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Air quality impact of open tyre burning: analysis of particulate matter and gases

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Abstract

Open tyre burning remains a significant environmental concern due to the release of harmful pollutants such as particulate matter (PM), toxic gases, and heavy metals including Cu, Cd, Pb, and Ni. This study assessed the impact of tyre burning on air quality in Makurdi metropolis using a 4-in-1 multi-gas detector, high-volume respirable dust sampler (APM 460NL Model), and Atomic Absorption Spectrometer (AAS). Results show that the concentrations of Cu (228.40 mg/kg), Cd (104.80 mg/kg), Pb (919.20 mg/kg), and Ni (304.60 mg/kg) exceeded recommended safety limits, while Zn (165.70 mg/kg) remained within acceptable levels. Similarly, the mean concentrations of CO (17 $\mu g/m^3$), SO_2 (93 $\mu g/m^3$), and NO_2 (110 $\mu g/m^3$) exceeded the World Health Organization (WHO) guideline limits of 4, 40, and 25 $\mu g/m^3$, respectively. Particulate matter analysis showed a mean $PM_{2.5}$ concentration of 10 $\mu g/m^3$, which was slightly below the WHO limit of 15 $\mu g/m^3$, while PM_{10} recorded a mean concentration of 52 $\mu g/m^3$, substantially exceeding the recommended limit of 45 $\mu g/m^3$. The Air Quality Index (AQI) indicated that CO levels fell within the "good" category, NO_2 showed occasional spikes, SO_2 frequently exceeded safe levels, and $PM_{2.5}$ posed the highest risk due to moderate to unhealthy concentrations. These findings highlight the severe public health implications of open tyre burning and underscore the need for regulatory action, public awareness, and adoption of safer waste-management alternatives.

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1. Introduction

Particulate Matter (PM) consists of solid and liquid particles introduced into the atmosphere through natural and human activities. The physical, chemical, and thermodynamic characteristics of PM vary widely, allowing it to remain suspended depending on its size, density, temperature, and wind conditions [1]. According to the World Health Organization, a significant majority of the global population is exposed to air that fails to meet recommended pollution standards, highlighting an urgent public-health concern. Air pollutants, including gases and particulate matter, contribute to millions of deaths annually and are known to trigger oxidative stress and inflammatory responses in biological systems [2].

In Makurdi, inadequate waste-management systems, increased demand for scrap-metal recovery, and cost-saving measures in abattoirs have promoted the practice of open tyre burning. This activity elevates air-pollution levels, particularly affecting nearby

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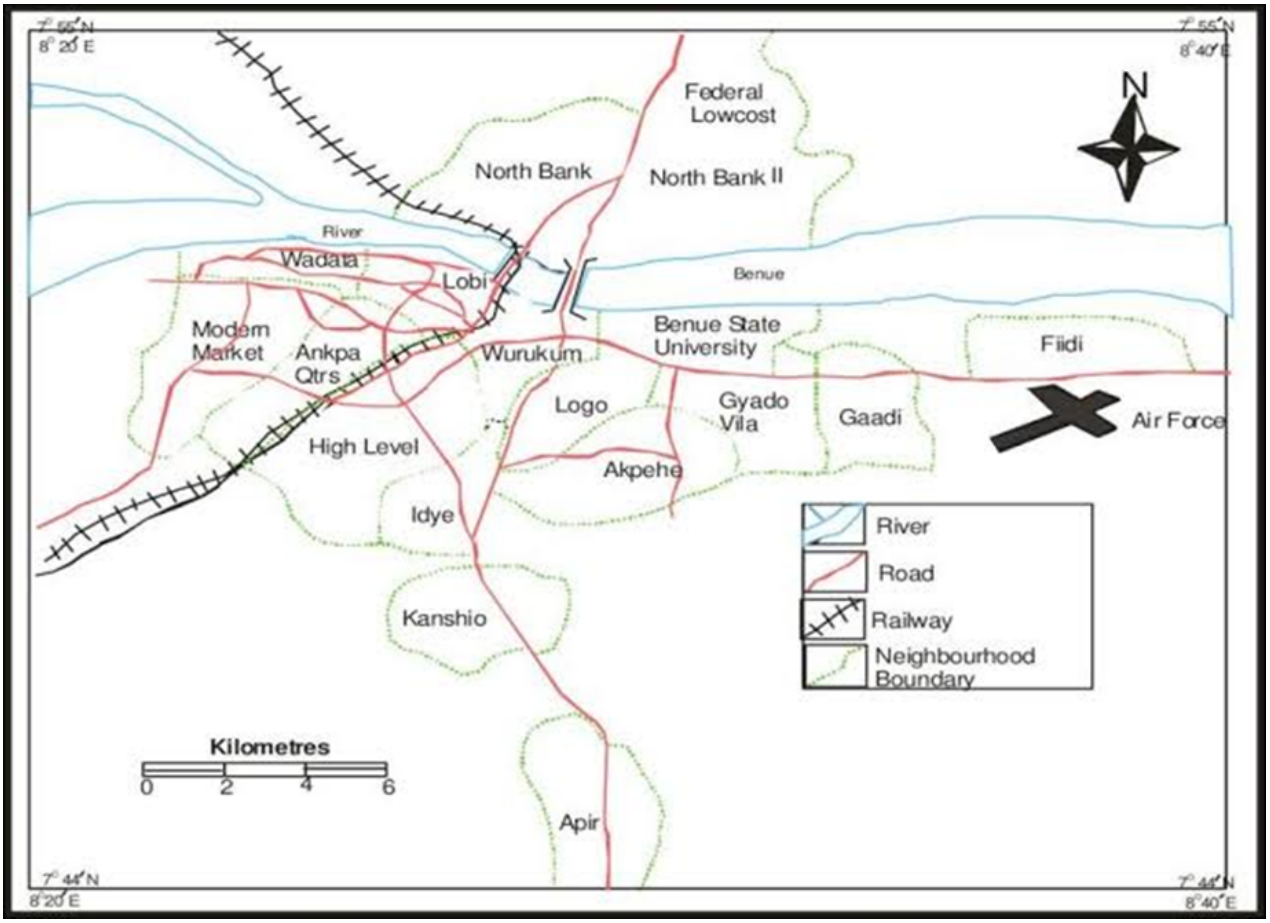

