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Air quality indices assessment in Artisanal Gold Mining Areas of Zamfara State, Nigeria

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ABSTRACT

Mining processes contribute significantly to air pollution which is the largest cause of human deaths worldwide. This research was conducted to assess air pollution in three gold mining areas, i.e. Kwali, Maraba, and Duke; and a non–mining area Kadauri in Zamfara State, Nigeria. Monthly measurements of CO, SO_2, and NO_2 were done using Gasman detection instrument (Crowcon–EExias IIC T5), particulates were determined using optical counter, and buffered KI solution was used to measure O_3 while temperature, humidity, and pressure were measured using their respective meters over a period of one year. Air quality indices were calculated using the USEPA (1999) AQI formula, pollutants and meteorological factors relationships were determined using Pearson's correlation and seasonal variation was measured using T–test. The highest and lowest CO were 25.85±7.42 μg/m^3 in Kwali and 12.08±3.32 μg/m^3 in Kadauri respectively, SO_2 was also highest (48.15±12.42 μg/m^3) and lowest (31.74±6.67 μg/m^3) in Kwali and Kadauri respectively. O_3 was highest (151.29±29.74 ppb) and lowest (107.38±21.95 ppb), while PM_{10} was highest (498.37±48.49 μg/m^3) and lowest (319.31±44.86 μg/m^3) in Duke and Kadauri respectively. Air quality parameters generally exceeded the WHO limit while CO, SO_2, and $PM_{2.5}$ had significant difference ($P<0.05$) across sampling stations. Mining areas had hazardous AQI with Duke being the highest (392) and Kadauri had 248 implying an unhealthy atmosphere. Pollutants correlated negatively with humidity and positively with pressure while temperature inversely correlated with NO_2, SO_2 and $PM_{2.5}$. Pollutants concentrations were significantly higher in dry season, hence the use of PPEs, information and regulation of mining activities as well as increased humidity are suggested.

ABSTRAK

Proses penambangan berkontribusi signifikan terhadap polusi udara yang merupakan penyebab kematian manusia terbesar di seluruh dunia. Penelitian ini dilakukan untuk mengkaji pencemaran udara di tiga wilayah pertambangan emas, yaitu Kwali, Maraba, dan Duke; dan kawasan non-pertambangan Kadauri di Negara Bagian Zamfara, Nigeria. Pengukuran bulanan CO, SO_2, dan NO_2 dilakukan dengan menggunakan instrumen pendeteksi Gasman (Crowcon–EExias IIC T5), partikulat ditentukan menggunakan penghitung optik, dan larutan buffer KI digunakan untuk mengukur O_3, sedangkan suhu, kelembaban, dan tekanan diukur menggunakan alat meter masing-masing selama periode satu tahun. Indeks kualitas udara dihitung menggunakan rumus AQI USEPA (1999), hubungan polutan dan faktor meteorologi ditentukan menggunakan korelasi Pearson dan variasi musiman diukur menggunakan uji T. CO tertinggi dan terendah masing-masing sebesar 25,85±7,42 μg/m^3 di Kwali dan 12,08±3,32 μg/m^3 di Kadauri, SO_2 juga masing-masing tertinggi (48,15±12,42 μg/m^3) dan terendah (31,74±6,67 μg/m^3) di Kwali dan Kadauri. O_3 tertinggi (151,29±29,74 ppb) dan terendah (107,38±21,95 ppb), sedangkan PM_{10} tertinggi (498,37±48,49 μg/m^3) dan terendah (319,31±44,86 μg/m^3) masing-masing terdapat pada Duke dan Kadauri. Parameter kualitas udara secara umum melebihi batas WHO, sedangkan CO, SO_2, dan $PM_{2.5}$ memiliki perbedaan yang signifikan ($P<0,05$) antar stasiun pengambilan sampel. Area pertambangan memiliki AQI berbahaya dimana Duke merupakan yang tertinggi (392) dan Kadauri memiliki 248 yang mengindikasikan atmosfer yang tidak sehat. Polutan berkorelasi negatif dengan kelembaban dan positif dengan tekanan, sedangkan suhu berkorelasi terbalik dengan NO_2, SO_2 dan $PM_{2.5}$. Konsentrasi polutan jauh lebih tinggi pada musim kemarau, oleh karena itu disarankan untuk menggunakan APD, informasi dan peraturan kegiatan penambangan, serta peningkatan kelembaban.

