	*Worst case*
Infant (birth–1 year)	3.6 × 10-1	6.5×10^{-1}	1.5×10^{-1}	3.7×10^{2}	9.0×10^{3}
Child (6–12 years)	3.6×10^{-1}	39.0×10^{-1}	1.5×10^{-1}	1.3×10^{4}	5.3×10^{4}
Adult (19–75 years)	2.2×10^{-1}	12.2×10^{1}	97.5×10^{1}	1.0×10^{4}	8.3×10^{4}

CO Concentration

The concentration values throughout the wet season are listed in Table 6. The 53–65 ppm concentration was greater than the 41–51 ppm recorded during the dry season. These concentration levels for both seasons exceeded the WHO, NAAQS, and FEPA standards of 50, 35, and 9 ppm, respectively, for carbon monoxide in the atmosphere. Figure 4 shows that the rainy season was the season most polluted with CO, suggesting that the atmosphere contained more CO pollution during the rainy seasons. The values obtained from the CO ANOVA analysis in Table 7, which are confirmed by the multi-comparative graph in Figure 5, show that the compared data are insignificantly different because the lines of the graph have only one color (blue). This indicates that there was no significant variation in the CO concentration level in either season; thus, the CO concentration in the atmosphere was not affected by seasonal changes.

The 1-hour average CO concentration of 309,145 µg/m^3 (123.7 ppm) and the 8-hour average CO concentration of 132,500 µg/m^3 (53 ppm) (Table 15) were higher than the 1-hour and 8-hour exposure limits recommended by the NAAQS, which are 87,500 µg/m^3 and 22,500 µg/m^3, respectively. Acute exposure to CO is estimated to have a risk of $HQ<1.0$ for adults, children, and babies (Table 22). This suggests that there is little risk, especially for vulnerable adults, children, and newborns. Nonetheless, adults (5.9 × 10-2) might experience the consequences, in contrast to newborns and kids (9.4 × 10-2). Furthermore, compared to infants and children with worst-case scenarios ($HQ>1.0$), adults, children, and babies residing in the research area are unlikely to suffer negative health effects from normal exposure scenarios to 8 h of CO ($HQ<1.0$).

Table 22. Hazard quotients for normal and worst-case exposure scenarios to carbon monoxide (CO) at different levels of exposure.

Exposed group	**Exposure**		
	Intermediate		
	Acute	*Normal*	*Worst case*
Infant (birth–1 year)	9.4×10^{-2}	1.5×10^{-1}	12.0×10^{-1}
Child (6–12 years)	9.4×10^{-2}	9.0×10^{-1}	12.0×10^{-1}
Adult (19–75 years)	5.9×10^{2}	2.8×10^{-1}	7.6×10^{-1}

DISCUSSION

Air quality assessment was carried out on data collected from 35 selected locations within the study area during both the dry and rainy seasons for a 2-year analytical period to investigate the effect of seasonal variation on the concentration levels of criteria air pollutants for quality assurance. The majority of the contaminants were found in higher amounts during the dry season than during the rainy season. This might be explained by the higher pollutant dispersion in the dry season compared to the wet season and the reduced pollutant output during the rainy seasons. Rainfall events may also play a role in scavenging air contaminants released from both natural and anthropogenic sources.