Figure 1: Study area.

communities and contributing to the overall degradation of urban air quality [3]. The harmful effects are more pronounced in vulnerable groups such as children, the elderly, and individuals with pre-existing respiratory conditions [4]. Therefore, assessing the air-quality implications of open tyre burning is essential for public-health protection and policy formulation.

Over the years, several epidemiological studies have evolved showing the harmful health impacts associated with short-term and long-term exposure to air pollutants. This made it necessary to investigate in order to understand the links between the emission sources, the air quality deterioration and the health effects they cause. This work will reveal the concentration and composition of particulate matter emitted from the burning of tyres and the gaseous emissions produced from burning of tyres into the environment in Makurdi metropolis. Furthermore, the result is significant in that it will create awareness to individuals, organization as well as government on the harmful effect of burning tyres as this will greatly assist the government to design actions for reducing the use of tyres for protests and for other purposes.

2. Materials and method

2.1. Study area

Makurdi town is located Lat. 7°47′ and 10°00′ North and Long 6^0 25′ and 8^0 8′ East of the equator. It is bounded by Guma local government to the North, Gwer Local Government Area to the South-West and Doma Local Government of Nasarawa State to the North-West (Figure 1). It is situated in the Benue Valley on the bank of river Benue. The town is strategically located on the North- South transportation network by road and by rail respectively, between Nasarawa and Enugu States with the total land area of about 810 square kilometers [5]. The temperature is generally high during the day, most especially in March and April. It records an average maximum and minimum daily temperature of 35°C and 21°C in summer, 37°C and 16°C in winter, respectively.

2.2. Site selection

Some of the principal factors that determined the locations of the sampling areas were the objectives, availability of resources, physical accessibility and security against loss and tampering. The area chosen for this work is the NUGA Park South Core Joseph Sarwuan Tarkaa University, Makurdi (JOSTUM).

Table 1: Concentration of heavy metals in burnt tyre particulate.

Heavy Metals	Concentration (mg/kg)
Cu	228.40
Cd	104.80
Ni	304.60
Pb	919.20
Zn	165.70
Co	32.90
Mn	54.65
K	275.70
Fe	275.70

Table 2: AQI category distribution.

