Air Quality Evaluation of Ugwuele Quarry Site, Uturu, Abia State, Nigeria

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ABSTRACT

Impacts of quarry activities at Ugwuele, Uturu on air quality were studied. The air sampling was carried out in both wet and dry seasons at the crusher, administrative block, gate, plant house, and drilling pit positions of the quarry site. Aeroqual and Crowcon gas monitors and analyzers were used for measuring the gases and particulate matter while the heavy metals in the dust were sampled using exposed filter papers and analyzed using atomic adsorption spectrophotometer. Noise levels were measured using sound level meters.

Results indicate that the concentrations of NO_2, SO_2, and particulate matter 1 (PM_1) in the air increased above World Health Organization (WHO) standards: NO_2 ranged from 0.02±0.01 to 0.22±0.08 mg/m^3, SO_2 0.13±0.10 to 0.80±0.02 mg/m^3, and PM_1 1.22±0.01 to 8.40±0.21 µg/m^3. All the analyzed heavy metals (Co, Zn, Cr, Cd, As and Pb) were present in the quarry dust. However, chromium recorded the highest concentrations in all the seasons. The concentrations of the heavy metals in the dust were significantly higher ($p<0.05$) in the quarry than in the control and higher in the dry season than in the wet season. Results also indicate that noise levels differed at the various activity areas of the quarry and were higher in the quarry when compared ($p<0.05$) to the control. However, the noise levels obtained from the gate and plant house were above the WHO standards.

These results suggest that Ugwuele quarry activities have adverse effects on the ambient air within its vicinity.

(Keywords: particulate matter, meteorological factors, noise, heavy metals)

INTRODUCTION

The mining industry, which involves quarrying, is very important as it creates job opportunities, generates income, and provides useful materials such as those used in road construction. However, quarrying activities are sources of different types of air pollutants which have impacts on air quality [1]. These activities include drilling, blasting, and crushing. The major air pollutants that can be generated by these activities include Sulphur dioxide (SO_2), oxides of Nitrogen (NO_x), Carbon monoxide (CO), Carbon dioxide (CO_2), ground level ozone (O_3), and particulate matter (dust) [1].

Particulate matter has health effects, however, the level of effect usually depends on the length of time of exposure, as well as the kind and concentration of chemicals and particles inbolbrf in the exposure. The effects of acute exposure include irritation of the eyes, nose and throat, and upper respiratory infections such as bronchitis and pneumonia. Others include headaches, nausea, and allergic reaction. Acute air pollution can aggravate the medical conditions of individuals with asthma and emphysema. Chronic effects include chronic respiratory disease, lung cancer, heart-disease, and even damage to the brain, nerves, liver, or kidneys [2].

Respirable particulate matters have become potential pollutants during quarrying and crushing operations such as crushing, screening, and in loading and transportation. Plants are also subject to impacts from particulate matter. The dust and other respirable particulate matter (RPM) cover the leaf surface and clog the stomata. This completely covers not only the photosynthetic surface but also interferes with the exchange of gases and reduces the transpiration rate. Plants sensitive to a particular air pollutant show visible symptoms like chlorosis, necrosis, and growth retardation [3, 4].

Noise can be defined as the level of sound which exceeds the acceptable level and creates annoyance [5]. Exposure to excessive noise levels also cause negative psychological and psychosocial impacts on humans and animals. Long term exposure to intense levels of noise leads to personality changes and violent reactions [6]. Since most studies on environmental pollutions are basically on water pollution [7-15], the present study extended environmental studies to accommodate air pollution and determined the impacts of quarrying activities on air quality.

MATERIALS AND METHODS

Area of Study

The study area is Ugwuele quarry site in Uturu, Isuikwuato Local Government Area of Abia State Nigeria. The quarry site lies within latitude 05°50'18" N of the equator and longitude 07°25' 17" E of the Greenwich Meridian (Figure 1). It has good access roads. The quarry is also surrounded by agricultural areas.

Rainy and dry seasons are the major climatic conditions of the area. The dry season starts in November and ends in March. The Harmattan also occurs during this season. The rainy season starts in April and ends in October [16]. The area is also located within the tropical rainforest belt of Nigeria and the annual rainfall is between 1500 mm and 2000 mm with an average temperature of about 27°C and relative humidity of about 70% [17]. The thickness of the sands and sandstones found in the area ranges from 2.0 m – 2200.0 m [18].

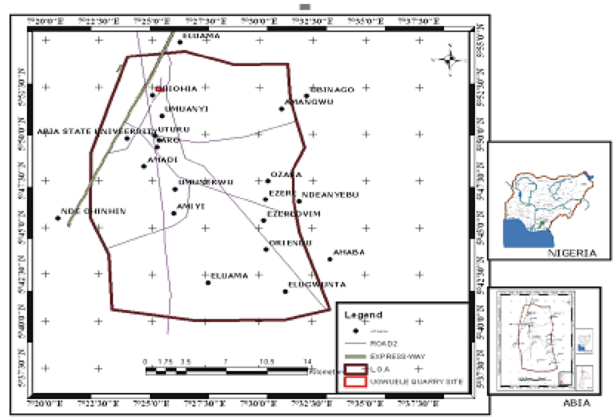

Figure 1: Map of Isuikwuato Showing Ugwuele Quarry Site.