MATLAB comparison model, bar charts, artificial neural network (ANN), Box and Whiskers Plot, multi-comparative graph, and ANOVA table discussion ANOVA best description lies on the multi-comparative graph, which normally has two lines of different colors. If the lines in the graph have different colors, it means that the data compared (mean data of the dry and rainy seasons of pollutants) vary significantly or are significantly different, indicating that the concentration level of the pollutant is affected by seasonal change. If the lines have one color (maybe blue and the other one is blurred), the data compared are insignificantly different (the concentration level of the pollutant is not affected by seasonal change) because it is a one-way ANOVA. The outcome of the ANOVA was confirmed by a multi-comparative graph. If the tips of the boxes in the box and whisker plot are not at the same level, the datasets are significantly different from each other. Both the “Box and Whiskers plot” and the “multi-comparative graph” affirm the presented information, explaining the same thing—the ANOVA table. The emphasis on determining the significance level of the data being compared was based on multi-comparative graphs. If the multi-comparative graphs indicate that there are significant differences, the ANOVA table suggests the same. An ANN, a tool in the MATLAB 2015 application, was plotted with actual data to determine whether it would track the actual data. If the lines follow the same pattern, the ANN tracks the actual data properly and can be used to represent/gather information or data with regard to pollutant concentration in all areas considered. If it does not, it means that the ANN cannot be utilized to represent the data. Once the ANN is used to model, one can predict with them to generate values of their own with which to plot their graphs. The line movements or plots clearly show discrepancies.

Globally, air pollution is a threat to both public health and the environment. According to previous research, ambient air pollution exposure can have negative health impacts at or below the levels permitted by national and international air quality regulations. Our study’s conclusions showed that during the monitoring period, the 24-hour PM10 ambient quality threshold of 75 $\mu g/m^3$ was surpassed. The average annual PM10 concentration found in our study was significantly higher than the 45 $\mu g/m^3$ NAAQS guideline limit. This could explain the chronic (annual) HQ>1 found in our study, which suggests a degree of risk associated with long-term PM10 exposure. According to estimates, outdoor air pollution caused 1.1% of deaths in children under the age of five and 3.7% of deaths in individuals aged 30 years and older due to lung, tracheal, and bronchus malignancies [19]. A 2001 assessment of 12 earlier studies confirmed that hospital admissions for ischemic heart disease and congestive heart failure increased with every 10 $\mu m/m^3$ increase in PM10. In susceptible populations (elderly people and those with a history of respiratory and cardiovascular disorders), long-term exposure to PM10 has been linked to an increase in morbidity and mortality from respiratory and cardiovascular diseases [19]. Large-population studies have also demonstrated a connection between hospital admissions for respiratory conditions (such as asthma, COPD, and pneumonia) and ambient PM10. In older patients, the effects were more pronounced even with minimal interactions. In this study, it was discovered that the mean concentrations of NO_2 over one-hour, twenty-four hours, and a year were greater than the national standard. According to data from the risk characterization assessment, a minimal risk exists for both acute and intermediate exposure to ambient NO_2 levels, with the exception of children's intermediate (normal) exposure. However, a sensitive person may be at risk after a year of exposure to ambient NO_2. According to recent epidemiological research, the general public may be more likely to be admitted to the emergency room for acute and obstructive lung disorders when exposed to low levels of NO_2 [20, 21]. Research from Canada, Denmark, and Italy has revealed a strong correlation between NO_2 exposure and acute ischemic stroke [22, 23]. Nevertheless, several studies have failed to discover any conclusive links between health impacts and exposure to ambient and personal NO_2 levels [24]. The ambient value of SO_2 in the study area was also higher than the national norm. Similarly, exposure to SO_2 for one-hour did not appear to pose any health risks (HQ<1). However, for the intermediate worst-case, chronic (year) exposure to SO_2 in the research area, some risk values for susceptible individuals were identified. According to the USEPA (2002), there is evidence that SO_2 aggravates childhood asthma at quite modest concentrations, well below the limits set by the US EPA and WHO. More evidence that SO_2 is associated with negative health outcomes in the short-term, such as mortality and morbidity, comes from studies conducted in Europe and Asia [25]. In this study, elevated ambient CO values were observed. Researchers believe that exposure to ambient CO levels is commonly missed and that its toxicity is usually underreported and misdiagnosed because CO is non-irritating and invisible in the air we breathe [26]. In the USA, CO exposure is associated with poison-correlated mortality [26]. Acute and intermediate exposure to ambient CO concentrations, with the exception of intermediate (normal) exposure, is also less likely to have an impact on adults than on infants and children, according to data from the risk characterization assessment. Both brief and prolonged NO_2 exposure also fell under this condition. Children are more susceptible to environmental pollutants than adults. A few of the factors that make them a risk group are that they breathe twice as much air while at rest as adults do, making them comparatively more susceptible to respiratory and immune system problems [27].

