



ENVIRONMENTAL MONITORING OF AIR POLLUTANTS IN THE VICINITY OF MAJOR GRANITE MINING AND PROCESSING SITES IN ABUJA, NIGERIA

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Key words: mining site, particulate matter, gaseous pollutants, air quality, autocorrelation function.

Abstract

This study assessed air quality in the vicinity of two major granite mining and processing sites in Abuja, Nigeria, focusing on particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10}) and gaseous pollutants (CO, HCHO, TVOC). Measurements were conducted at three points – processing area, staff premises, and entrance/exit – during dry and rainy seasons using calibrated air quality detectors. Data were analyzed for temporal trends and compliance with National Ambient Air Quality Standards (NAAQS, US EPA) and National Environmental Standards and Regulations Enforcement Agency (NESREA) limits. Results revealed that particulate matter concentrations were consistently higher at processing points compared to other locations, with $PM_{1.0}$ and $PM_{2.5}$ exceeding regulatory limits for 24-hour averages in both seasons. Gaseous pollutants were generally low and within permissible limits, though CO showed elevated variability at staff premises and entrance/exit points, likely due to vehicular and equipment emissions. Seasonal comparison indicated higher pollutant levels during the dry season, attributed to intensified quarry activities and reduced atmospheric dispersion. Autocorrelation analysis using ARIMA modelling showed no significant trends between measured and modelled concentrations, suggesting random variability rather than systematic patterns. Although gaseous pollutants were below threshold values, their presence alongside elevated particulate matter underscores cumulative health risks for workers and nearby communities. Continuous monitoring and implementation of dust suppression and emission control strategies are recommended to mitigate occupational and environmental exposure.

Introduction

Air pollution remains one of the most pressing environmental challenges globally, with significant implications for human health, ecosystems, and climate. Among the major pollutants, particulate matter (PM) and gaseous compounds are of particular concern due to their widespread occurrence and harmful effects. Particulate matter consists of microscopic solid or liquid particles suspended in the atmosphere, while gaseous pollutants include volatile organic compounds and other chemical species emitted from natural and anthropogenic sources (RAASCHOU-NIELSEN et al. 2016). Globally, the primary contributors to air pollution include fossil fuel combustion in energy production and transportation, industrial activities, agricultural practices, and open waste burning (ROMANA et al. 2022, BICI et al. 2024, MANDAL et al. 2025). In addition to these large-scale sources, localized activities such as traffic emissions, domestic fuel use, and mining operations significantly degrade air quality in their immediate surroundings (UGWUANYI et al. 2016, BILIAMINU et al. 2021). Mining and mineral processing, in particular, release substantial quantities of dust and gaseous pollutants into the atmosphere, creating occupational hazards and environmental risks for nearby communities.

The health impacts of air pollutants depend on their size, chemical composition, and exposure duration. Fine particles such as $PM_{2.5}$ can penetrate deep into the respiratory system, reaching the alveoli and even entering the bloodstream. This exposure is associated with short-term effects such as eye and throat irritation, coughing, and bronchitis, as well as long-term conditions including cardiovascular disease, chronic obstructive pulmonary disease, and lung cancer (BALA et al. 2021, LEDERER et al. 2021). Gaseous pollutants, including carbon monoxide (CO), formaldehyde (HCHO), and total volatile organic compounds (TVOCs), contribute to smog formation, acid rain, and global warming, and are linked to respiratory illnesses and cancer (OGAH et al. 2020).

Around mining sites, the combined presence of particulate matter and gaseous pollutants can lead to occupational illnesses such as chronic respiratory infections and visual impairment (PATRA et al. 2016). These risks are exacerbated by inadequate dust suppression measures and the use of fuel-powered machinery, which emit combustion-related gases.