Keywords: *air pollutants, air quality index, gold mining, meteorological factors, Zamfara State*

INTRODUCTION

Air is an essential factor necessary for life as it is a mixture of gases such as oxygen which supports respiration, nitrogen which provides nutrients for plant growth and forms bases for amino acids, and carbon dioxide which is important in photosynthesis (Belnap 2013). Tropospheric air composition in an unpolluted environment contains about 78.08% N_2, 20.95% O_2, 0.93% Ar, 0.039% CO_2 and 0.003% water vapour, particulate matter and others (Strobel et al., 2009). Polluted air may have higher or lower percentage compositions of these individual elements and the presence of other elements or compounds as well which brings about an imbalance in the normal function of the entire ecosystem and the overall quality of individual life

(Manisalidis et al., 2020). Zawar–Reza and Sponken–Smith (2005) defined air pollution as the contamination of the atmosphere by physical, chemical or biological agents that produce measurable adverse effects on man, animals, vegetation or materials. Common air pollutants consist of CO, NO, NO_2, SO_3, tropospheric O_3, hydrocarbons and dispersed particles most of which come from internal combustion engines of heavy industrial machines, gas flaring in oilfields, volcanic eruptions mining and other anthropogenic activities (Francis et al., 2017; Fawole et al., 2019; Abaje et al., 2020). Air pollution has been identified as the largest cause of human fatalities worldwide, accounting for about 8.8 million deaths each year, and reducing by 3 years the average life expectancy of man (Lelieveld et al., 2020; Rajveer and Puneeta, 2021).Gold mining processes entail excavation through drilling, digging or blasting, followed by processing through washing, grinding, smelting etc and lastly refining, all of which lead to serious air pollution (Ratan, 2005).

Air quality index (AQI) is a scheme that transforms the overall weighted individual values of air quality parameters into a single value or a set of values (Tiwari, 2015). AQI is used as a warning system to the public based on measurements of gases such as CO, SO_2, NO_2, ground level O_3 and particulate matter ($PM_{2.5}$ and PM_{10}) in the atmosphere. It shows the extent of air pollution at different locations and helps in their temporal and spatial comparison. This study was carried out to assess the air quality of artisanal gold mining areas in Zamfara state, Nigeria.

MATERIALS AND METHODS

The Study Area

Zamfara State of Nigeria is located between latitude 12°10'N and 12°167'N, and longitude 06 °15'E and 06°250'E, with a total area of 39,762 square kilometers (Asuquo and Bate, 2020). Air quality parameters of three gold mining areas namely Kwali (05°45.49'E to11°59.66'N), Duke (06°19.56'E to12°21.45'N), Maraba (06°22.43'E to12°20.26'N) and a non mining area: Kadauri (06°08.71'E–12°13.56'N) were assessed. Figure 1 shows the map of the study area.

Air Quality Parameters Analysis

Air quality parameters; CO, SO_2 and NO_2were measured monthly during working hours using an automatic handheld Gasman detection instrument (Crowcon–EExias IIC T5) at purposefully selected locations within each mining site over a period of twelve months covering both dry and wet seasons according to Adekunle et al. (2020). Particulate matter ($PM_{2.5}$ and PM_{10}) were determined using a portable handheld optical particle counter which detects particles' size and amount by measuring the amount of light scattered as they passed through a beam of light. Ozone was determined using buffered potassium iodide solution method developed by Byers and Saltzman (1958) where 1% buffered KI was used for trapping O_3,as it reacts with iodine in neutral buffer solution (Benavent et al., 2022). Weather elements; temperature, humidity, pressure were also measured using their respective meters.

