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Environmental impact of quarrying on air quality in Ebonyi state, Nigeria

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Abstract

Background The insatiable demand for rock supplies has enticed numerous building and construction enterprises to participate in stone quarrying. However, this has had an environmental impact on air quality. This paper examines the environmental impact of quarrying on air quality in Ebonyi State, Nigeria. To achieve the main aim of the study, an objective was set to detect air pollutants at the quarry sites. A total of 220 air samples were measured from six points around the quarry locations and recorded in situ for analysis. The samples were measured three times a day (morning, afternoon, and evening) for three days. Gas monitors were used to monitor air pollutants. The generated data were subjected to completely random design (CRD) sampling techniques. The separation of means and tests was performed using Fisher's Least Significant Difference (FLSD) at a significance probability level of 5%.

Results Based on statistical analysis, the findings detected significantly higher concentration levels of particulate matter, nitrogen dioxide, hydrogen sulphide, carbon monoxide, sulphur dioxide, chlorine, volatile organic compounds, ammonia, and hydrogen cyanide in the quarry areas than the value detected in the control area. The findings also confirmed higher noise levels in the locations. It was also observed that the concentration levels of the parameters differed from point to point and at different times of the day. This really means the occurrence of a high rate of air pollution in the study locations.

Conclusions Based on the above findings, it is highly recommended that, (i) if situation is not timely addressed, it will lead to a severe environmental disaster or hazard, as nobody selects the air he or she breathes; (ii) air pollution control equipment be installed in-situ at quarry sites where free air flow is available in order to reduce gaseous (pollutant) emissions, and (iii) the seasonal effects, meteorological parameters and time that were influenced by the activities of quarry should be put in check.

Keywords Air quality, Gaseous emission, Mining, Pollution, Quarry site

Introduction

Stone quarrying and crushing are a global phenomenon and have caused widespread concern throughout the world, including developed countries [1]. Quarry work is a necessity that provides many of the materials used in traditional laying, such as limestone, granite, marble, slate, sandstone, and even clay, in order to produce ceramic tiles [2].

Quarrying has become critical in several developing countries, including Nigeria. Nigeria is endowed with enormous quarry resources, which have greatly contributed to national wealth and accompanying socioeconomic benefits. Quarry resources are an essential source of income for a country, but they must first be explored, mined, and processed before they can be used [3]. Various sorts of environmental harm and risks, according to [4], unavoidably follow their three phases of mineral

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growth. The intricate brew of gases that compose the earth's atmosphere has seen significantly more change recently. Due to the increase in pollutants, human activities ranging from residential energy use to large-scale industrial operations are mostly to blame for this poor state of the atmospheric elements. A significant environmental issue that affects both industrialised and developing nations worldwide is air pollution. Due to the fact that there are numerous sources, it has a wide range of impacts on human health.

According to [5], mineral discovery and growth in Nigeria date back to the Palaeolithic age. According to [6], the colonial authorities began quarrying limestone in Nigeria in 1920 at Abakaliki, and as a result of its further exploitation, the Nkalagu Cement Company (NIGERCEM) was founded. Despite the fact that limestone was only discovered in Nigeria in 1920, according to [7], quarrying at Old Ebonyi Local Government Area began around 1800.

Research has revealed that for the past 30 years, quarrying, limestone production, and the crushing of solid rock have been the main industries in Ebonyi State, Nigeria. The existing quarry industries in Ebonyi State range from stone quarrying to small and medium-sized quarries using heavy equipment, and the number of such industries is estimated to be between 100 and 150 [8]. Dust from quarries is a major source of air pollution, although the severity will depend on factors such as the local climate, the concentration of dust particles in the surrounding air, the size of the dust particles, and their chemical constituents because limestone quarries produce highly alkaline (active) dust while granite quarries produce acidic dust [9]. Dust is caused by explosions, material handling, wind blows, soil erosion, and truck movement [10]. Air pollution is not only annoying, but it has health effects, especially for those with respiratory problems.

A significant negative impact of environmental quarrying is the damage to biodiversity [11], where plants (plant cover) represent a major part of the ecosystem as they play a key role in maintaining balance in oxygen content and carbon dioxide through photosynthetic activities [12]. Such plant mutations have been a major concern for botanists and biologists in recent years, who have promoted a careful and prudent approach to activities that promote such mutations [13].

According to [14] research, of all the non-fuel mineral commodities produced globally, quarry rocks come in third in terms of size and fourth in terms of value. According to [15], the building sector uses 75% of the crushed stone that is generated in the United States and comes from rock quarries. On the slope of a hill, along or into a valley, or flat on the ground, a quarry may be found. The loss of sinkholes and underground passageways is typically the only significant geomorphological effect of quarries constructed on flat terrain.

In ref. [14] reported that quarry on valley side can extend laterally along the valley side causing large geomorphic impacts or they can work back into the valley wall, where the impact is less. Quarries on hills generally have large geomorphic impacts which indicate that crushed stone quarrying have removed an entire karsts hill. The work of [16] states that people living close to the quarries are affected by the activities that go on in that area. In quarrying areas like the village of Pali in India, the safety of human beings is not put into considerations. There is no personal protective equipment being provided to workers, helmet, safety belts, masks, safety shoes are foreign [16]. The study reported that approximately 200 people have been buried alive during the mine blasting operations in the past decade only. The work postulates that the workers and their family who are residing close to these units are more vulnerable to silica exposure. The children, women and elderly are all breathing these toxins regularly.

However, from an environmental management point of view, air pollution in the form of particles (dust) can also have significant effects on surrounding plants, such as blocking and damaging their internal structures, leaves, and cuticles, as well as chemical effects that can affect longevity [17]. Quarry activities in Ebonyi State, Nigeria, have had a devastating impact on the environment, with the explosive explosion of rocks causing air pollution, water pollution, biodiversity damage, and man-made environmental degradation that negatively impacts the environment of a specific area through unfinished or abandoned pits that leave a large open space. This not only looks like an eyesore but also endangers livestock, wildlife, and humans [18]. For example, an Ebonyi State youth leader and his entourage crashed into one of the mines in July 2021 and died on the spot. The number of quarry industries in Ebonyi State, Nigeria, is on the rise. Although it has an impact on internal revenue, there is a need to look at its impact on air quality in general. Heavy metal levels in the soil and plants of quarry locations have been studied [19] but much work remains to be done on the environmental impact of quarrying on air quality in the study area. The study therefore, intends to examine the environmental impact of quarrying on air quality in Ebonyi State, Nigeria to detect air pollutants at the quarry sites.

Materials and methods

The study area

The study was conducted in three zones of Ebonyi districts, namely: the Ishiagu quarry site in Ebonyi South

Senatorial District, the Umuoghara quarry site in Ebonyi Central Senatorial District, and the Ngbo quarry site in Ebonyi North Senatorial District. Ebonyi State is located in south-eastern Nigeria, approximately within latitudes 05^0 4′ and 06^0 4′ N at lengths 07^0 35′ and 08^0 25′ E (Figs. 1 and 2).