Several studies have examined air quality near mining sites in Nigeria. For example, OMEIZA et al. (2022) reported elevated concentrations of PM and gaseous pollutants around quarry sites in Mpape, Abuja, exceeding NESREA standards. Similarly, BILIAMINU et al. (2021) found that PM_{2.5} and PM₁₀ levels near granite quarries in Yangoji surpassed NAAQS limits, posing health risks to residents. Other investigations, such as those by ANYAHARA et al. (2021) and OGAH et al. (2020) have documented variations in pollutant levels across different mining regions, with some sites showing concentrations above permissible limits. ABULUDE and ABULUDE (2021) further highlighted the prevalence of particulate matter across Nigeria, often exceeding international benchmarks.

Despite these efforts, there is limited research on newly established granite mining and processing sites in Abuja, particularly regarding seasonal variations, pollutant interrelationships, and compliance with regulatory standards. Understanding these dynamics is essential for effective environmental monitoring and policy development.

The present study addresses this gap by conducting comprehensive measurements of PM_{1.0}, PM_{2.5}, PM₁₀ and gaseous pollutants (CO, TVOC, HCHO) at two major granite mining sites in Abuja. Specific objectives are to:

- quantify pollutant concentrations at different operational points during dry and rainy seasons;
- analyze temporal trends and interrelationships among pollutants;
- evaluate compliance with NAAQS and NESREA standards.

By providing robust data and statistical insights, this research aims to inform strategies for air pollution control, occupational health protection, and sustainable mining practices in Nigeria's rapidly developing construction sector.

Materials and Methods

Study area

Two major granite mining and processing sites at different locations within Abuja were selected for this study. The location of the sites is shown in Table 1, while the map of the study areas is shown in Figure 1.

Table 1

Locations of study sites

Mining site	Code	Latitude	Longitude	State
Pyakassa Quarry Site	PQS	N08°57'10.21"	E07°24'17.47"	FCT Abuja
Daijinja Quarry Site	DQS	N08°55'36.87"	E07°19'17.60"	FCT Abuja