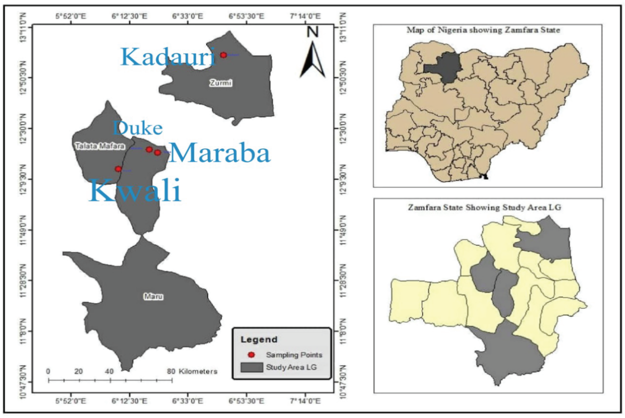

Figure 1. Map of Zamfara State, Nigeria showing the Sampling Locations

All chemicals used in this research were of analytical grade and strict guidelines were followed in handling them during the experiment to avoid errors while the experiments were replicated to ensure accuracy and reliability of data. All utensils used were washed with water and liquid soap, rinsed in distilled water and dried before use while standard potassium iodide solution was always freshly prepared when needed according to Abdulraheem and Adekola (2011).

Air Quality Index Calculation

Air quality index was calculated using the USEPA (1999) AQI formula:

$$AQI= \frac{Ih\text{-}Il}{Ch\text{-}Cl}\,(C\text{-}Cl) + Il \quad (1)$$

Where:
C= concentration of the pollutant
Ch = concentration breakpoint that is $\geq C$
Cl = concentration breakpoint that is $\leq C$
Ih = index breakpoint corresponding to Ch
Il = index breakpoint corresponding to Cl

For multiple pollutants, AQI is the highest value obtained for each pollutant using the formula above (Kanchan et al., 2015). Table 1 shows the concentration breakpoints and corresponding index breakpoints of some air pollutants while table 2 shows the category and interpretation of each index breakpoint according to USEPA (1994).

Table 1. Air pollutants with their Concentration and Index Breakpoints

CO ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	O_3 (ppb)	AQI
Cl-Ch	*Cl-Ch*	*Cl-Ch*	*Cl-Ch*	*Cl-Ch*	*Cl-Ch*	*Il-Ih*
0.0-4.4	0-35	0-53	0.0–12.0	0–54	0–54	0–50
4.5-9.4	36-75	54-100	12.1–35.4	55–154	55–70	51–100
9.5-12.4	76-185	101-360	35.5–55.4	155–254	71–85	101– 150
12.5-15.4	186-304	361-649	55.5–150.4	255–354	86–105	151–200
15.5-30.4	304-604	650-1249	150.5–250.4	355–424	106–200	201–300
30.5-40.4	605-804	1250-1649	250.5–350.4	425–504	201–404	301–500
40.5-50.4	805-1004	1650-2049	350.5–500.4	505–604	405–504	

Source: USEPA,1994

Table 2. Air Quality Index Categories and Interpretation

Air Quality Index	Category
0-50	Good
51-100	Moderate
101-150	Unhealthy for sensitive groups
151-200	Unhealthy
201-300	Very Unhealthy
301-500	Hazardous

Statistical Analysis

Variations in mean air quality parameters across sampling locations were determined using analysis of variance (ANOVA), relationship between air quality parameters and weather elements were determined using Pearson's correlation analysis while Student T–test was used to determine the seasonal differences in air quality parameters.