Ebonyi State falls within the Asu-River Geologic Group (Lower Cretaceous), Eze-Aku Shale Formation, and Nkporo Formations (Fig. 3). The state is mostly made up of hydromorphic soils, which are shallow-depth reddish-brown gravelly and pale-colored clayey soils with shale parent material. The terrain is mostly flat, with a high point of 162 m and a low point of 15 m above sea level. The state lies within the Cross River Drainage Basin. It has a population of 2,176,947 and a 5,533 km^2 landmass [20]. Pseudo-bimodal (April to July and September to November) is the pattern of the rainfall in the study area. It has an annual rainfall range of 1700–2000 mm and 1800 mm as the annual mean. Ebonyi State has 27 ^{0}C as the minimum temperature and 31 ^{0}C as the mean maximum daily temperature. During the rainy season, the humidity of the study area is 80% high, while the dry

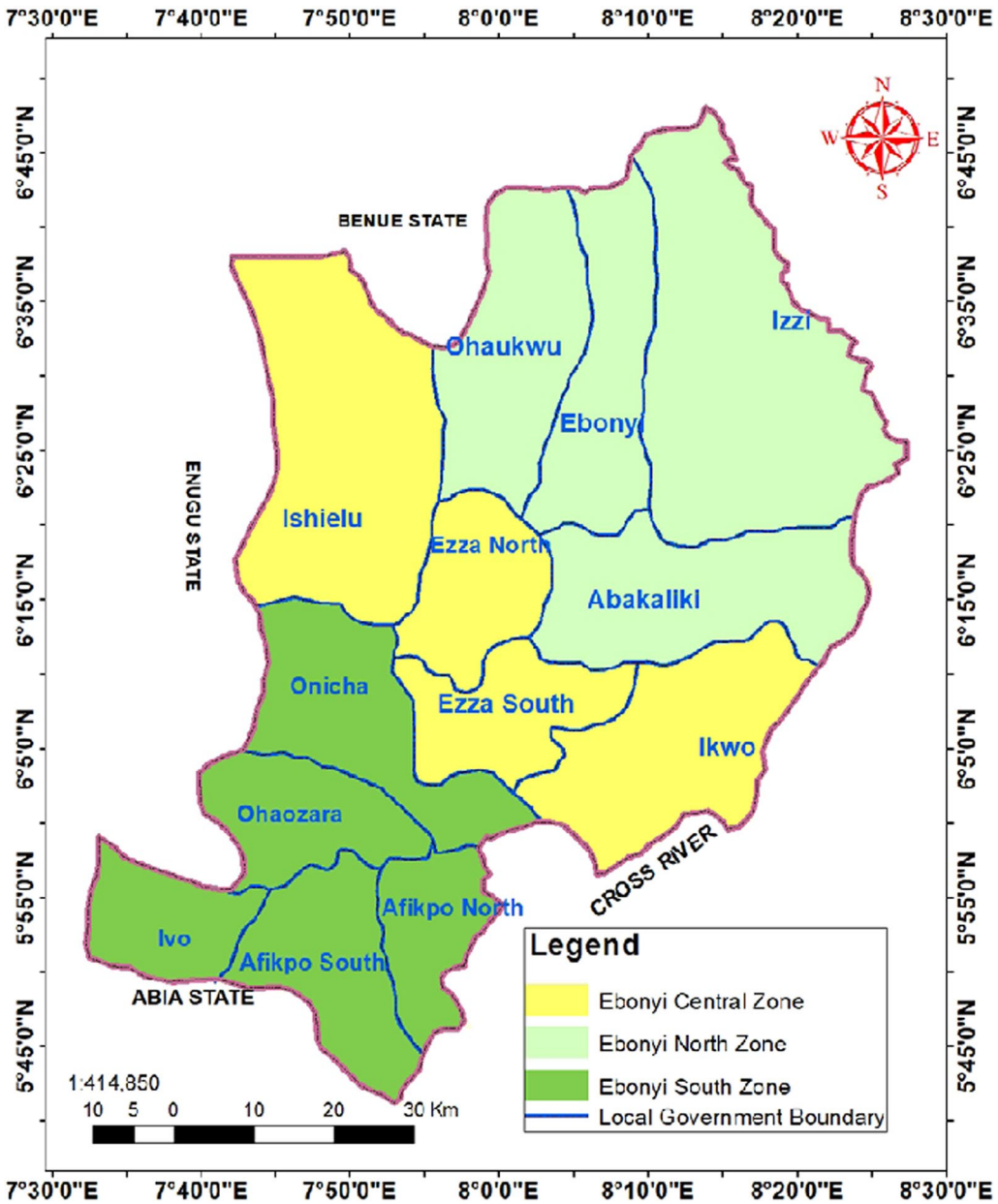

Fig. 1 A Map of Ebonyi State showing the Senatorial Zones Source [23]

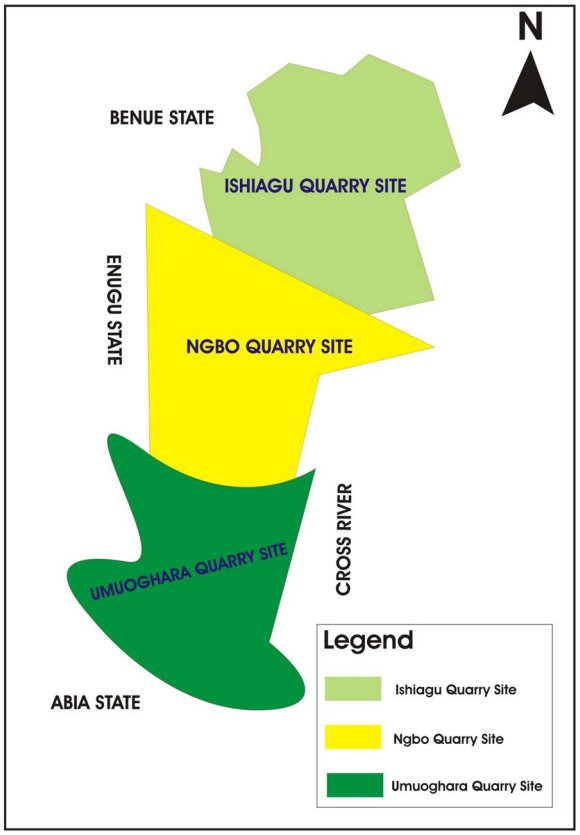

Fig. 2 A Map depicting the different quarry sites Source: Researcher's Intern (2021)

season is 60% low. Despite the high amount of rainfall in the area, groundwater resources are relatively scarce [21]. This is because the shale, which predominantly underlies the study area, is rarely aquiferous. They are predominantly hard, massive, and impermeable [22].