Sampling Methods

Ambient air samples were taken at the crusher, admin. block, gate, plant house, and drilling pit locations of the quarry. Aeroqual and Crowcon Gasman monitors/analyzers were used for all the parameters except the heavy metals where, exposed filter paper was used. Average time of sampling was 30 minutes for gases and particulate matter and 8 hours for heavy metals at each point. Control samples were taken at a location outside the quarry (about 7km away).

Determination of Noise Level

The sound level meter was turned on and raised to a height of 2 meters from the ground. The readout was recorded in decibel (dB) after about 4 minutes.

Determination of Wind Speed and Direction

The anemometer was turned on and raised to a height of 2 meters from the ground. The values of both wind speed and direction displayed simultaneously on the meter and were recorded after 5 minutes.

Determination of Gases and Particulate Matter

The measured parameters in the sampled air are Sulphur (IV) oxide (SO_2), Nitrogen (IV) oxide (NO_2), Carbon (II) oxide and ground level ozone (O_3). Total suspended particulates (TSP), respirable and inhalable particulates ($PM_{2.5}$ and

PM_{10}), other particulates and heavy metals (Pb, Cr, Co, As, Zn, and Cd) were also measured. The method described by [19] was used. The monitors' power switch was turned on and allowed to warm up for 3 minutes. The air monitors were raised to a height of 2 meters from the ground. The readout was recorded after about 5 minutes.

The Atomic Absorption Spectrophotometer (AAS) Determination of Heavy Metals

The method as described by [20] was used. The elements wavelengths were 358, 283.3, 229, and 213.9 nm for Cr, Pb, Cd, and Zn, respectively.

Statistical Analysis

Results were analyzed statistically using Analysis of variance (ANOVA) and standard T-distribution test using statistical package for social sciences (SPSS), version 20. Level of significance was at 5%.

RESULTS

The results of meteorological factors and noise measurements at Ugwuele Quarry site are presented in Tables 1 and 2.

Air Temperature (°C): In the wet season, the value of air temperature ranged from 29.47±1.05 (in the admin. block) to 31.50±0.25 (in the drilling pit). The lowest recorded value (28.20±1.11) was from the control. During the dry season, the value ranged from 30.80±1.80 (at the gate) to 33.90±2.00 (at the drilling pit). The value of 31.17±0.35 was recorded in the control. Air temperature of the quarry site increased significantly ($p<0.05$) compared to the control.

Wind Speed (m/s): During the wet season, the value of wind speed varied from 1.30±0.03 (at the drilling pit) to 2.50±0.04 (at the plant house). The least recorded value (1.53±0.16) for the wet season was from the control point. During the dry season, the values ranged from 1.10±0.10 (at the drilling pit) to 2.20±0.02 (at the plant house). A value of 1.27±0.83 was recorded at the control point. Wind speed in the quarry site increased significantly ($p<0.05$) compared to the control.

Wind Direction: In the wet season, the values of wind direction varied from 120.00±2.31° SSE (at the drilling pit) to 305.33±6.00° SW (at the gate). The value of 157.67±3.50 °SSE was recorded at the control point. In the dry season, the values ranged from 145.33±0.25° NE (at the drilling pit) to 318.07±0.20° NE (at the admin. block). The value at the control was 198.17±3.10° NE. Wind direction in the quarry site was significantly different ($p<0.05$) compared to the control.

Table 1. Meteorological Factors and Noise Measurements at Ugwuele, Uturu Quarry Site (Wet Season).

Parameters	Crusher	Admin. block	Gate	Plant house	Drilling pit	Control	WHO STD. [12]
Air Temp. (°C)	31.40±1.20^b	29.47±1.05^d	29.83±1.05^f	31.23±1.00^h	31.50±0.25^j	28.20±1.11^a	
Wind Speed (m/s)	2.10±0.50^b	1.60±0.10^d	1.60±0.03^f	2.50±0.04^h	1.30±0.03^j	1.53±0.16^a	
Wind Direction	240.07±9.20^b SSW	300.67±5.40^d NE	305.33±6.00^f SW	157.67±3.50^a SSE	120.00±2.31^i SE	157.67±2.41^a SSE	
Noise (dB)	81.73±5.12^b	80.67±2.05^d	90.37±1.27^f	91.23±2.42^h	79.30±2.01^j	76.33±0.02^a	90.00

Values in the table are mean ± standard deviation of triplicate values. Values in the same row, having different letters of alphabet are statistically different at 5% level of significance.