RESULT AND DISCUSSION

Mean Air Quality Parameters of Artisanal Gold Mining Areas of Zamfara, Nigeria Compared with WHO Limit

Mean Carbon monoxide concentration was highest (25.85±7.42 $\mu g/m^3$) in Kwali mining area and lowest (12.08±3.32 $\mu g/m^3$) in Kadauri with a significant difference (P<0.05) among them and all values exceeded the WHO limit, likewise the highest and lowest SO_2 were 48.15±12.42 $\mu g/m^3$ in Kwali and 31.74±6.67 $\mu g/m^3$ in Kadauri respectively with only Kadauri complying with the WHO limit. NO_2,$O_3$and PM_{10} did not fifer significantly (P>0.05) across sampling stations but were all above the WHO limit. Atmospheric pressure was highest (3786.36±283.71 N/m^2) in Kwali and lowest(3391.61±269.17 N/m^2) in Kadauri with a significant difference (P<0.05) among sampling stations while temperature, pressure and humidity did not differ significantly (P>0.05). Mean air quality parameters of gold mining areas in Zamfara state, Nigeria compared with the World Health Organization standards for air quality are presented in table 3.

All the criteria air pollutants analysed in this study were above the WHO limit for air quality except for SO_2 in the Control. This implies a serious health risk for the miners and inhabitants of the area as air pollution is seen as one of the biggest environmental threats to human health (WHO, 2005). Air pollution is particularly dangerous because of the route of exposure which allows the pollutants to cross over through the alveoli into the bloodstream that takes them straight to the heart from where they are pumped into the systemic circulation before coming to the liver for detoxification as the liver

Table 3. Mean Air Quality Parameters of Gold Mining Areas and Control in Zamfara, Nigeria compared with WHO Limits

Parameters	Kwali	Duke	Maraba	Kadauri	P-Value	WHO Limit
CO ($\mu g/m^3$)	25.85±7.42	19.19±5.83	16.40±4.62	12.08±3.32	P<0.05	7
SO_2 ($\mu g/m^3$)	48.15±12.42	44.39±4.31	45.94±5.87	31.74±6.67	P<0.05	40
NO_2 ($\mu g/m^3$)	113.29±47.85	91.48±42.61	103.49±39.97	97.74±41.48	P>0.05	10
$PM_{2.5}$ ($\mu g/m^3$)	304.72±121.21	297.15±87.64	273.38±91.37	197.53±78.15	P<0.05	5
PM_{10} ($\mu g/m^3$)	479.33±46.82	498.37±48.49	432.11±39.50	319.31±44.86	P>0.05	15
O_3 (ppb)	134.91±33.58	151.29±29.74	110.32±22.34	107.38±21.95	P>0.05	100
Temperature (^0C)	33.29±11.06	34.48±13.81	31.37±12.49	33.86±45.83	P>0.05	–
Pressure (N/m^2)	3786.36±283.71	3611.82±291.03	3519.36±305.13	3791.61±269.17	P>0.05	
Humidity (%)	35.09±4.76	38.14±4.93	36.94±8.82	36.05±6.68	P>0.05	

receives only about 25% of cardiac output (Søren and Mauro, 2013; Ghorani–Azam, 2016). The non mining area (control) atmosphere which is about 20 kilometers away from the mining areas was found to be highly polluted and this could be due to high mobility of air pollutants as they are not limited to regional boundaries (Marks and Miller, 2022) and can extend several thousands of kilometers and cause harm away from the point sources (Abaje et al., 2020). Similar results were obtained by Bhanu et al. (2014) in their analysis of particulate and gaseous pollutants in Jharia coal mines of Dhanbad district, India where they found out that all the pollutants exceeded the prescribed national ambient air quality standards (NAAQS) and showed significant spatial variation while higher concentrations were observed around coal mine areas compared to other areas. They described mining as a leading industry causing fatal injuries and other chronic health problems such as black lung disease among miners and nearby communities.