Site selection and experimental design

The following study sites were chosen after an initial survey of the study sites was conducted in 2021 during the dry season (March) and the rainy season (July).

However, the three quarries were chosen based on the senatorial zones that make up the state to ensure proper research representation and coverage (Table 1).

Sampling

The air quality parameters measured in the sampled air were particulate matter (PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), hydrogen sulphide (H_2S), sulphur dioxide (SO_2), chlorine (Cl_2), volatile organic compounds (VOCs), ammonia (NH_3), hydrogen cyanide (HCN). Noise levels were also measured. Air quality was measured 0–50 m away from three different quarry areas (Ishiagu, Umuoghara, and Ngbo). The control was taken 3 km from each quarry area. The sampling lasted for 24 h; the reading of each parameter was taken in accordance with the hours indicated in the [24]. The air quality instruments were installed in the tripod stand position at 6 m above ground level and at stability for air quality measurement. However, in order to obtain accurate data

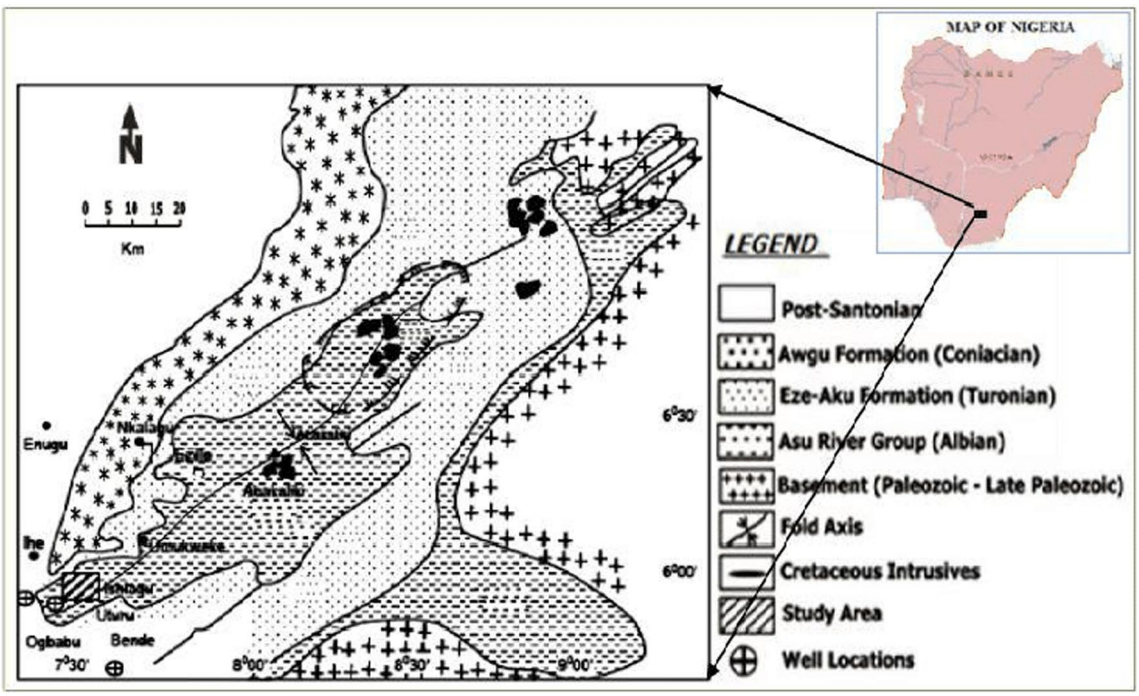

Fig. 3 Geological setting of Ebonyi State Source [23]

Table 1 Quarry study sites selection

S/N	Senatorial zones	Sites	Distance
1	Ebonyi South zone	Ishiagu Quarry Site	0–50 m away from Ishiagu Quarry Site
2	Ebonyi Central Zone	Umuoghara Quarry Site	0–50 m away from Umuoghara Quarry Site
3	Ebonyi North zone	Ngbo Quarry Site	0–50 m away from Ngbo Quarry Site
4	Control	More than 3 km from each quarry location(s)	

on the effect of quarry activities on air quality in the study area, the quarry site was visited in the morning (6:00am), afternoon (12:00 noon), and evening (6:00 pm) (Table 2). Therefore, the measurements for each parameter were taken three times and the average reading is taken from each parameter.

Statistical analysis

The generated data was analyzed using analysis of variance (ANOVA) in a Completely Randomized Design (CRD). To statistically differentiate between datasets, Fisher's Least Significant Difference (FLSD) was used. The level of significance was accepted at a 5% probability level [25, 26]. There were also comparative analyses between the data and World Health Organization [24] standards.

Results and discussion

Environmental impact of quarrying on PM_{10}, CO, H_2S, NO_2, SO_2, Cl_2, VOCs, NH_3, HCN and noise during the dry season

The results of PM_{10}, CO, H_2S, NO_2, SO_2, Cl_2, VOC, NH_3, HCN and Noise levels during the dry season are shown in Tables 3, 4, and 5. The tables showed significant differences ($p < 0.05$) in PM_{10}, CO, H_2S, NO_2, SO_2, Cl_2, VOCs, NH_3, HCN, and noise levels in the study area.

According to Table 3, the concentration levels of particulate matter (PM_{10}) in the various locations studied are lowest at 360.00 µg/m^3, 650.07 µg/m^3, and 800.12 µg/m^3 in the evening for Ishiagu, Umuoghara and Ngbo. They are slightly higher in the morning at 365.09 µg/m^3, 700.13 µg/m^3, and 830.10 µg/m^3 for Ishiagu, Umuoghara and Ngbo; while they are 380 µg/m^3, 710.12 µg/m^3 and 860.30 µg/m^3 highest in the afternoon for Ishiagu, Umuoghara and Ngbo. However, control was 8.10 µg/m^3, 8.97 µg/m^3 and 5.79 µg/m^3 in the morning, afternoon and evening. The diurnal pattern for all observed PM_{10} concentration levels in the dry season showed a unimodal distribution pattern. The concentration level of PM_{10} slowly increased at 6:00 am, significantly increased at 12:00 pm, and then decreased significantly at 6:00 pm. This significant increase and decrease can be attributed to rush-hour traffic and vehicular congestion in the afternoon and the closing of work in the evening. When the three quarry sites were compared, this observation revealed that the PM_{10} concentration level was higher in the Ngbo quarry site than in the Umuoghara and Ishiagu quarry sites. They are all above the [24] recommended permissible limit of 45 µg/m^3, except for control. High PM_{10} concentrations are known to irritate mucous membranes and can lead to a number of respiratory issues, including coughing and asthma [27] Inhaling fine particles for an extended period of time and in excess can increase the risk of developing cancer and dying from respiratory diseases. Furthermore, PM_{10} can harm materials by discoloring or destroying painted surfaces and corroding metals (at relative humidity levels above 75%)