Table 2. Meteorological Factors and Noise Measurements at Ugwuele, Uturu Quarry Site (Dry Season).

Parameters	Crusher	Admin. block	Gate	Plant house	Drilling pit	Control	WHO STD. [12]
Air Temp. (°C)	32.40±0.90^c	30.97±2.00^e	30.80±1.80^g	31.40±0.40^i	33.90±2.00^K	31.17±0.35^a	
Wind speed (m/s)	1.80±0.10^c	1.37±0.08^e	1.37±0.03^g	2.20±0.02^i	1.10±0.10^k	1.27±0.83^a	
Wind direction	249.87±5.02^c NE	318.07±0.20^e NE	308.47±4.00^g SW	196.90±2.50^h NE	145.33±0.25^j NE	198.17±3.10^a NE	
Noise (dB)	82.43±2.00^c	82.27±2.10^e	92.13±3.00^g	92.50±2.55^i	79.13±2.45^k	75.20±0.95^a	90.00

Values in the table are mean ± standard deviation of triplicate values. Values in the same row, having different letters of alphabet are statistically different at 5% level of significance.

Noise (dB): The values of noise measurement in the wet season varied from 79.30±2.01 (at the drilling pit) to 91.23±2.42 (at the plant house). The control point recorded the least value of 76.33±0.02. In the dry season, the values ranged from 79.13±2.45 (at the drilling pit) to 92.50±2.55 (at the plant house). The least recorded value (75.20±0.95) was from the control. Noise values at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control. However, noise levels at various locations in the quarry site were below the World Health Organization (WHO) standard except the levels at the quarry's gate and plant house which were higher than the standard.

The results of concentrations of gaseous pollutants and particulate matter at Ugwuele Quarry site, Uturu are presented in Figures 2 and 3.

CO (mg/m^3): During the wet season, the concentration of carbon (II) oxide (CO) in the air ranged from 0.01±0.01 (at the gate) to 0.17±0.02 (at the crusher). Carbon monoxide was not detected at the plant house while the highest value (1.67±0.06) was recorded at the control point. Whereas, in the dry season the value ranged from 0.60±0.01 (at the gate) to 1.17±0.04 (at the admin. block). The highest recorded value (2.87±0.43) was at the control. Concentrations of CO in the quarry site decreased significantly ($p<0.05$) compared to the control.

O_3 (mg/m^3): In the wet season, the concentration of the ground-level ozone (O_3) ranged from 0.02±0.01 (at the plant house) to 0.05±0.02 (at the crusher). The value of 0.02±0.01 was also recorded at the control. In the dry season, the value ranged from 0.04±0.01 (at the plant house) to 0.11±0.02 (at the drilling pit). The highest recorded value of 0.27±0.01 was from the control. Concentrations of O_3 in the quarry site increased significantly ($p<0.05$) compared to the control.

NO_2 (mg/m^3): During the wet season, the concentration of nitrogen (IV) oxide (NO_2) in the ambient air ranged from 0.02±0.01 (at the drilling pit) to 0.12±0.03 (at the gate). The control recorded a value of 0.07±0.02. In the dry season, the concentration varied from 0.12±0.03 (at the crusher) to 0.22±0.08 (at the admin.block). The lowest recorded value (0.05±0.02) was at the control point. Concentrations of NO_2 at various locations in the quarry site were also higher than the WHO standard.