Carbon monoxide is a non–irritating but very poisonous, colorless and odorless gas, common sources of which include incomplete combustion of organic matter, metallurgical operations etc (Ibush et al., 2022). Due to the similarity of its physico-chemical properties and that of O_2, CO is easily absorbed into the circulatory system and it exerts its toxic effects by reacting with haemoglobin to form Carboxyhaemoglobin (COHb) which blocks oxygen receptor sites and limits the amount of oxygen transported to tissues by the haemoglobin, resulting in cardiovascular, developmental and other effects (Bilska-Wilkosz et al., 2022). Mean CO concentration was highest in Kwali during this research which may be due to the fact that it's the most active mining area. SO_2 is formed from the burning of organic matter and smelting of sulphur–containing mineral ores, exposure to which has been linked to respiratory diseases such as bronchospsm, pneumonitis, irritation to the eyes, nose, throat etc especially among sensitive groups (Shofi and Hamzah, 2022). It is a colorless gas with strong pungent odor that easily dissolves in water to form sulphuric acid in the atmosphere, a major component of the acid rain which damages structures, vegetation and animals, it also forms sulphate aerosols which reflect sunlight into space and act as condensation nuclei, making clouds more reflective and having a significant effect on global and regional climate (Haradhan, 2014). SO_2 concentration was highest in Kwali mining area which may not be unconnected to the activity there while in the Control area it was below the WHO limit, indicating lower risk for the inhabitants there. NO_2 is a reddish brown poisonous gas that is formed during combustion, it reacts with water to form nitric acid which is another component of the acid rain that is highly corrosive (Debbie et al., 2010). It is the main ingredient in the formation of photochemical smog reducing visibility while exposure at high concentrations causes painful inflammation of the lungs which may lead to cancer and eventually death if not treated (Maduna and Tomašić, 2017; Javed et al., 2021). The highest concentration of NO_2 in Zamfara gold mining areas during this research was in Kwali which tells further the volume and complexity of activities going on in the area which exposes the inhabitants to the hazards of air pollution.

A mixture of solid particles such as dust and liquid droplets with associated adsorbed organic chemicals and reactive metals which comes in different shapes and sizes in the atmosphere is referred to as the Particulate matter (PM_{10} and $PM_{2.5}$) (Robert and Gökhan, 2018). PM_{10} are coarse particles whose diameter is generally 10 µM and below while $PM_{2.5}$ include fine and ultrafine particles with a diameter of 2.5 µM and below both of which are emitted from excavation, transportation and processing of gold ores and from the complex reactions of chemicals such as SO_2, NO_2 and metals in the atmosphere (Duarte et al., 2022). $PM_{2.5}$ followed the trend of the gaseous pollutants with the highest mean concentration in Kwali and lowest in Kadauri while the case was not so with PM_{10} where the highest mean concentration was in Duke gold mine which signify that particle sizes and composition differ with the type and intensity of activities in an area. $PM_{2.5}$ and PM_{10} fundamentally differ in their chemical compositions, processes of formation, atmospheric residence time, modification and removal as the latter include dust from construction and mining activities, pollens and fragments of organic matter while the former is made from combustion of fuel and other chemical reactions in the atmosphere (Seinfeld and Pandis, 2006; Gieré and Querol, 2010). Exposure to particulate matter generally has been linked to adverse health effects such as lung and heart diseases, $PM_{2.5}$ particularly is responsible for the greatest proportion of air pollution related health effects as it can enter the bloodstream through the walls of the alveoli, causing acute and chronic bronchitis, irregular heartbeat, decreased lung function, cancer, worsening respiratory conditions such as asthma and eventually death while PM_{10} is associated with coughing and sneezing, difficulty in breathing and long term exposure leads to respiratory mortality (Du et al., 2016; Mark and David, 2020). Tropospheric Ozone is formed by a series of complex cycles of photochemical reactions of oxides of Nitrogen (NO_X) and volatile organic compounds (VOCs) in the atmosphere and the catalytic oxidation of CO by NO_X (Finlayson-Pitt and Pitts Jr., 1993; Sillman, 2003). The emission of these gases through the use of heavy equipments and vehicles as well as the use of O_3 in treatment of acid mine drainage and purifying water for dust suppression and washing of ores and minerals leave behind a high O_3 concentration in the troposphere exposure to which causes damage and inflammation to respiratory tract tissues, cardiovascular diseases, damage to plant cells and inability to photosynthesize, leading to reduction in yield (Philip and Clive, 2002; Lim et al., 2019). O_3 concentration was highest in Duke mining area and it was lowest in Kadauri the non–mining area though the difference was not significant which could be as a result of dispersion as Dayana et al. (2014) reported that higher values occurred downwind due to the transport of precursors. Temperature, pressure and humidity did not significantly differ among sampling stations, they are influenced by and they also influence other weather elements such as sunshine, rainfall etc (Frances and Chika, 2017). In essence, the studied air quality parameters and weather elements put together, constitute a serious threat to the health and well-being of the inhabitants of the study area as human activities trigger the release of atmospheric pollutants in higher than usual concentrations leading to reduced air quality and in turn poor health conditions such as cough and sneezing, asthma, pulmonary and cardiac diseases or even death (Kathrin et al., 2017). Ecosystem functions and services are not exempted from the severe adverse effects of atmospheric pollution as SO_2 and NO_x cause acidification beyond normal range of pH, leading to death of aquatic organism, stunted growth in plants and general low productivity (Kalender and Alkan, 2019). Nitrogen also causes eutrophication, leading to bloom in growth of some organisms and changes in species diversity, and consequently a disruption in both the aquatic and terrestrial ecosystems (Xi et al., 2018) When it leach into the ground or surface water, Nitrogen is consumed by man and other organisms the excess of which restricts oxygen transport in the bloodstream and is very harmful to infants and young livestock, a situation known as blue baby syndrome (Ward et al., 2018). Tropospheric O_3 enters plant stomata, oxidizing leaves and spikes leading to non-availability of green surfaces for photosynthetic activities thereby limiting plant growth and lower yields in agricultural crops (Sumitra et al., 2022). The presence of particulate matter in measures beyond the recommended limits can also adversely affect visibility and photosynthesis/food production by forming a shield to the incoming solar radiation which is the energy used by green plants for photosynthesis.