Table 2 Methods deployed in the determination of Gaseous Emissions and Noise

Parameters	Equipment	Averaging Time (h)	Range (ppm)	Alarm Level(s)
PM_{10}	Riken Keiki PM_{10} monitor model NP-237H	24 h	0.1–200 ppm	+0.1
NO_2	GASMAN NO_2 Gas monitor model 19685H	24 h	0–10 ppm	3.00 ppm
CO	Handheld GASMAN CO Gas monitor model 19256	24 h	0–50 ppm	50 ppm
H_2S	GASMAN H_2S Gas monitor model 19,770	24 h	0–50 ppm	10 ppm
SO_2	Handheld SO_2 Gas monitor Gasman model 19648H	24 h	0–10 ppm	2.0 ppm
Cl_2	Handheld Cl_2 Gas monitor Gasman model 19812H	24 h	0–5 ppm	0.5 ppm
VOCs	Handheld PCE-VOC 1 Environmental VOCs Meter	24 h	0–200 ppm	-
NH_3	Handheld NH_3 Gas monitor Gasman model 19730H	24 h	0–50 ppm	25 ppm
HCN	Handheld HCN Gas monitor Gasman model 19,773	24 h	0–25 ppm	500 ppm
NOISE	Handheld Noise dosimeter (TES sound level meter model TES 1350a)	24 h	90 dB(A)	-

Table 3 Air quality concentration during the dry season

Location	Particulate matter (µg/m^3)			Nitrogen dioxide (µg/m^3)			Hydrogen sulphide (µg/m^3)			Carbon Monoxide (µg/m^3)		
	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)
Ishiagu	365.09	380.20	360.00	23.45	26.70	19.10	62.01	65.10	60.40	1500	1900	1750
Umuoghara	700.13	710.12	650.07	45.26	49.87	41.82	80.01	82.25	75.50	2400	2750	2600
Ngbo	830.10	860.30	800.12	18.36	20.97	15.60	92.10	96.01	90.60	3700	3950	3850
Control	8.10	8.97	5.79	4.24	4.28	3.18	6.01	6.02	5.28	30	31	31
Mean	475.85	489.89	453.99	22.83	25.46	19.93	60.03	61.35	58.02	1907.5	2157.8	2057.8
S. Error	2.10	1.59	2.09	1.44	1.79	1.37	0.01	0.01	0.02	0.01	0.02	0.02
F-LSD ($p < 0.05$)	3.53	4.08	4.69	4.02	5.19	6.57	0.01	0.01	0.02	0.09	0.10	0.12
WHO (2021)	45			10			20			1000		

Table 4 Air quality concentration during the dry season

Location	Sulphur dioxide (µg/m^3)			Chlorine (µg/m^3)			Volatile organic compound (µg/m^3)			Ammonia (µg/m^3)		
	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)
Ishiagu	44.50	53.10	42.80	22.10	30.21	23.01	20.20	27.63	19.30	49.70	63.12	53.43
Umuoghara	43.10	51.99	41.60	23.15	31.01	24.33	21.21	30.04	20.50	50.05	65.21	52.01
Ngbo	45.01	58.30	44.00	21.47	31.25	24.20	23.42	33.06	22.90	53.80	66.32	54.30
Control	3.01	5.00	2.90	6.01	6.20	6.01	5.90	6.00	4.89	10.03	11.12	10.45
Mean	33.91	42.09	32.83	19.39	24.66	19.39	17.68	24.18	16.89	40.89	51.44	42.55
S. Error	2.00	3.23	2.80	1.26	2.01	2.80	0.02	0.03	0.01	0.04	0.01	0.03
F-LSD ($p < 0.05$)	4.35	3.80	4.12	4.11	5.20	5.31	3.10	3.25	4.01	2.21	2.36	3.00
WHO (2021)	100			10			20			1000		

Table 5 Air quality concentration during the dry season

Location	Hydrogen cyanide			Noise		
	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)
Ishiagu	43.77	65.13	45.21	39.89	50.57	41.01
Umuoghara	46.40	66.01	47.02	40.01	52.30	42.77
Ngbo	43.10	62.66	44.20	38.99	53.60	40.33
Control	5.18	5.40	5.20	09.10	10.11	09.23
Mean	34.61	49.80	35.41	31.99	41.65	33.34
S. Error	0.01	0.01	0.02	0.03	0.01	0.03
F-LSD ($p < 0.05$)	0.02	0.03	0.02	0.03	0.03	0.04
WHO (2021)	0.01			90		

[28] By blocking sunlight and serving as a catalytic surface for the reaction of absorbed chemicals, it can also be unpleasant.

The concentration levels of NO_2 in the different locations and controls studied are the lowest in the evening, with concentration levels of 19.10 μg/m^3 (Ishiagu), 41.82 μg/m^3 (Umuoghara), 15.60 μg/m^3 (Ngbo), 3.18 μg/m^3 (control), and increase lightly in the morning to 23.45 μg/m^3 (Ishiagu), 45.26 μg/m^3 (Umuoghara), 18.36 μg/m^3 (Ngbo) and 4.24 μg/m^3 (control), with the highest concentration levels in the afternoon at 26.70 μg/m^3 (Ishiagu), 49.87 μg/m^3 (Umuoghara), 20.97 μg/m^3 (Ngbo), and 4.28 μg/m^3 (control). The diurnal variation of NO_2 in the dry season showed a unimodal pattern, with the first peak at 6:00 am, the highest peak at 12:00 pm, and the declination at 6:00 pm, respectively. However, the concentration of NO_2 increased significantly in the afternoon and decreased significantly in the evening. The unimodal distribution pattern of the NO_2 diurnal variation showed that the peak occurs during the afternoon due to the presence of high levels of UV radiation [29]. The NO_2 diurnal variation clearly shows that the increase in the number of motor vehicles on the roads greatly influences the air quality on the study sites during the peak hours. This study showed that a higher NO_2 concentration level was observed in the Umuoghara quarry site than in the Ishiagu or Ngbo quarry sites when the three quarry sites were compared. They are all above the [24] recommended permissible limit of 10 μg/m^3, except control. The high concentration of NO_2 in the locations can be attributed to the usage of heavy equipment such as crushing plants, trucks, and generators, among others. The formation of nitrogen oxides often occurs during higher-temperature combustions, such as those found in industrial settings and car engines. Nitrogen is easily partially oxidized to generate NO_2, which is typically released through the exhaust pipes of cars and other vehicles, as well as the manifolds of power generation equipment. Nitrogen can also be oxidized at high temperatures to produce NO_2. Long-term exposure to NO_2 levels exceeding 10 μg/m^3 can increase a person's vulnerability to bacterial infections and induce lung illness.