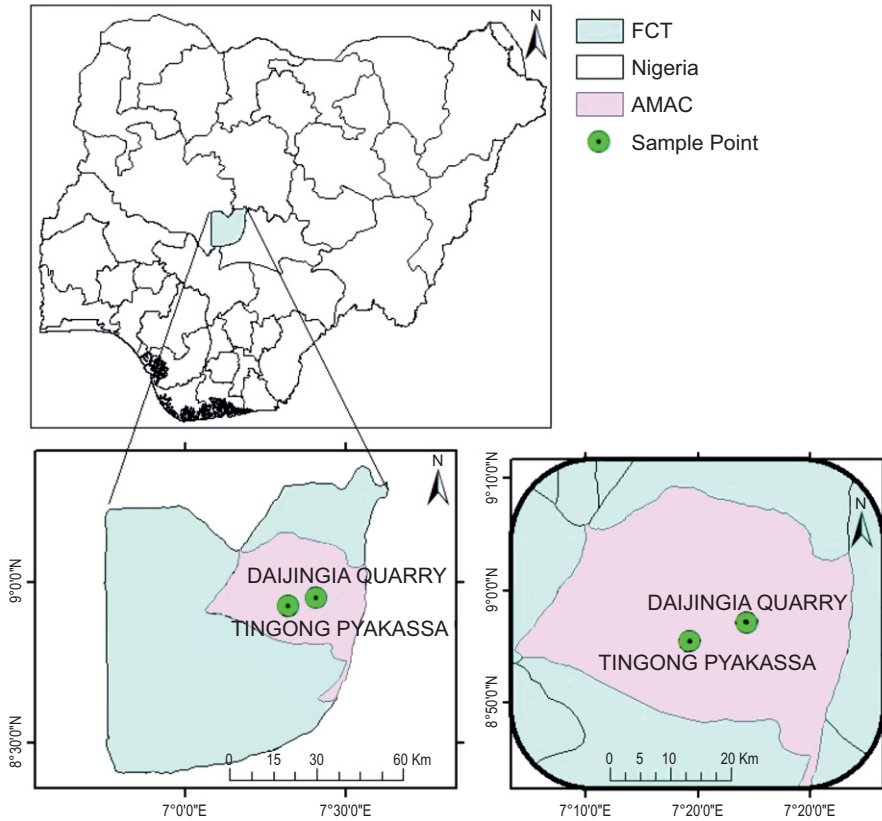


Fig. 1. Map of the study sites located within the Federal Capital Territory (FCT), showing the Abuja Municipal Area Council (AMAC) and the granite mining and processing locations

Data collection

Particulate matter of sizes $PM_{1.0}$, $PM_{2.5}$, and PM_{10} and gaseous pollutants such as CO, HCHO (Formaldehyde), and TVOC (Total Volatile Organic Compounds) were considered in this study. Particulate matter and gaseous pollutants were monitored at the following points: mining and processing point, staff premises, and entrance/exit point 50 m away from the emission source points. The monitoring period took place from February to May 2023, capturing both the dry and rainy seasons. An air quality detector (Model WP6932, Vson Technology Co., Ltd., China) and a multi-gas leak detector (Model GC310, Henan Chicheng Electric Co., Ltd., China) were used for the measurements. The WP6932 employs advanced electrochemical sensors for gaseous pollutants and a laser-scattering optical sensor for particulate

matter. It measures HCHO, TVOC, PM_{1.0}, PM_{2.5}, PM₁₀, temperature, and humidity. The instrument integrates a 32-bit ARM (Advanced RISC Machine) processing chip with multi-point calibration and AD (Analog-to-Digital) intelligent filtering, providing improved accuracy and measurement stability. The TVOC sensor is factory-calibrated using isobutylene standard gas. For CO measurements, the GC310 uses an electrochemical sensor with an accuracy of $<\pm 3\%$ F.S. The instrument is equipped with automatic zero calibration and built-in span adjustment to ensure stable and reliable readings. The measuring devices were held 1.0 m above the ground due to the average breathing height of human beings and the concentration of particulate matter and gaseous pollutants were measured over a repeated time interval of 2 minutes 4 seconds for 100 consecutive readings for each studied point and site during dry and rainy seasons.

Autocorrelation analysis

The concentrations of particulate matter and gaseous pollutants measured were subjected to an autocorrelation analysis. Autocorrelation is a statistical concept that is used to measure the relationship of a new version of values of a variable to its older values. This method is used with an Autoregressive Integrated Moving Average (ARIMA) model to uncover trends accompanied by the measured concentrations of the monitored pollutants. The ARIMA model was used to generate in-sample modelled values of the monitored pollutants. Thereafter, the residuals were computed. The residuals were tested for autocorrelation by the use of an autocorrelation function graph (ACF), to examine for any dependency between the measured and the modelled concentrations.

Model analysis

ARIMA model is based on the patterns and dependencies within a time series data. The model takes into account the historical values of the time series and forecasts future values based on the assumption that future patterns will resemble past patterns. In doing this, appropriate parameters of the model such as the order of the autoregressive (AR) and the order of the moving average (MA) were estimated based on the pollutant concentrations. Each respective model order was taken concerning the significant lag spikes determined using an autocorrelation function graph and a partial autocorrelation function graph before modelling.