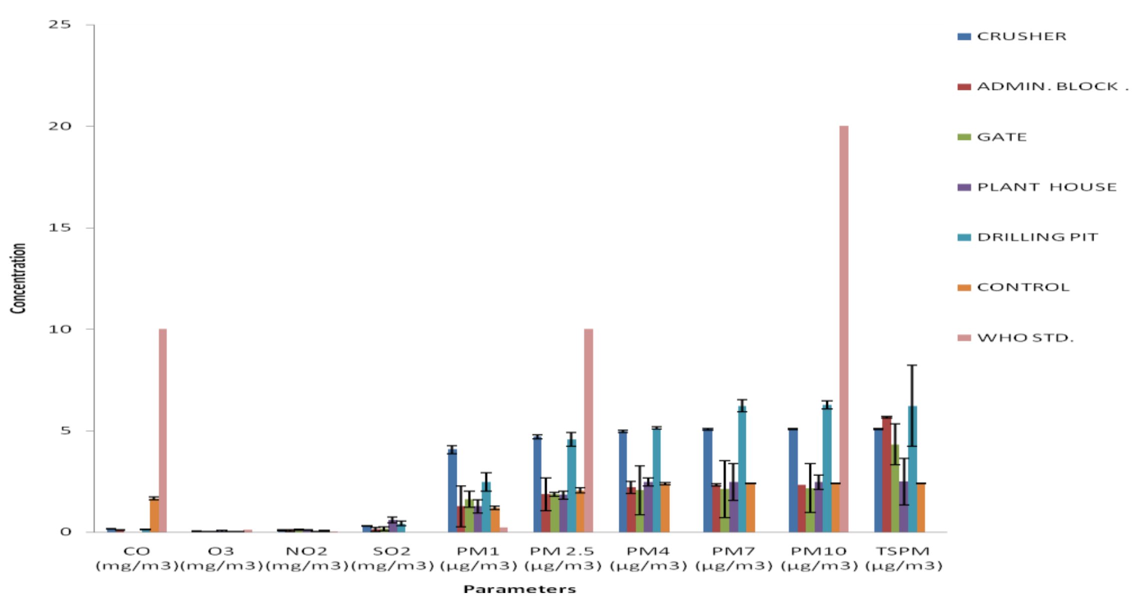

Figure 2. Concentrations of Gaseous Pollutants and Particulate Matter at Ugwuele Quarry site, Uturu (Wet Season). Values in the bar chart are mean ± standard deviation of triplicate values. Bars having different letters of alphabet are statistically different at 5% level of significance.

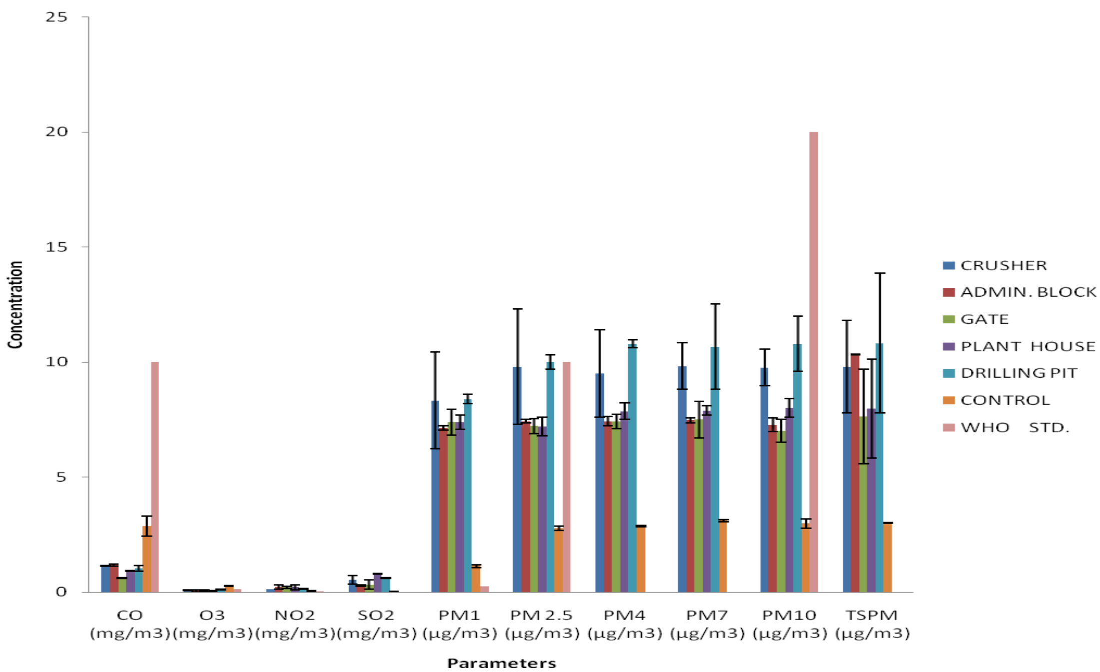

Figure 3. Concentrations of Gaseous Pollutants and Particulate Matter at Ugwuele Quarry Site, Uturu (Dry Season). Values in the bar chart are mean ± standard deviation of triplicate values. Bars having different letters of alphabet are statistically different at 5% level of significance.

SO_2 (mg/m^3): In the wet season, the concentration of Sulphur (IV) oxide (SO_2) in the ambient air ranged from 0.13±0.10 (at the admin. block) to 0.60±0.15 (at the plant house). Sulphur dioxide was not detected at the control point. In the dry season, the concentration ranged from 0.29±0.03 (at the admin. block) to 0.80±0.02 (at the plant house). The least recorded value (0.02±0.01) was at the control. Concentrations of SO_2 at various locations in the quarry site were also higher than the WHO standard.

PM_1 ($\mu g/m^3$): The value of the particulate matter in the wet season ranged from 1.27 (at both, the admin. block and plant house) to 4.07±0.20 (at the crusher). The least recorded value (1.20±0.09) was at the control. Whereas, in the dry season, the values ranged from 7.13±0.10 (at the admin. block) to 8.40±0.21 (at the drilling pit). The least recorded value (1.13±0.07) was from the control. Concentrations of PM_1 at various locations in the quarry site were also higher than the WHO standard.