The study also discovered that H_2S concentrations were lowest in the evening at 60.40 μg/m^3 (Ishiagu), 75.50 μg/m^3 (Umuoghara), 90.60 μg/m^3 (Ngbo) and 5.28 μg/m^3 (Control), highest in the afternoon at 65.10 μg/m^3 (Ishiagu), 82.25 μg/m^3 (Umuoghara), 96.01 μg/m^3 (Ngbo), 6.02 μg/m^3 (Control), and moderate in the morning at 62.01 μg/m^3 (Ishiagu), 80.01 μg/m^3 (Umuoghara), 92.10 μg/m^3 (Ngbo) and 6.01 μg/m^3 (Control). The diurnal variation of H_2S in the dry season showed a unimodal pattern, with the first peak at 6:00 am, the highest peak at 12:00 pm, and the decrease at 6:00 pm, respectively. When the three quarry sites were compared, this observation revealed that the H_2S concentration level was higher in the Ngbo quarry site than in the Umuoghara and Ishiagu quarry sites. They are all above the [24] recommended permissible limit of 20 μg/m^3, except control. H_2S gas is very poisonous, pungent, and corrosive. In some areas, it can be found in natural gas, and in some quarry conditions, sulphate-reducing bacteria can release it. Therefore, sustained exposure to H_2S gas at levels higher than 20 μg/m^3 can be fatal.

CO had the lowest concentrations of 1500 μg/m^3 (Ishiagu), 2400 μg/m^3 (Umuoghara), 3700 μg/m^3 (Ngbo) and 30 μg/m^3 (Control) in the morning, slightly higher levels in the afternoon with concentration levels of 1900 μg/m^3 (Ishiagu), 2750 μg/m^3 (Umuoghara), 3950 μg/m^3 (Ngbo), 31 μg/m^3 (Control) and moderate levels in the morning with a concentration levels of 1500 μg/m^3 (Ishiagu), 2400 μg/m^3 (Umuoghara), 3700 μg/m^3 (Ngbo) and 30 μg/m^3 (Control). The diurnal pattern for all observed CO concentration levels in the dry season showed a unimodal distribution sequence.

The concentration level of CO slowly increased at 6:00 am, significantly increased at 12:00 pm, and then decreased significantly at 6:00 pm. This observation indicated that a higher CO concentration level was recorded in the Ngbo quarry site than in the Umuoghara and Ishiagu quarry sites when the three quarry sites were compared. CO is produced when fossil fuels are only partially oxidized (hydrocarbon). Large diesel-powered generating plants, processing plants, vehicular emissions, diesel and gasoline engines found in heavy-duty machinery, welding machines, trucks, and other items, among other things, are sources of CO in the study region. Long-term and excessive exposure to ambient CO concentrations of more than 1000 $\mu g/m^3$ can cause the production of carboxyhemoglobin and prevent the blood from oxygenating, which can result in asphyxia and eventual death. The most vulnerable groups to the effects of this gas exposure include children and the elderly, as well as those with cardiovascular and respiratory conditions.

According to Table 4, the concentration levels of SO_2 in the locations are lowest in the evening at 42.80 $\mu g/m^3$ (Ishiagu), 41.60 $\mu g/m^3$ (Umuoghara), 44.00 $\mu g/m^3$ (Ngbo) and 2.90 $\mu g/m^3$ (Control), and slightly higher in the morning at 44.50 $\mu g/m^3$ (Ishiagu), 43.10 $\mu g/m^3$ (Umuoghara), 45.01 $\mu g/m^3$ (Ngbo), 3.01 $\mu g/m^3$ (Control), and in the afternoon at 53.10 $\mu g/m^3$ (Ishiagu), 51.99 $\mu g/m^3$ (Umuoghara), 58.30 $\mu g/m^3$ (Ngbo) and 5.00 $\mu g/m^3$ (Control). The diurnal variation for all observed SO_2 concentration levels in the dry season showed a unimodal distribution sequence. The concentration level of SO_2 slowly increased at 6:00 am, significantly increased at 12:00 pm, and then decreased significantly at 6:00 pm. When the three quarry sites were compared, this observation revealed that the SO_2 concentration level was higher in the Ngbo quarry site than in the Ishiagu or Umuoghara quarry sites. The different value of SO_2 in the study area can be attributed to low activities in the study area in the late hours of the day and high activities during the afternoon hour of the day. [30] contributed to the discovery that SO_2 concentrations are generally low in the morning and rise throughout the day because most of the SO_2 concentration must have settled down during the early hours of the day. However, one significant air contaminant is SO_2. It typically develops at quarry sites from the oxidation of sulfur-containing fuels, biomass, oil combustion, and car exhaust gases. In humans, exposure to SO_2, at concentrations exceeding 100 $\mu g/m^3$, may increase mucus secretion, broncho-constriction (as in asthma), and eye irritation. Long-term exposure to lower concentrations may increase the prevalence of associated symptoms and cause death from cardiac and/or respiratory disorders.

Cl_2 had its lowest concentration levels of 22.10 $\mu g/m^3$ (Ishiagu), 23.15 $\mu g/m^3$ (Umuoghara), 21.47 $\mu g/m^3$ (Ngbo) and 6.01 $\mu g/m^3$ (Control) in the morning and 23.01 $\mu g/m^3$ (Ishiagu), 24.33 $\mu g/m^3$ (Umuoghara), 24.20 $\mu g/m^3$ (Ngbo) and 6.01 $\mu g/m^3$ (Control) in the evening; with its highest concentration levels of 30.21 $\mu g/m^3$ (Ishiagu), 31.01 $\mu g/m^3$ (Umuoghara), 31.25 $\mu g/m^3$ (Ngbo) and 6.20 $\mu g/m^3$ (Control) being in the afternoon. During the dry season, the diurnal variation of all observed Cl_2 concentration levels revealed a unimodal distribution sequence. The concentration of Cl_2 gradually increased at 6:00 a.m., increased significantly at 12:00 p.m., and then decreased significantly at 6:00 p.m. When the three quarry sites were compared, this observation revealed that the Cl_2 concentration level was higher in the Ngbo quarry site than in the Ishiagu or Umuoghara quarry sites. The high concentration of Cl_2 in the afternoon can be attributed to explosive and drilling activities that take place around the time and unvented gas leaks from air compressors and other sources within the quarry areas.

VOCs had its lowest recorded concentration levels of 19.30 $\mu g/m^3$ (Ishiagu), 20.50 $\mu g/m^3$ (Umuoghara), 22.90 $\mu g/m^3$ (Ngbo) and 4.89 $\mu g/m^3$ (Control) in the evening and 20.20 $\mu g/m^3$ (Ishiagu), 21.21 $\mu g/m^3$ (Umuoghara), 23.42 $\mu g/m^3$ (Ngbo) and 5.90 $\mu g/m^3$ (Control) in the morning, its highest concentration levels of 27.63 $\mu g/m^3$ (Ishiagu), 30.04 $\mu g/m^3$ (Umuoghara), 33.06 $\mu g/m^3$ (Ngbo) and 6.00 $\mu g/m^3$ (Control) in the afternoon. The diurnal variation for all observed VOCs concentration levels in the dry season showed a unimodal distribution pattern. The concentration level of VOCs gradually increased at 6:00 a.m., significantly increased at 12:00 p.m., and then decreased significantly at 6:00 p.m. When the three quarry sites were compared, the VOCs concentration level was higher in the Ngbo quarry site than in the Umuoghara and Ishiagu quarry sites. The VOCs might be connected to machine and vehicle operations [31]. The sources of VOCs may be through aerosol sprays, wood preservatives, cleaners, and disinfectants.