AQI Values	Levels of Health Concern	Frequency (%)				
		CO (ppm)	NO_2(ppb)	SO_2(ppm)	$PM_{2.5}$($\mu g/m^3$)	PM_{10}($\mu g/m^3$)
0–50	Good	100.0	75.0	50.0	0.0	87.5
51–100	Moderate	0.0	12.5	50.0	62.5	12.5
101–150	Unhealthy (sensitive groups)	0.0	12.5	0.0	37.5	0.0
151–200	Unhealthy	0.0	0.0	0.0	0.0	0.0
201–300	Very unhealthy	0.0	0.0	0.0	0.0	0.0
301–500	Hazardous	0.0	0.0	0.0	0.0	0.0

2.3. *Methods*

2.3.1. *Quantification of gaseous and particulate pollutants*

Two portable air quality detector devices WP6932 and GC310 (4 in 1) multi gas detector were used for the quantification of the gases and particulates emitted from the burning of the tyres. These portable devices are designed to analyse air pollutants that are released continuously from the combustion chamber by withdrawing it into its device and analysing it. Pollutants that are analysed by these devices include CO, NO_2, SO_2, $PM_{2.5}$ and PM_{10}.

2.3.2. *Determination of elemental composition*

The filters with pollutants emitted from the tyre samples were collected with the high-volume respirable dust sampler (APM 460NL Model) on filter paper and was examined for the presence of heavy metals concentration. The filters were digested using a nitric acid (HNO_3) and perchloric acid ($HClO_3$) mixture in a 2:1 ratio [6]. The mixture was heated on a hot plate at 105°C for about 1 hour until the color changed from reddish-brown to colorless in a fume cupboard. After cooling, the solution was filtered through Whatman No. 42 filter paper and adjusted to 25 ml with distilled water. A 25 ml of this digest was analyzed for heavy metal concentrations using a A.A.S Thermo-Scientific ICE 3000 Model at the Sheda Science and Technology Complex (SHESTCO) F.C.T. Abuja, Nigeria.

The instrument was calibrated with suitable standards to generate calibration curves. The metals analyzed included Co, Pb, Cr, Ni, Cd, Mg, Mn, Fe, Cu, and Zn, which are commonly found in tyre materials [7]. The concentrations of these heavy metals in the particulate matter in the emission from the burning of the tyres are presented in Table 1.

2.3.3. *Air quality index (AQI) and its computation*

The Air Quality Index (AQI) stands for a quantitative tool that allows for the easy reporting of air pollution data, that provides valuable information on the cleanliness or pollution levels of the air [8]. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects [9, 10]. Computation of the AQI requires an air pollutant concentration over a specified averaging period, obtained from an air monitor or model. The AQI values were obtained using Eq. (1):

$$I_p = \frac{I_{HI} - I_{LO}}{BP_{HI} - BO_{LO}} \left(C_p - BP_{LO} \right) + I_{LO}, \tag{1}$$

where I_p = AQI for pollutant p, C_p = observed concentration of pollutant p, $BP_{HI} - BO_{LO}$ = upper and lower breakpoint concentrations surrounding C_p, $I_{HI} - I_{LO}$ = AQI values corresponding to the breakpoints.