Air Quality Indices of Gold Mining Areas in Zamfara, Nigeria during the Study

The highest air quality index observed was 392 in Duke mining area while the lowest was 248 in Kadauri while Kwali and Maraba mining areas had AQI of 369 and 324 respectively. Figure 2 presents the air quality indices of the gold mining areas during the study.

All the mining areas had air quality indices in the hazardous category while the non mining area had a very unhealthy AQI which could be attributed to dispersion and atmospheric transportation of substances (Marks and Miller, 2022). The high AQI in the region implies a grave danger and health risk to the inhabitants as many respiratory diseases such as respiratory infections, chronic obstructive pulmonary disease, bronchiectasis, asthma, idiopathic pulmonary fibrosis, lung cancer etc are directly associated with it. Sarmadi et al. (2021) reported that AQI of some industrial and

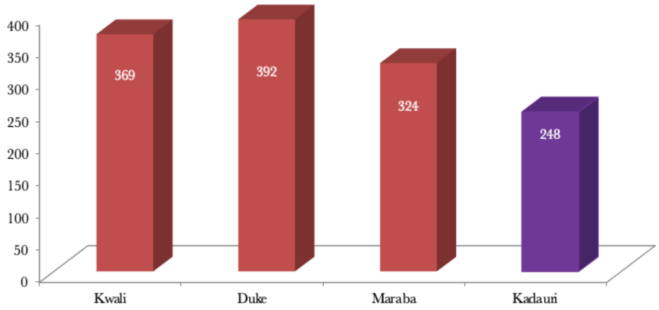

Figure 2. Air Quality Indices of Gold Mining Areas and Control in Zamfara State, Nigeria during the Study

densely populated capital cities across the world differed significantly before and after 2020 with the latter period having lower AQI due to COVID-19 restrictions that cut down on industrial activities. The quality of air or level of pollution is closely linked to the activities and meteorological data in an area as Bălă et al. (2021) described it as a silent killer that hides around us, representing one of the biggest risk factors for human health. Mondal et al. (2020) in their spatio-temporal variation of air pollutants analysis in Jharia Coalfield, India found out that coal mines were the major sources of air pollution in the area, it was also revealed that the AQI of the coal mine affected area was nearly 1.5 times higher than that of the non-mining areas. Transportation is a major contributor to the poor air quality index in the area as the mining activities involve moving the ores from excavation to processing points and movements of humans as well as working materials. The transport sector has been estimated to be responsible for approximately 45% of NOx emission, high quantity of greenhouse gases (GHGs) and particulate matter as a result of fossil fuel combustion and dust from heavy vehicular movements (Nnaji et al., 2023).