NH_3 had its lowest concentration levels of 49.70 $\mu g/m^3$ (Ishiagu), 50.05 $\mu g/m^3$ (Umuoghara), 53.80 $\mu g/m^3$ (Ngbo) and 10.03 $\mu g/m^3$ (Control) in the morning, unlike the other parameters considered under study, and slightly higher in the evening 53.43 $\mu g/m^3$ (Ishiagu), 52.01 $\mu g/m^3$ (Umuoghara), 54.30 $\mu g/m^3$ (Ngbo), 10.45 $\mu g/m^3$ (Control) and highest in the afternoon 63.12 $\mu g/m^3$ (Ishiagu), 65.21 $\mu g/m^3$ (Umuoghara), 66.32 $\mu g/m^3$ (Ngbo) and 11.12 $\mu g/m^3$ (Control), respectively. The diurnal variation for all observed NH_3 concentration levels in the dry season showed a unimodal distribution pattern. The concentration level of NH_3 gradually increased at 6:00 am, significantly increased at 12:00 pm, and then decreased significantly at 6:00 pm. When the three quarry sites

were compared, the NH_3 concentration levels were higher in the Ngbo quarry site than in the Umuoghara and Ishiagu quarry sites. The high concentration of NH_3 can be attributed to drilling activities and gas leaks from air compressors during mining activities.

Table 5 showed that HCN had its lowest concentration levels of 43.77 μg/m^3 (Ishiagu), 46.40 μg/m^3 (Umuoghara), 43.10 μg/m^3 (Ngbo) and 5.18 μg/m^3 (Control) in the morning, 45.21 μg/m^3 (Ishiagu), 47.02 μg/m^3 (Umuoghara), 44.20 μg/m^3 (Ngbo), 5.20 μg/m^3 (Control) in the evening, and 65.13 μg/m^3 (Ishiagu), 66.01 μg/m^3 (Umuoghara), 62.66 μg/m^3 (Ngbo) and 5.40 μg/m^3 (Control) in the afternoon, respectively. The diurnal variation for all observed HCN concentration levels in the dry season showed a unimodal distribution pattern. The concentration level of HCN gradually increased at 6:00 am, significantly increased at 12:00 pm, and then decreased significantly at 6:00 pm. This observation indicated that the HCN concentration level was evidently higher in the Umuoghara quarry site than in the Ishiagu and Ngbo quarry sites when comparing the three quarry sites. However, the combustion of synthetic fibres, wool, and silk produces hydrogen cyanide. Additionally, the catalytic digestion of nitrogen oxides during the burning of gasoline in automotive engines results in the production of hydrogen cyanide as well. Only in the absence of a catalyst is the level of HCN in the exhaust gases higher [32]. Cyanides are primarily gaseous in nature and can travel great distances from their source of emission before entering the atmosphere [33].

Noise dB(A) had its lowest levels of 39.89 dB(A) (Ishiagu), 40.01 dB(A) (Umuoghara), 38.99 dB(A) (Ngbo), and 09.10 dB(A) (Control) in the morning, followed by 41.01 dB(A) (Ishiagu), 42.77 dB(A) (Umuoghara), 40.33 dB(A) (Ngbo), and 09.23 dB(A) (Control) in the evening, and its highest levels of 50.57 dB(A) (Ishiagu), 52.30 dB(A) (Umuoghara), 53.60 dB(A) (Ngbo) and 10.11 dB(A) (Control) in afternoon. The diurnal variation of all observed noise dB(A) levels revealed a unimodal distribution pattern during the dry season. The level of noise dB(A) gradually increased at 6:00 a.m., significantly increased at 12:00 p.m., and then decreased significantly at 6:00 p.m. This observation revealed that the noise dB(A) level was clearly higher in the Umuoghara quarry site than in the Ishiagu and Ngbo quarry sites when the three quarry sites were compared. The primary sources of noise in the research area were rock blasting operations, crushing and processing facilities for rock, haulage lorries, diesel power plants, heavy-duty vehicles, industrial machinery, heavy traffic on the highway, traffic hooting, anthropogenic activities in the area, and so on.

The level of the parameters at different times of the day is highly influenced by the variation in the temperature of Ebonyi State, where the study area is located. The temperature at the time (March) when the field survey was carried out was between 27 and 31 °C. Low temperatures prevail in the mornings and evenings, rising sharply as noon approaches and gradually decreasing as evening approaches. As a result of this, concentration levels of all parameters are at their lowest in the morning and evening.

In a similar vein, during the dry season, the research area's wind direction is either NE or SW. This is to be expected since the NE trade winds from the Sahara desert are often the predominant wind pattern in Nigeria during the dry season. Throughout the dry season, the wind is also moderate and does not change greatly. The air pressure during the dry season also reflects this.

In ref. [4] collaborated on the findings that temperature, wind direction, and speed affect the concentration of air quality in the area. [34] also reported the finding that the concentration of gases in quarry areas is typically low in the morning and increases slightly as production activities kick off in the afternoon and evening. In ref. [35] also reported that a particle in the air does travel as there is more wind and atmospheric pressure during this period. Furthermore, most quarries increase their activities during the dry season because construction work also increases. Most construction works involving the use of quarried stones, like road construction, bridge construction, and even other operations requiring large quantities of stone, increase during the dry season. Since the companies increase their activities in the dry season, the implications for air pollution increase. This assertion is supported by [36], who reported increased activity at a quarry in Obajana, Kogi State.

Environmental impact of quarrying on PM_{10}, CO, H_2S, NO_2, SO_2, Cl_2, VOCs, NH_3, HCN and noise of air during the raining season

The Tables 6, 7, and 8 showed significant differences ($p < 0.05$) in PM_{10}, CO, H_2S, NO_2, SO_2, Cl_2, VOCs, NH_3, HCN, and noise concentration levels in the study area.