$PM_{2.5}$ ($\mu g/m^3$): The value of $PM_{2.5}$ in the wet season, varied from 1.83±0.20 (at the plant house) to 4.70±0.09 (at the crusher). A value of 2.07±0.12 was recorded at the control point. In the dry season, the values ranged from 7.20±0.40 (at plant house) to 10.00±0.32 (at the drilling pit). The lowest recorded value (2.77±0.10) for the dry season was from the control. Concentrations of $PM_{2.5}$ in the quarry site increased significantly ($p<0.05$) compared to the control.

PM_4 ($\mu g/m^3$): The value of PM_4 in the wet season ranged from 2.07±0.12 (at the gate) to 5.13±0.06 (at the drilling pit). The control recorded a value of 2.40±0.06. In the dry season, the value ranged from 7.43±0.31 (at the admin. block and gate) to 10.80±0.17 (at the drilling pit). The lowest recorded value (2.87±0.03) was at the control. Concentrations of PM_4 at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

PM_7 ($\mu g/m^3$): The values of PM_7 in the wet season, ranged from 2.13±1.40 (at the gate) to 6.23±0.30 (at the drilling pit). A value of 2.40±0.01 was recorded at the control point. Whereas, during the dry season, the values ranged from 7.47±0.10 (at the admin. block) to 10.67±10.67 (at the drilling pit). The least recorded value (3.10±0.04) was from the control. Concentrations of PM_7 at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

PM_{10} (µg/m^3): In the wet season, the value of PM_{10} ranged from 2.17±1.20 (at the gate) to 6.27±0.19 (at the drilling pit). A value of 2.40±0.02 was recorded at the control point. In the dry season, the values ranged from 7.27±0.30 (at the admin. block) to 10.80±1.21 (at the drilling pit). The least recorded value (2.97±0.21) was from the control. Concentrations of PM_{10} at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

TSPM (µg/m^3): The values of the total suspended particulate matter (TSPM) in the wet season, varied from 2.50±1.15 (at the plant house) to 6.23±2.00 (at the drilling pit). The least recorded value (2.40±0.01) was from the control point. In the dry season, the values ranged from 7.63±2.05 (at the gate) to 10.83±3.03 (at the drilling pit). The least recorded value (3.00±0.02) was from the control. Concentrations of TSPM at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

The results of heavy metals in the dust at Ugwuele quarry site, Uturu are presented in Figures 4 and 5

Co (ppm): The value of cobalt (Co) in the dust during the wet season ranged from 0.18 (at both the gate and admin-block) to 0.24±0.10 (at the drilling pit). The least value (0.01±0.01) was from the control. In the dry season, the values ranged from 0.20±0.02 (at the gate) to 0.39±0.01 (at the drilling pit). The lowest value (0.03±0.00) was recorded at the control. . Concentrations of Co at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

Zn (ppm): In the wet season, the value of zinc (Zn) in the dust, ranged from 0.04±0.02 (at the admin.block) to 0.06 (at the crusher and plant house). Zinc was not detected at the drilling pit. A value of 0.24±0.12 was recorded at the control point. During the dry season, the concentration ranged from 0.02±0.01 (at the drilling pit) to 0.22±0.04 (at the admin.block). The highest value (0.52±0.01) was recorded at the control. Concentrations of Zn at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