Uncertainties and limitations

Despite the existence of uncertainty in risk assessment, its application of risk assessment has proven beneficial in offering a consistent and quantitative framework for methodically assessing environmental health hazards and control options. The HHRA method used in this study is conservative because it incorporates several process-integrated safety measures. Consequently, the final risk estimate is likely to overestimate the actual danger. In our research, we employed the USEPA equations to account for these uncertainties and benchmark values derived from national and international norms and guidelines, which were developed based on the subsequent health effects on humans from exposure to identified pollutants. The following restrictions were considered when evaluating the findings of our investigation. Because of its ecological focus, this study's unit of analysis was populations or groups of people, rather than individual participants. The ecological technique assumes that everyone in the research region is exposed to the same level of air pollution and is unaware of any personal risk factors that could contribute to the development of disease outcomes. These risk variables included genetics, sociodemographic characteristics, occupational exposure to pollutants, and respiratory risks at work. Furthermore, it was not possible to identify the potential health risks associated with exposure to a combination of pollutants rather than individual pollutants, as measured in our study. This study had several strengths. The study's first-ever description of the health risks associated with human exposure to PM and other gaseous pollutants makes it a unique field of study. Furthermore, the study uses hourly air pollution data and has a proven data-gathering approach, and its findings are broadly applicable. Because we employed the USEPA HHRA framework, which was first authorized by the National Research Council in 1994, our results can also be compared with those of other investigations.

CONCLUSIONS

The study used MATLAB 2015 software to generate air pollution models that were applied in the monitoring and health risk evaluation of atmospheric pollutants in Owerri Metropolis and sub-urban areas of Imo State, Nigeria, using Chemometric methods. The findings indicated that the contaminants were year-round but with seasonal variations in concentration and levels beyond the WHO, NAAQS, and FEPA thresholds. The dry season was more polluted by SO_2 and PM_{10} than the rainy season. This might be explained by the increased pollution dispersion in the dry season compared to the wet season and decreased pollutant emissions during the rainy seasons. Rainfall events may also play a role in scavenging air contaminants released from both natural and anthropogenic sources. Recently, there have been reports of the use of nanomaterials to remediate air pollution. Although these studies have demonstrated their efficacy in laboratory settings, more research is necessary to fully understand how nanotechnology can significantly affect the remediation of air contaminants in real-world scenarios.

The measured acute, intermediate, and chronic ambient PM10 and gaseous pollutant concentrations were higher than those measured by the NAAQS. Significant health risks have been linked to acute, intermediate, and long-term exposure to contaminants. Nevertheless, adults and children are more likely to experience negative health outcomes than babies. Risk severity varied among groups, and sensitive individuals faced various degrees of risk from common and worst-case exposure scenarios to each pollutant over long-term chronic (annual) exposure. When it comes to taking more proactive measures to protect and extend human life, government officials, environmental experts, and other relevant stakeholders will greatly benefit from the identification of potential health risks associated with these pollutants, as determined by the HHRA framework. These results will also help legislators enforce and improve the current laws that establish risk management plans and restrict the amount of pollution that can be released into the atmosphere.

Suggestions for Further Study

1. An empirical model should be deployed in the prediction of pollution factors with outcomes compared to those of the ANN model.
2. Other Artificial Intelligence models should be used and compared to determine the best model that represents environmental pollutants obtained from the field.

Conversion Rates

- 1 mg/L = 1 ppm
- 1 ppm = 2,500 µg/m^3
- 1 ppb = 1,000 ppm
- 1 mg/m^3 = 1,000 µg/m^3

1 ppm = 1.15 mg/m^3 Declarations

Conflict of Interest

There is no conflict of interest, according to the authors.

Consent for Publication

It was agreed upon by all authors to publish this research.

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