A careful examination of Table 6 revealed that the concentration levels of PM_{10} were lowest in the morning at 280.10 μg/m^3 (Ishiagu), 580.70 μg/m^3 (Umuoghara), 632.00 μg/m^3 (Ngbo), 4.60 μg/m^3 (Control), highest in the afternoon at 286.00 μg/m^3 (Ishiagu), 620.07 μg/m^3 (Umuoghara), 680.22 μg/m^3 (Ngbo) and 6.79 μg/m^3 (Control), and lowest in the evening at 282.11 μg/m^3 (Ishiagu), 601.20 μg/m^3 (Umuoghara), 640.34 μg/m^3 (Ngbo) and 6.19 μg/m^3 (Control). The diurnal pattern for all observed PM_{10} concentration levels in the rainy season reflects the same unimodal distribution pattern as in the dry season. It has also been said that because there is less wind and temperature during this time, airborne

Table 6 Air quality concentration during the rainy season

Location	Particulate matter (µg/m^3)			Nitrogen dioxide (µg/m^3)			Hydrogen sulphide (µg/m^3)			Carbon monoxide (µg/m^3)		
	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)
Ishiagu	280.10	286.00	282.11	17.00	21.56	24.01	40.15	43.70	38.18	843	887	790
Umuoghara	580.70	620.07	601.20	28.20	33.62	36.23	57.20	59.52	52.07	1240	1290	1200
Ngbo	632.00	680.22	640.34	11.25	12.77	15.45	64.75	69.24	61.10	2210	2900	2000
Control	4.60	6.79	6.19	3.01	3.20	4.27	4.11	4.22	3.76	22	23	21
Mean	382.46	398.27	374.35	14.87	17.79	19.99	41.55	44.17	38.78	1078.8	1275.0	1002.8
S. Error	1.09	1.87	1.50	1.20	1.43	1.30	0.02	0.03	0.01	0.02	0.01	0.04
F-LSD ($p < 0.05$)	2.35	3.81	3.91	3.21	4.20	5.77	0.02	0.01	0.02	0.06	0.08	0.10
WHO (2021)	45			10			20			1000		

Table 7 Air quality concentration during the raining season

Location	Sulphur dioxide (µg/m^3)			Chlorine (µg/m^3)			Volatile organic compound (µg/m^3)			Ammonia (µg/m^3)		
	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)
Ishiagu	40.00	50.23	41.19	20.87	29.60	22.10	18.53	23.19	15.44	23.54	54.11	31.00
Umuoghara	39.21	49.12	40.30	22.23	30.20	23.14	19.00	26.80	17.13	27.80	53.32	32.07
Ngbo	40.13	54.00	42.40	21.79	31.00	24.10	21.20	29.14	19.10	29.29	66.32	34.23
Control	2.99	4.50	2.60	5.77	6.00	5.77	5.10	5.89	4.13	09.45	10.00	09.77
Mean	31.58	39.46	30.62	18.78	24.20	18.78	15.96	21.26	13.95	22.52	45.94	26.77
S. Error	1.99	3.01	2.10	1.11	2.00	2.40	0.01	0.02	0.01	0.03	0.01	0.02
F-LSD ($p < 0.05$)	4.02	3.10	3.99	4.00	5.01	5.08	2.77	2.60	3.01	2.07	2.12	2.93
WHO (**2021**)	100			10			20			1000		

Table 8 Air quality concentration during the rainy season

Location	Hydrogen cyanide (µg/m3)			Noise dB(A)		
	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)	Morning (6am)	Afternoon (12:00 pm)	Evening (6.00 pm)
Ishiagu	42.13	63.00	44.60	37.01	48.20	39.56
Umuoghara	45.12	65.11	46.24	38.22	50.11	40.14
Ngbo	41.52	60.01	42.09	36.01	50.42	38.67
Control	5.00	5.26	5.09	09.00	10.00	09.12
Mean	33.44	48.35	34.51	30.06	39.68	31.87
S. Error	0.02	0.02	0.01	0.01	0.01	0.02
F-LSD ($p < 0.05$)	0.01	0.02	0.01	0.02	0.02	0.03
WHO (2021)	0.01			90		

particles do not move. The majority of quarries also scale back their operations during this rainy season as a result of the drop in the amount of construction work, including the building of roads, bridges, and even other projects needing vast quantities of stone. Because businesses scale back during the rainy season, there is a corresponding decrease in air pollution compared to the dry season.

The concentration levels of NO_2 are observed lower in the morning 17.00 µg/m^3 (Ishiagu), 28.20 µg/m^3 (Umuoghara), 11.25 µg/m^3 (Ngbo), 3.01 µg/m^3 (Control) and increase lightly in the afternoon 21.56 µg/m^3 (Ishiagu), 33.62 µg/m^3 (Umuoghara), 12.77 µg/m^3 (Ngbo), 3.20 µg/m^3 (Control) with an increase in the evening 24.01 µg/m^3 (Ishiagu), 36.23 µg/m^3 (Umuoghara), 15.45 µg/m^3 (Ngbo) and 4.27 µg/m^3 (Control). The diurnal variation of NO_2 during the rainy season follows the same unimodal pattern as during the dry season. This observation indicated that a higher NO_2 concentration level was observed in the Umuoghara quarry site than in the Ishiagu or Ngbo quarry sites when comparing the three quarry sites as observed in the dry season. They are all above the [24] recommended permissible limit of 10 µg/m^3, except for control.

The study also observed that H_2S had the lowest concentration levels of 38.18 µg/m^3 (Ishiagu), 52.07 µg/m^3 (Umuoghara), 61.10 µg/m^3 (Ngbo) and 3.76 µg/m^3 (Control) in the evening, the highest in the afternoon 43.70 µg/m^3 (Ishiagu), 59.52 µg/m^3 (Umuoghara), 69.24 µg/m^3 (Ngbo), 4.22 µg/m^3 (Control) and a moderately higher concentration in the morning 40.15 µg/m^3 (Ishiagu), 57.20 µg/m^3 (Umuoghara), 64.75 µg/m^3 (Ngbo) and 4.11 µg/m^3 (Control), respectively. The diurnal variation of H_2S in the rainy season showed the same unimodal pattern as in the dry season. This observation indicated that the H_2S concentration level was lower during the rainy season than in the dry season. This is because the majority of quarries scale back their operations during this rainy season as a result of the drop in the amount of construction work when compared with the dry season.

That of CO too is lowest in the evening 790 µg/m^3, 1200 µg/m^3, 2000 µg/m^3 and 21 µg/m^3; slightly highest in the afternoon 887 µg/m^3 (Ishiagu), 1290 µg/m^3 (Umuoghara), 2900 µg/m^3 (Ngbo), 23 µg/m^3 (Control) and moderate in the morning 843 µg/m^3 (Ishiagu), 1240 µg/m^3 (Umuoghara), 2210 µg/m^3 (Ngbo) and 22 µg/m^3 (Control). They are all above the [24] recommended permissible limit of 1000 µg/m^3, except for control. The diurnal variation of CO in the rainy season showed the same unimodal pattern as in the dry season. This observation indicated that CO concentration levels were lower during the rainy season than during the dry season. The lower CO concentration during the rainy season compared to the dry season could be attributed to lower quarry output during the rainy season.