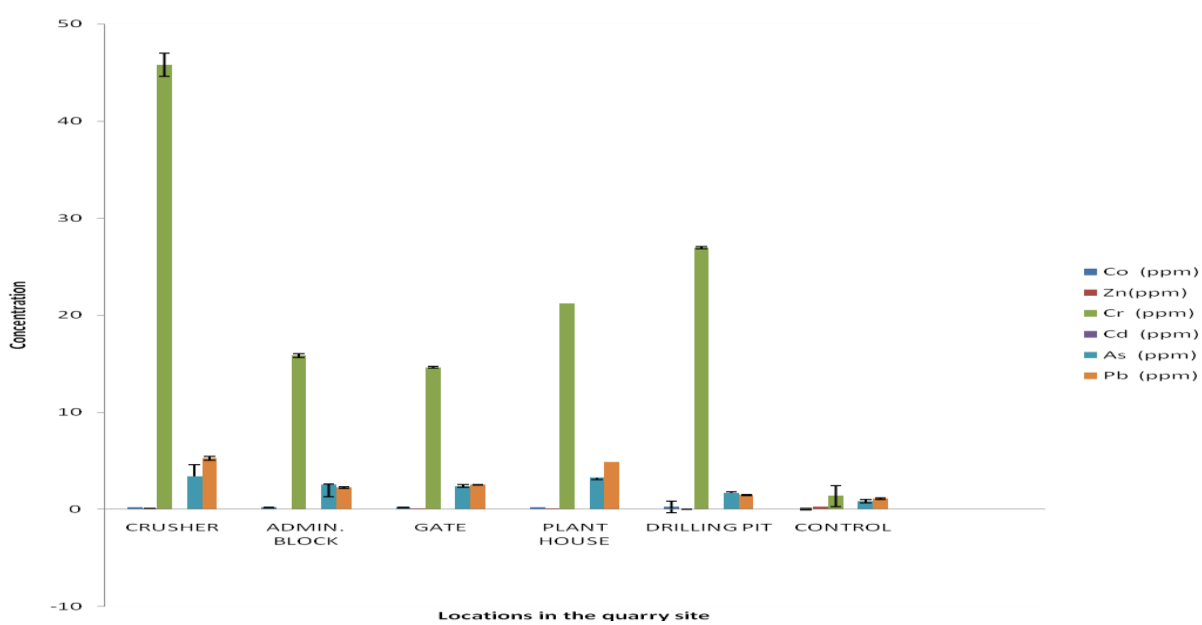

Figure 4. Concentrations of Heavy Metals in the Dust of Ugwuele Quarry Site Uturu (Wet Season). Values in the bar chart are mean ± standard deviation of triplicate values. Bars having different letters of alphabet are statistically different at 5% level of significance.

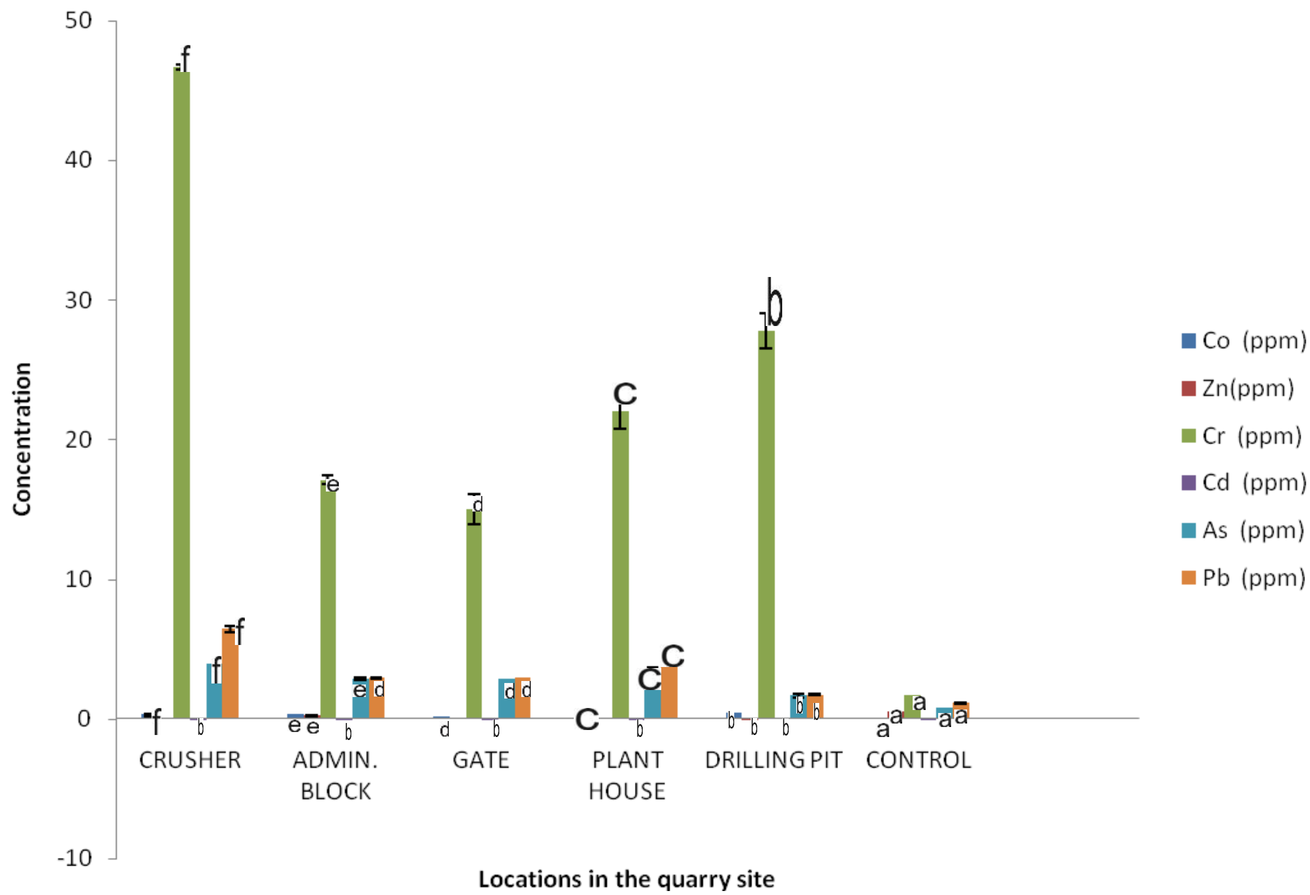

Figure 5. Concentrations of Heavy Metals in the Dust of Ugwuele Quarry Site Uturu (Dry Season). Values in the bar chart are mean ± standard deviation of triplicate values. Bars having different letters of alphabet are statistically different at 5% level of significance