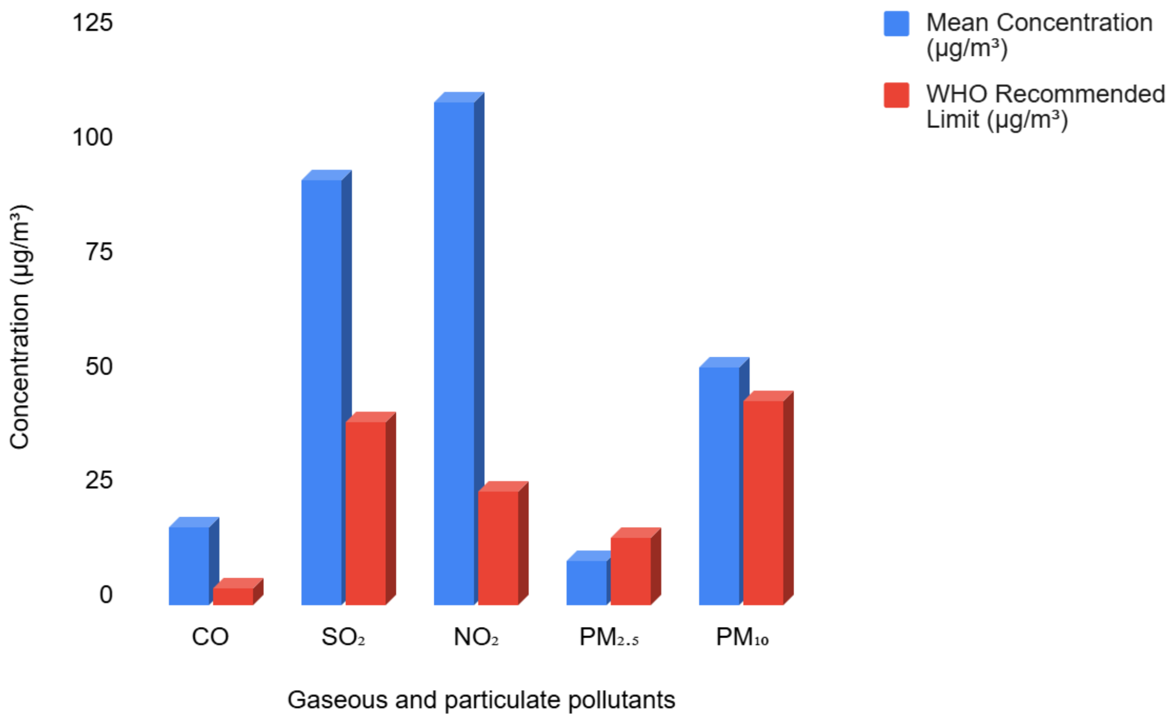

Figure 2: Comparison of measured mean concentration of gaseous pollutants and particulates at NUGA park with WHO limit.

3. Results and discussion

3.1. Air pollutants concentrations

The elevated concentrations of gaseous pollutants observed in this study indicate significant air quality deterioration at the sampling location. The concentration of NO_2 recorded in this study (110 μg/m^3) exceeded the WHO guideline limit, consistent with findings from controlled and uncontrolled tyre-burning scenarios reported in the literature. Shakya *et al*. [11] observed substantial emissions of NO_2, SO_2, and CO from open-air combustion of waste vehicle tyres, with concentrations far surpassing recommended air-quality thresholds, thereby supporting the elevated NO_2 (110 μg/m^3) and SO_2 (93 μg/m^3) levels measured in Makurdi. These elevated concentrations suggest strong contributions from combustion-related activities such as open tyre burning and vehicular emissions.

This pattern is further reinforced by the field investigation of Downard *et al*. [12], who documented high gaseous emissions including NO_x, SO_2, and CO during a large tyre-fire event, attributing these spikes to the incomplete combustion characteristics of rubber fuels. In the present study, carbon monoxide concentrations (17 μg/m^3) exceeded the WHO guideline of 4 μg/m^3, further indicating incomplete combustion processes. Similarly, the elevated SO_2, CO, and PM_{10} concentrations observed align with emissions profiles reported during tyre-fire episodes, where sulphur-based gases and coarse particulate matter were identified as dominant pollutants [12].

Although the mean $PM_{2.5}$ concentration recorded in this study (10 μg/m^3) was below the WHO guideline value of 15 μg/m^3, prolonged exposure at this level may still pose potential health risks. In contrast, PM_{10} concentrations (52 μg/m^3) far exceeded the recommended limit of 45 μg/m^3, highlighting coarse particulate pollution as a major air quality concern. This observation is consistent with previous studies in developing urban environments, where particulate matter particularly PM_{10} has been identified as a dominant contributor to respiratory and cardiovascular health risks [12].

3.2. Heavy metals concentration in particulates from the burning tyres

Analysis of the particulates revealed the presence of several heavy metals originating from the burning tyres. The concentrations obtained and their comparison with regulatory limits are presented in Figures 2 and 3 and Table 1. Cu was detected at 228.4 mg/kg, which falls below the permissible guideline, although tyre-burning studies have shown that Cu is commonly released during combustion of rubber and can contribute to long-term health problems such as anaemia, cardiac complications, and thyroid dysfunction when exposure becomes excessive [12].