SO_2 concentrations (Table 7) are 40.00 µg/m^3 (Ishiagu), 39.21 µg/m^3 (Umuoghara), 40.13 µg/m^3 (Ngbo) and 2.60 µg/m^3 (Control) at their lowest in the morning, slightly higher at 50.23 µg/m^3 (Ishiagu), 49.12 µg/m^3 (Umuoghara), 54.00 µg/m^3 (Ngbo), 4.50 µg/m^3 (Control) in the afternoon, and decreasing at 41.19 µg/m^3 (Ishiagu), 40.30 µg/m^3 (Umuoghara), 42.40 µg/m^3 (Ngbo) and 2.99 µg/m^3 (Control) in the evening. The diurnal variation of SO_2 in the rainy season showed the same unimodal sequence as in the dry season. This observation indicated that SO_2 concentration levels were lower during the rainy season than during the dry season. The low concentration level of SO_2 in the rainy season when compared with the dry season effect may be attributed to low quarry operation output during the rainy season.

Cl_2 had the lowest concentration levels in the morning of 20.87 µg/m^3 (Ishiagu), 22.23 µg/m^3 (Umuoghara), 21.79 µg/m^3 (Ngbo) and 5.77 µg/m^3 (Control), with the highest concentration levels in the afternoon of 29.60 µg/m^3 (Ishiagu), 30.20 µg/m^3 (Umuoghara), 31.00 µg/m^3

(Ngbo) and 6.00 μg/m^3 (Control), and decreased in the evening to 22.10 μg/m^3 (Ishiagu), 23.14 μg/m^3 (Umuoghara), 24.10 μg/m^3 (Ngbo) and 5.77 μg/m^3 (Control). The diurnal variation of Cl_2 in the rainy season followed the same unimodal pattern as the dry season. This finding indicated that Cl_2 concentrations were lower during the rainy season than during the dry season. The low concentration of Cl_2 in the rainy season when compared to the dry season data may be attributed to low quarry operation output in the study areas during the rainy season.

The lowest recorded concentration levels of VOCs were 15.44 μg/m^3 (Ishiagu), 17.13 μg/m^3 (Umuoghara), 19.10 μg/m^3 (Ngbo) and 4.13 μg/m^3 (Control) in the evening, 18.53 μg/m^3 (Ishiagu), 19.00 μg/m^3 (Umuoghara), 21.20 μg/m^3 (Ngbo) and 5.10 μg/m^3 (Control) in the morning, and 23.19 μg/m^3 (Ishiagu), 26.80 μg/m^3 (Umuoghara), 29.14 μg/m^3 (Ngbo) and 5.89 μg/m^3 (Control) in the afternoon. The diurnal variation of VOCs in the rainy season showed the same unimodal flow as identified in the dry season. This showed that VOCs concentration levels were lower during the rainy season than during the dry season. The low concentration level of VOCs in the raining season when compared with dry season data may be attributed to low quarry operation output during the raining season in the study areas.

NH_3 had the lowest concentration levels in the morning at 23.54 μg/m^3 (Ishiagu), 27.80 μg/m^3 (Umuoghara), 29.29 μg/m^3 (Ngbo) and 09.45 μg/m^3 (Control), and slightly higher in the evening at 31.00 μg/m^3 (Ishiagu), 32.07 μg/m^3 (Umuoghara), 34.23 μg/m^3 (Ngbo), 09.77 μg/m^3 (Control), and highest in the afternoon at 54.11 μg/m^3 (Ishiagu), 53.32 μg/m^3 (Umuoghara), 66.32 μg/m^3 (Ngbo) and 10.00 μg/m^3 (Control). NH_3 diurnal variation in the rainy season is the same unimodal pattern as identified in dry season. During the rainy season, NH_3 concentration levels were lower than in the dry season. The low concentration level of NH_3 in the rainy season when compared with dry season data may be akin to low quarry operations during the rainy season in the study areas.

Table 8 showed that HCN had its lowest concentration levels of 42.13 μg/m^3, 45.12 μg/m^3, 41.52 μg/m^3 and 5.00 μg/m^3 in the morning, 44.60 μg/m^3, 46.24 μg/m^3, 42.09 μg/m^3, 5.09 μg/m^3 in the evening, and 63.00 μg/m^3, 65.11 μg/m^3, 60.01 μg/m^3 and 5.26 μg/m^3 in the afternoon, respectively. NH_3 diurnal variation in the rainy season is the same unimodal pattern as identified in the dry season.

During the rainy season, HCN concentration levels were lower than in the dry season. The low concentration level of HCN in the rainy season when compared with dry season data may be akin to low quarry operations during the rainy season in the study areas. However, the combustion of synthetic fibres, wool, and silk produces hydrogen cyanide. Additionally, the catalytic digestion of nitrogen oxides during the burning of gasoline in automotive engines results in the production of hydrogen cyanide as well. Only in the absence of a catalyst is the level of HCN in the exhaust gases higher [30]. Cyanides are primarily gaseous in nature and can travel great distances from their source of emission before entering the atmosphere [31].

Noise dB(A) had the lowest levels in the morning of 37.01 dB(A), 38.22 dB(A), 36.01 dB(A), and 09.00 dB(A), followed by 39.56 dB(A), 40.14 dB(A), 38.67 dB(A), and 09.12 dB(A) in the evening, and 48.20 dB(A), 50.11 dB(A), 50.42 dB(A) and 10.00 dB(A) in the afternoon. Noise level is lower in the rainy season than in the dry season.

However, the temperature variation and wind speed are lower in the rainy season than in the dry season. This seasonal variation in temperature and wind speed is expected.

Conclusion

The results of this study confirmed that quarrying in the three zones of Ebonyi districts released air pollutants into the environment. In the quarry areas, air pollutants such as PM_{10}, NO_2, H_2S, CO, SO_2, Cl_2, VOCs, NH_3, HCN, and noise were detected. Statistical analysis confirmed that quarrying has a significant negative impact on air quality. For sustainable quarrying, it is recommended to install air pollution control equipment such as High-Efficiency Particulate Air (HEPA) Filters, Selective Non-Catalytic Reduction (SNCR), Adsorbers (Activated Carbon), Packed-Bed Scrubbers, Selective Catalytic Reduction (SCR), and Wet Gas Scrubbers in-situ in the quarry area where free air flow is available and to develop an industrial code of conduct as a means of self-regulation to reduce pollutant emissions to the atmosphere. However, proven case studies of quarry air pollution control can be seen in the Case study at Tan Uyen quarry, Ho Chi Minh megapolis, Vietnam. Additional observations showed that the effects reported were seasonal because all the parameters had higher values during the dry season than they did during the rainy season. Conclusively, if this situation is not timely addressed, it will lead to a severe environmental disaster or hazard, as nobody selects the air he or she breathes. Also, the seasonal effects, meteorological parameters and time that were influenced by the activities of quarry should be put in check.

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Author contributions
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Data availability
The datasets generated during this work are not publically available for reasons known to the authors, but they are available upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate
All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors".

Consent for publication
Not applicable.

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