Cr (ppm): During the wet season, the values of chromium (Cr) in the dust ranged from 14.62±0.09 (at the gate) to 45.80±1.20 (at the crusher). The least recorded value (1.36±0.03) was from the control point. In the dry season the values ranged from 15.02±1.05 (at the gate) to 46.70±0.20 (at the crusher). The lowest recorded value (1.72±0.01) was from the control. Concentrations of Cr at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

Cd (ppm): Cadmium (Cd) was detected at only the drilling pit and the control with the same value of 0.01, during the wet season. Whereas, during the dry season, the value (0.01) was the same in all the areas and control, except a value of 0.03±0.01 recorded at the drilling pit.

As (ppm): During the wet season, the values of arsenic (As) ranged from 1.69±0.18 (at the drilling pit) to 3.40±1.20 (at the crusher). The least recorded value (0.81±0.01) was from the control. During the dry season, the values ranged from 1.69±0.18 (at the drilling pit) to 3.97±0.01 (at the crusher). The least recorded value (0.83±0.01) for the season, was from the control.

Pb (ppm): In the wet season, the concentration of lead (Pb) in the quarry dust ranged from

1.48±0.10 (at the drilling pit) to 5.24 ±0.21 (at the crusher). The least recorded value (1.10±0.10) was from the control. In the dry season, the values ranged from 1.72±0.04 (at the drilling pit) to 6.44±0.20 (at the crusher). The lowest recorded value (1.13±0.02) for the dry season was from the control. Concentrations of all these heavy metals at the various locations in the quarry site increased significantly ($p<0.05$) compared to the control.

DISCUSSION

Meteorological factors are determinants of pollutants and inversions. Particulate matter concentration increases with decrease in wind velocity and air temperature [22]. Variations in air temperature also control the atmospheric heat transfer by convection. This can also affect the concentrations of air pollutants [23]. Results from the present study show that air temperature values were not the same at the different activity areas of the quarry site. The values of air temperature at different areas within the quarry were also higher when compared to the control. This may be attributed to effect of the combination of greenhouse gases (such as CO and NO_2) which are higher in the quarry site. Such greenhouse gases are known to trap heat from the sun [24] or other industrial process that generate heat.

The results of this study also show that air temperature values were higher in the dry season than in the wet season. This may be mainly due to the fact that dry season is always hotter than the wet season. Wind speed and direction determine the dispersion of air pollutants. The results from this study show that wind speed and direction varied at different areas within the quarry. Wind speed values were higher in the quarry than in the control. This may be attributed to the topography of the area under study.

The results also show that the values of wind speed were higher in the wet season than in the dry season. This may be because highest wind speeds are normally associated with winds from the South-East [25]. This corresponds with the results of this study that show that wind speeds were chiefly South-Easterly in the wet season and chiefly North-Easterly in the dry season.

Noise is unwanted sound which occurs as a result of both human and non-human activities. It affects hearing, metabolism, and behavioral conditions [6]. The results obtained from the present study show that noise levels differed at the different activity areas of the quarry. Also, the noise levels were higher in the quarry when compared to the control. This may be attributed to the higher level of noise generated by the generator, crusher, drilling equipment, vehicular movements, and other activities within the quarry. However, in both seasons noise levels in the quarry were below the World Health Organization (WHO) standard value, apart from levels obtained from the gate and plant house.

Carbon monoxide is a colorless, odorless, and tasteless gas which is produced from the incomplete combustion of carbon and carbon containing compounds [16]. The results of the present study reveal that the concentrations of carbon (II) oxide varied from one activity area to the other within the quarry and were higher at the control than at the quarry. This may be due to the greater movements of vehicles at the control. The results of this study also show that the concentrations of CO were higher in the dry season than in the wet season. This may be attributed to the fact that low wind speed, high temperature, and low humidity reduce the rate of dispersion of air pollutants, thus increasing ground level concentration of same pollutants [26].

Certain pollutants such as volatile organic compounds (VOCs) react with oxides of nitrogen in the presence of sunlight to form ozone at ground level [27]. Results from this study show that the concentrations of ozone were higher in the dry season than in the wet season. This may be chiefly because of the high temperature and NO_2 recorded during the dry season [26]. Also, the concentrations of ground level ozone in the area under study exceeded the WHO standard values. Increased concentration of ozone can cause coughs, respiratory tract irritations, and headache [27].