The equation for an ARIMA model is given as (AL-CHALABI et al. 2018):

$$Y_t = c + \varphi_1 \cdot Y_{t-1} + \varphi_2 \cdot Y_{t-2} + \dots + \varphi_p \cdot Y_{t-p} + \theta_1 \cdot \varepsilon_{t-1} + \theta_2 \cdot \varepsilon_{t-2} + \dots + \theta_q \cdot \varepsilon_{t-q},$$

where:

Y_t – represents the value of the time series at time t ;

c – constant term;

φ_1, φ_2 , to φ_p – the autoregressive coefficients, representing the impact of the past values of the time series on the current value;

Y_{t-1}, Y_{t-2} , and to Y_{t-p} – the lagged values of the time series;

θ_1, θ_2 , and θ_q – the moving average coefficients, representing the impact of the past error terms on the current value;

$\varepsilon_{t-1}, \varepsilon_{t-2}$, to ε_{t-q} – the error terms, which capture the unexplained variation in the time series. The general notation of the model is expressed as:

$$\text{ARIMA}(p, d, q),$$

where:

p – order of the autoregressive component

d – degree of differencing required to achieve stationary

q – order of the moving average component.

Results

Particulate matter and gaseous pollutants during dry season

Particulate matter concentrations were highest at processing points across both sites, followed by staff premises and entrance/exit points (Table 2). This pattern indicates that workers near crushing and loading operations face the greatest exposure risk. Gaseous pollutants exhibited greater variability than particulate matter, as reflected by high standard deviations, with CO levels notably higher at staff premises and entrance/exit points compared to processing areas (Table 3). These findings suggest that combustion-related emissions from vehicles and equipment contribute significantly to gaseous pollutant presence.

Particulate matter and gaseous pollutants during rainy season

During the rainy season, particulate matter concentrations decreased across all locations (Table 4), consistent with reduced quarry activity and enhanced pollutant dispersion due to precipitation. Gaseous pollutants

Table 2
Mean concentrations of measured and modelled Particulate Matter [$\mu\text{g}/\text{m}^3$]
at the two mining and processing sites and points during the dry season

Mining site points	PQS			DQS		
	PM _{1.0}	PM _{2.5}	PM ₁₀	PM _{1.0}	PM _{2.5}	PM ₁₀
Processing point						
Measured concentration	23.82	29.98	33.29	19.88	26.65	29.05
Standard deviation	13.20	14.50	15.72	30.93	39.58	39.65
Modelled concentration	23.64	29.90	33.23	19.51	26.49	28.96
Staff premises						
Measured concentration	16.94	22.07	24.37	15.16	20.30	23.14
Standard deviation	13.20	14.50	15.72	7.06	8.50	9.82
Modelled concentration	16.93	16.93	24.48	15.18	20.34	23.18
Entrance/exit point						
Measured concentration	11.96	16.31	18.47	10.00	13.75	15.35
Standard deviation	3.15	3.97	4.49	3.77	4.96	5.68
Modelled concentration	11.94	16.29	18.44	9.88	13.73	15.33

Table 3
Mean concentrations of measured and modelled detected Gaseous Pollutants [$\mu\text{g}/\text{m}^3$]
at the two mining and processing sites and points during the dry season

Mining site points	PQS			DQS		
	CO	HCHO	TVOC	CO	HCHO	TVOC
Processing point						
Measured concentration	0.00	0.00	1.00	171.84	1.00	2.00
Standard deviation	0.00	3.00	2.00	412.41	2.00	4.00
Modelled concentration	0.00	0.00	0.00	0.00	1.00	2.00
Staff premises						
Measured concentration	0.00	0.0606	1.00	572.80	0.00	0.00
Standard deviation	0.00	3.00	2.00	1065.41	0.00	0.00
Modelled concentration	0.00	0.00	0.00	584.25	0.00	0.00
Entrance/exit point						
Measured concentration	1111.23	0.00	1.00	206.20	0.00	0.00
Standard deviation	1821.50	1.00	4.00	595.71	0.00	0.00
Modelled concentration	1260.16	0.00	0.00	206.20	0.00	0.00

remained low overall, though CO was detected at staff premises and entrance/exit points, while processing points showed occasional presence of CO, HCHO, and TVOC (Table 5). Despite lower concentrations compared to the dry season, the persistence of these pollutants indicates ongoing emissions from supporting activities.