Relationship between Air Quality Parameters in the Study Area

There was a negative relationship between humidity and all other air quality parameters measured with the highest r–value being –0.91 in CO and the lowest was –0.43 in NO_2 while atmospheric pressure had positive correlation with all the parameters, highest r–value of which was1.00 in its relationship with CO and the lowest was 0.59 in NO_2. Temperature had strong positive relationship with O_3 (r=0.59), weak positive relationships with CO and PM_{10} (r=0.05) and negative relationships with NO_2, SO_2 and $PM_{2.5}$ (r=–0.48, –0.35 and –0.08 respectively). Table 4 is a correlation matrix showing the relationship between pairs of air quality parameters in the study area.

Table 4. Correlation Matrix showing the Relationship between Air Quality Parameters

Name	Humid.	O_3	Temp.	NO_2	CO	Press.	SO_2	$PM_{2.5}$	PM_{10}
Humidity	1								
O_3	-0.76	1							
Temperature	-0.44	00.59	1						
NO_2	-0.43	-0.19	-0.48	1					
CO	-0.91	0.65	0.05	0.62	1				
Pressure	-0.92	0.68	0.07	0.59	1	1			
SO_2	-0.55	0.53	-0.35	0.46	0.82	0.83	1		
$PM_{2.5}$	-0.69	0.75	-0.08	0.31	0.86	0.88	0.96	1	
PM_{10}	-0.68	0.83	0.05	0.14	0.8	0.83	0.9	0.98	1

Humidity reduces significantly the level of air pollution, it prevents air pollutants from dispersing into the atmosphere by trapping them close to the ground (Mokoena et al., 2020) hence the negative correlation between humidity and all other pollutants obtained in this research which also implies that miners are safer under humid conditions with all other factors held constant. Humidity however, makes the air damp and uncomfortable while it encourages the development of molds, mildews, bacteria, viruses and other allergens in the atmosphere (Mendell et al., 2011). The positive relationship between air pollutants and atmospheric pressure could be due to the increased vertical mixing and decreased horizontal dispersion that come along with increase in pressure as observed by Guicai et al., (2018) in their work on weather systems and air quality where they reported that an inland high pressure led to temperature inversion and low horizontal wind speed which favour the increase in air pollutants. Liu et al. (2020) reported significant negative correlation between air pollutants and wind speed, precipitation and relative humidity while positive correlation was observed with pressure in their study of air pollution and meteorological conditions. They posited that air pollution and alterations in pollutant concentration are significantly influenced by meteorological conditions and a systematic understanding of this relationship is required for a scientific air pollution management policies formulation. Chao and Min (2022) reported that temperature has obvious effects on air pollutants, they observed a positive linear relationship between air pollutants and temperature in their work on atmospheric pollutants and meteorological factors where increased temperature makes it conducive for vertical flow as well as the diffusion of pollutants. The negative relationships of NO_2, SO_2, $PM_{2.5}$ and temperature in this research could be accounted for by the fact that air pollutants absorb radiant energy thereby affecting the surrounding temperature (Pawar et al., 2023), although meteorological factors do not act in isolation but are in constant multiple and complex reactions with one another and with air pollutants in the atmosphere (Daniel, 2008; Grigorieva and Lukyanets, 2021). Negative relationship between ambient air temperature and gaseous pollutants was also observed by Okimiji et al. (2021) and they explained that conversion of these pollutants to ozone which happens with increased temperature and vertical dispersion regime was responsible for the inverse relationship.