Nitrogen dioxide (NO_2) is a respiratory toxic gas produced when nitrogen mono-oxide (NO) reacts with oxygen in the atmosphere [28]. The results from the present study show that the levels of atmospheric NO_2 differed from place to place within the quarry and were above the WHO standard (0.04-0.06 mg/m^3). This may be attributed to the anthropogenic emissions of NO_2 through combustion processes in the generators and other engines including some emissions during blasting [29]. Our results also show that the concentrations of NO_2 were lower in the wet season than in the dry season. This may be because more NO_2 is converted to trioxonitrate (V) acid (HNO_3) during the wet season. Nitrogen (IV) oxide dissolves in water to give trioxonitrate (V) acid [30]. Nitrogen dioxide may have many negative effects on the environment and health. It affects the respiratory function and can lead to a broncho-constriction [28].

Sulphur dioxide is a colorless gas at ordinary temperature. It has some negative effects on the ecosystems through direct impact on plants. In humans, inhaled SO_2 stimulates bronchial epithelial irritant receptors in the tracheobronchial tree. It may also lead to bronchial constriction [31]. The results from this study show that the concentrations of SO_2 in the quarry were higher than the control in all the seasons and were also above the World Health Organization (WHO) standard permissible standard value. This may be due to anthropogenic emissions through industrial processes [29]. The results also show that the concentrations of SO_2 were lower in the wet season than the dry season. This may be because SO_2 is highly soluble in water. It dissolves in water to give tetraoxosulphate (VI) acid (H_2S0_4) upon emission into the atmosphere [30]. Sulphur dioxide is considered the major cause of acid rain.

PM_1 is particulate matter with an aerodynamic diameter ≤ 1µm. It is a major component of $PM_{2.5}$ but more harmful. It can reach deeper into the respiratory system with more toxicants attached to it [32]. The results from this study show that in all the seasons, the levels of PM_1 in the quarry were higher than in the control and the WHO standard value. This is primarily due to the emissions of dust from the quarry.

$PM_{2.5}$ is particulate matter with an aerodynamic diameter ≤2.5µm. It is usually referred to as fine particulate matter [33]. Inhalation of $PM_{2.5}$ can cause cardiovascular diseases with wheezing, chest tightness, and difficulty breathing as symptoms [34]. Results from this study show that the levels of $PM_{2.5}$ varied at different locations within the quarry and lower in the wet season than in the dry season. This may be attributed to the washout by rainfall and the consequent higher relative humidity during the wet season which decreases re-suspension of dust [29].

PM_4 is particulate matter with a diameter ≤4µm. PM_4 is a particulate matter that can be inhaled through breathing. It is particularly important because it can penetrate into the gas-exchange region of the lungs beyond the terminal bronchioles [36]. Results obtained from the present study show that the levels of PM_4 varied at different areas within the quarry and were higher in the quarry than the control. This may be attributed to the emissions of dust in the quarry through crushing and drilling of rocks. The results also show that the level of PM_4 was lower in the wet season than the dry season. This may be attributed to the washout by rainfall during rainy season [29] and longer residence time of particles in the atmosphere during dry season due to low wind speeds and low mixing height [35]. The inhalation of PM_4 causes respiratory disease [36].

PM_7 is particulate matter with diameter of ≤7µm. When inhaled, it is likely deposited at the tracheobronchial region [37]. The results obtained from the present study reveal that the levels of PM_7 varied from place to place within the quarry and were higher in the dry season than in the wet season. This may also be attributed to low wind speeds, low relative humidity, and longer residence time of particulates in the atmosphere during the dry season.

PM_{10} is a coarse particulate matter with a diameter ≤10µm. Short term exposure to PM_{10} can have severe effects on health [38]. The results from the present study reveal that the levels of PM_{10} varied at different areas within the quarry and were higher in the dry season than in the wet season. This may be attributed to low wind speeds and higher temperature during the dry season [35].

TSPM is the concentration of all particulate matter in the atmosphere. They may be harmful to both living and non-living things [39]. The results from this study show that in both seasons, the concentrations of TSPM were higher in the quarry than in the control. This is mainly due to the dust generated by the quarrying activities. The results also show that the levels of TSPM were higher in the dry season than in the wet season. Nartey *et al*. [39] reported similar result from a quarry.

CONCLUSION

The quarry caused air pollution by nitrogen (IV) oxide (NO_2), sulphur (IV) oxide (SO_2), particulate matter (PM_1) and heavy metals of its immediate environment. NO_2, SO_2 and PM_1 in the quarry were all higher, in both seasons than the World Health Organization standard values. Noise levels were higher in the quarry when compared to the control ($p<0.05$) and higher in the dry season than in the wet season. However, noise levels were below the WHO standard value in all the studied areas of the quarry apart from the gate and plant house which recorded 90.37±1.27 to 92.13±3.00 and 91.23±2.42 to 92.50±2.55, respectively, for both seasons. We therefore recommend that the quarry workers, more especially those at the crusher section should always wear appropriate personal protective equipment during their working periods to avoid the dangers of air pollution.

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