Table 4

Mean concentrations of measured and modelled Particulate Matter [$\mu\text{g}/\text{m}^3$] at the two mining and processing sites and points during the rainy season

Mining site points	PQS			DQS		
	PM _{1.0}	PM _{2.5}	PM ₁₀	PM _{1.0}	PM _{2.5}	PM ₁₀
Processing point						
Measured concentration	11.45	15.87	17.89	11.72	16.06	18.17
Standard deviation	4.03	5.24	6.01	6.03	7.83	9.12
Modelled concentration	11.44	15.84	17.90	11.72	16.06	18.17
Staff premises						
Measured concentration	9.94	13.78	15.58	11.08	15.17	17.10
Standard deviation	4.05	5.24	6.04	3.63	4.71	5.43
Modelled concentration	9.94	13.78	15.58	11.10	15.20	17.20
Entrance/exit point						
Measured concentration	10.47	14.54	16.41	7.35	10.24	11.38
Standard deviation	3.34	4.37	5.10	1.87	2.50	2.80
Modelled concentration	10.47	14.53	16.40	7.36	10.25	11.40

Table 5

Mean concentrations of measured and modelled detected Gaseous Pollutants [$\mu\text{g}/\text{m}^3$] at the two mining and processing sites and points during the rainy season

Mining site points	PQS			DQS		
	CO	HCHO	TVOC	CO	HCHO	TVOC
Processing point						
Measured concentration	0.00	0.00	0.00	687.36	10.00	102.00
Standard deviation	0.00	1.00	0.00	1157.05	100.00	1000.00
Modelled concentration	0.00	0.00	0.00	813.37	0.00	0.00
Staff premises						
Measured concentration	343.68	0.00	0.00	572.80	0.00	0.00
Standard deviation	927.93	1.00	2.00	1065.41	0.00	0.00
Modelled concentration	0.00	0.00	0.00	584.25	0.00	0.00
Entrance/exit point						
Measured concentration	114.56	0.00	0.00	206.20	0.00	0.00
Standard deviation	572.80	0.00	0.00	595.71	0.00	0.00
Modelled concentration	126.01	0.00	0.00	0.00	0.00	0.00

Seasonal and spatial trends

Across both sites, dry season concentrations of particulate matter and gaseous pollutants were higher than rainy season values, aligning with previous studies that link seasonal variations to operational intensity and meteorological conditions. Processing points consistently recorded the highest particulate matter levels, while gaseous pollutants were more pronounced at staff premises and entrance/exit points, likely due to vehicular movement and fuel combustion.

Autocorrelation analysis

ARIMA-based autocorrelation analysis revealed no significant dependency between measured and modelled concentrations, indicating absence of systematic trends in pollutant levels. This suggests that variations are primarily driven by operational and environmental factors rather than predictable temporal patterns (Figure 2).