Seasonal Variation of Air Quality Parameters in the Study Area

The mean wet and dry season concentrations of Carbon monoxide were 20.14±2.38 and 32.47±51(μg/m^3) respectively, SO_2 wet and dry seasons concentrations were 39.93±3.62 and 43.05±3.48 (μg/m^3) respectively both of which were significantly different ($P<0.05$) while NO_2 concentrations were 104.81±3.95 and 106.78±2.68 (μg/m^3) respectively, though with no significant difference ($P>0.05$) but dry season concentration was higher. Mean atmospheric pressure during the wet and dry seasons were 3799.38±81.86 and 3421.07±89.62 (N/m^2) respectively while humidity was 49.89±5.83 and 33.75±3.90%respectively with the wet season having significantly higher values. Seasonal variations of the mean air quality parameters of the study area are presented in figure 4.

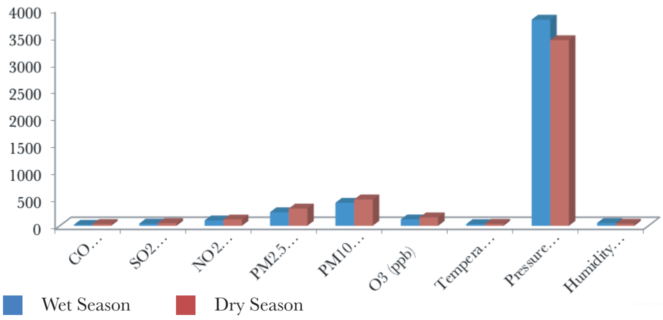

Figure 3. Seasonal Variation of Air Quality Parameters

Air pollutants' dry season concentrations were generally significantly higher than those of the wet season which may be attributed to higher relative humidity and washout by rainfall which reduces re–suspension of particulates as reported by Oji and Adamu (2020) where they observed lower levels of pollutants under conditions of increased precipitation, higher humidity and lower temperature compared to the dry season and concluded that these meteorological factors have washout or scavenging effect on the pollutants. Similar result was obtained by Eghomwanre et al. (2022) in their research on air pollutants concentration and health risk assessment around residential areas in Benin City, Nigeria and they attributed the higher dry season concentrations to higher temperatures, leading to the downward movement of pollutants and higher ground level concentrations. Onuorah et al. (2019) added that adsorption of water vapour onto particles is enhanced by increase in relative humidity brought about by rainfall during the wet season, leading to settling and dry deposition of particles. Measures that increase humidity in the mining area such as groundwater harvesting, artificial rain etc will be useful in reducing atmospheric pollution particularly during the dry season.

CONCLUSION

Air quality parameters in the mining areas and control site were found to be above the WHO limits except for SO_2 in the control, the mining areas had higher pollutant values with a significant difference in CO, SO_2, and $PM_{2.5}$ across sampling stations indicating the impact of mining activities on air pollution in the areas which can manifest in incidences such as acid precipitation, cardiovascular diseases etc. The AQI of the mining areas were all in the hazardous category while that of the non–mining area was very unhealthy implying serious health risks for the miners and inhabitants of these places. Humidity had a negative correlation with all air quality parameters, the highest of which (–0.91) was in CO which could be due to the washout effect of rain hence miners and inhabitants are at less risk during high humidity. Atmospheric pressure had positive correlation with all air pollutants which was attributed to increased vertical mixing and decreased horizontal dispersion, temperature was inversely correlated with NO_2, SO_2 and $PM_{2.5}$ which could be due to radiant energy absorption by these pollutants as well as the conversion of gaseous pollutants to O_3 which comes with increased temperature and vertical dispersion. There was a significant difference ($P<0.05$) in air pollutants concentrations between seasons with the dry season having higher values which could be attributed to high humidity brought about by rainfall and its actions in the atmosphere. In essence, meteorological factors do not act in isolation but are in constant multiple and complex reactions with one another and with air pollutants in the atmosphere. It is therefore recommended that information and regulation of mining processes should be done to emit less pollutants and make the work safer, the use of personal protective equipments (PPEs) should be encouraged and miners should limit their duration of exposure to these pollutants, provision of first aid kits and other essential services is also important as some of the issues are acute and require emergency attention. Also, measures should be taken to increase humidity in the mining area such as groundwater harvesting and artificial rain especially during the dry season.

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