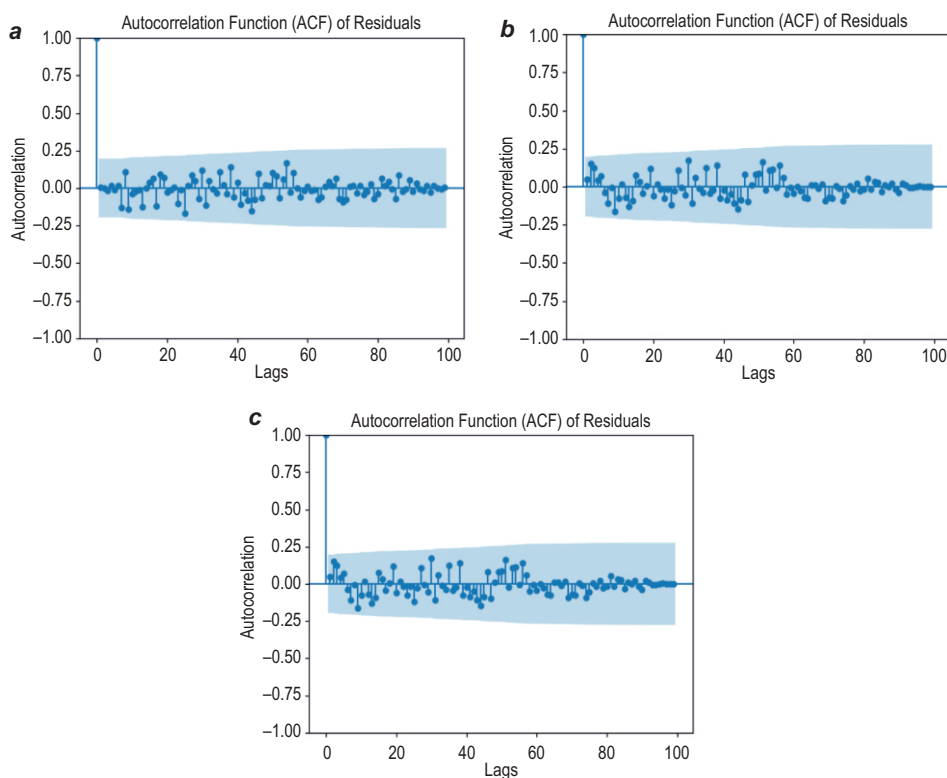


Fig. 2. Autocorrelation function (ACF) plots for : *a* – $PM_{1.0}$; *b* – $PM_{2.5}$; *c* – PM_{10} at the processing point of Pyakassa Quarry Site (PQS) studied site

Regulatory compliance and health implications

Comparison with NAAQS and NESREA standards (Table 6) shows that $PM_{1.0}$ and $PM_{2.5}$ exceeded permissible limits for 24-hour averages at all monitoring points during both seasons, while PM_{10} exceeded limits only at processing points. Gaseous pollutants remained below regulatory thresholds; however, their presence alongside elevated particulate matter raises concerns about cumulative exposure risks. Chronic inhalation of fine particles and intermittent exposure to CO and VOCs can lead to respiratory and cardiovascular health issues, emphasizing the need for continuous monitoring and preventive measures.

Table 6
Comparison of estimated 24-hour mean concentrations of Particulate Matter [$\mu\text{g}/\text{m}^3$] during dry and rainy seasons with the standard Index Limit by NAAQS and NESREA

Mining Sites	Dry season			Rainy season		
	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}
Pyakassa Quarry Site (PQS)						
Processing point:	142.92	179.88	199.74	68.7	95.22	107.34
Staff premises	101.64	132.42	146.22	59.64	82.68	93.48
Entrance/exit point	71.76	97.86	110.82	62.82	87.24	98.46
Daijinjia Quarry Site (DQS)						
Processing point:	119.28	159.90	174.30	70.32	96.36	109.02
Staff premises	90.96	121.8	138.84	66.48	91.02	102.60
Entrance/exit point	60.00	82.50	92.10	44.10	61.44	68.28
NAAQS	–	35.00	150.00	–	35.00	150.00
NESREA	–	40.00	150.00	–	40.00	150.00

Discussion

High concentrations of particulate matter were observed across the studied sites compared to gaseous pollutants, and the highest levels consistently occurred at the processing points. This reflects typical emission characteristics associated with granite mining, where crushing, grinding, conveyor movement, and loading operations generate substantial amounts of fine dust. Similar patterns have been documented in quarry environments globally (PATRA et al. 2016, BILIAMINU et al. 2021, NAGARAJA et al. 2024).

The dominance of fine particulate matter ($PM_{1.0}$ and $PM_{2.5}$), which exceeded NAAQS and NESREA limits in both seasons, is of particular concern. Fine particles travel long distances and penetrate deeply

into the human respiratory tract, increasing the risk of adverse health effects. This aligns with epidemiological evidence linking $PM_{2.5}$ exposure to respiratory and cardiovascular diseases (RAASCHOU-NIELSEN et al. 2016, XING et al. 2016, LEDERER et al. 2021). Workers stationed near processing activities therefore face heightened risk of chronic exposure, especially in environments where dust suppression measures and personal protective equipment are inadequate.

In contrast, gaseous pollutants such as CO, HCHO, and TVOC were more elevated at staff premises and entrance/exit points than at processing points. This pattern likely reflects supporting activities such as vehicle movements, fuel combustion from generators and machinery, and emissions from equipment maintenance. These findings indicate that while particulate emissions are driven mainly by mechanical processing, gaseous pollutants originate primarily from transport and auxiliary operations.

Seasonal variation showed that pollutant concentrations were higher during the dry season than the rainy season across both sites. This could be attributed to low mining activities and the rate of dispersion of the pollutants. According to OMEIZA et al. (2022), quarry activities are generally reduced during the rainy season because construction works that require large quantities of granite products, such as road and bridge construction, decline during this period. In addition, prevailing atmospheric conditions influence the variation in pollutant concentrations between dry and rainy seasons, as meteorological factors play a key role in pollutant dispersion and removal from the atmosphere. This effect is particularly associated with wind speed and precipitation (MATHEW and SADAUKI 2022).

The ARIMA-based autocorrelation analysis indicated no significant temporal trends in pollutant levels, suggesting that emissions were primarily influenced by irregular operational patterns and environmental factors rather than systematic temporal behavior. Such irregularities are characteristic of mining operations, which do not always follow constant or predictable activity cycles.

Overall, the findings demonstrate that quarry operations contribute significantly to local air quality deterioration, particularly through fine particulate emissions. Elevated particulate levels pose both short-term and long-term health risks to miners and nearby residents, increasing the likelihood of respiratory tract disorders and other health complications (OGAH et al. 2020). Although gaseous pollutants remained below regulatory thresholds, their presence indicates ongoing emissions from combustion sources and fuel evaporation. Studies have shown that even when individual pollutants remain below their threshold limits, combined or recurrent exposure can pose cumulative risks to human health, especially in workplaces with recurring emission sources (ATA et al. 2024).

Even when gaseous pollutants remain within permissible limits, their combined effects with high particulate matter can intensify overall health risks. Therefore, continuous monitoring, enforcement of dust-control measures, equipment maintenance, and provision of appropriate protective gear are essential to minimize occupational exposure. Extending monitoring to surrounding communities would also help evaluate broader public health implications associated with quarry operations.

Conclusion

1. Mean concentrations of particulate matter were higher at the processing point as compared to other monitoring points. This depicts a higher health risk to workers at this point.

2. Among the selected gaseous pollutants measured it was observed that the staff premises and the entrance/exit points recorded high concentrations of gaseous pollutants as compared to the processing points and that the gaseous pollutants concentrations measured show higher standard deviations than the mean computed values which indicates that the data points are more spread out from the mean, as a result of high degree of variability or dispersion in the gaseous pollutants concentrations.

3. No trends between measured and modelled concentrations during dry and rainy seasons.

4. Higher concentrations of particulate matter and gaseous pollutants were observed during the dry season in the two study sites as compared to the rainy season.

5. Observed concentrations of $PM_{1.0}$ and $PM_{2.5}$ in the studied sites were above the limits of $35 \mu\text{g}/\text{m}^3$ and $40 \mu\text{g}/\text{m}^3$ for a 24-hourly average time by the National Ambient Air Quality Standards (NAAQS, US EPA) and National Environmental Standards and Regulations Enforcement Agency (NESREA).

6. The effects of the observed concentration suggest that the air in the vicinity may be polluted, thereby leading to attenuation of the air quality.

Acknowledgment

The authors are grateful to the staff and management of the Pyakassa Quarry Site and Daijinja Quarry Site for their permission and support in carrying out this research work in the vicinities of their mining and processing sites.

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