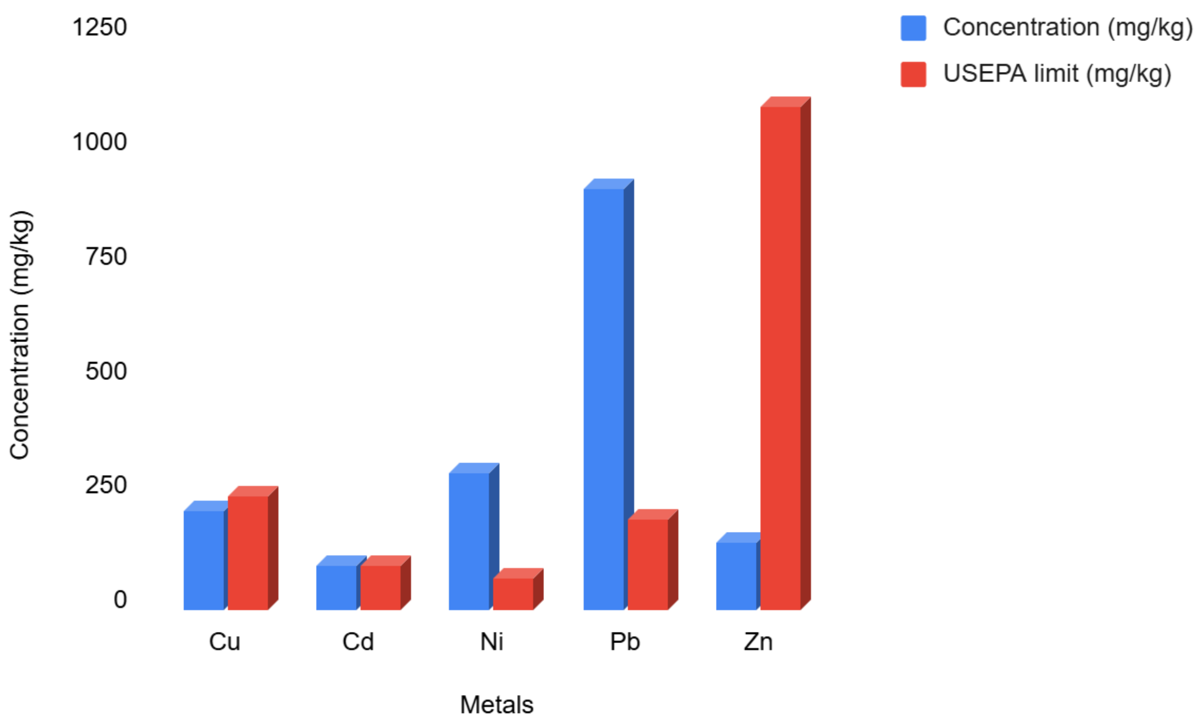

Figure 3: Comparison of concentration of heavy metals in the particulates with USEPA limit.

Cd was measured at 104.8 mg/kg, far exceeding the permissible limit of 0.48 mg/kg [6]. Elevated Cd levels are consistent with findings from experimental tyre-burning assessments, which have documented significant cadmium content in tyre-ash and particulates due to the high Cd content inherent in tyre materials [13].

Ni concentration was 304.6 mg/kg, surpassing the USEPA guideline of 72 mg/kg [6]. The presence of Ni at such high levels aligns with reports from combustion studies indicating that nickel is one of the trace metals commonly mobilized during tyre fires, with inhalation exposure linked to respiratory cancers, chronic bronchitis, and cardiovascular complications [12].

Pb was also detected at an elevated concentration of 919.2 mg/kg, greatly exceeding the USEPA limit of 210 mg/kg [6]. This pattern agrees with documented evidence showing that tyre combustion releases substantial quantities of lead into airborne particulates and ash, posing long-term risks to renal, reproductive, and immune functions [13].

Zn was found at 165.7 mg/kg, which remains below the permissible limit of 1100 mg/kg [6]. This is expected, as tyres are known to contain high proportions of zinc oxide, and tyre-burning studies consistently identify Zn as the dominant metal in residues and emissions, though actual concentrations vary depending on combustion temperature and oxygen availability [11]. Excessive exposure to zinc, particularly in environments with repeated burning events, has been associated with gastrointestinal distress, vomiting, and nausea.

3.3. Air quality index of the gaseous pollutants

The values of CO, NO_2, SO_2, $PM_{2.5}$ and PM_{10} emissions from open burning of scrap tyres are shown in Table 2. For CO, all readings fell within the 'good' AQI range, indicating very low pollution and minimal health concern [10]. This pattern is consistent with the findings of Okonkwo *et al.* [14] who reported similarly low CO levels around tyre-singeing abattoirs in Abuja, attributing this to incomplete but low-yield carbon combustion during tyre burning. For NO_2, most values also fell in the 'good' category, with occasional spikes into 'moderate' and 'unhealthy for sensitive groups' ranges [10]. Comparable NO_2 fluctuations were observed by Jimoda *et al.* [15] who recorded transient increases in NO_x concentrations during laboratory-scale tyre combustion in Nigeria, noting that nitrogen-containing additives in tyres are partially responsible for the intermittent peaks.

SO_2 values in this study more frequently appeared in the 'moderate' and 'unhealthy for sensitive groups' categories, highlighting tyre burning as a persistent source of sulphur emissions. This agrees with findings of Ikwebe and Bando [16] who documented elevated SO_2 levels around informal tyre incineration points, linking them to the sulphur-rich rubber compounds characteristic of waste tyres. $PM_{2.5}$ values in the present study ranged between 'moderate' and 'unhealthy for sensitive groups', reflecting the generation of very fine, respirable particulates. This trend aligns with reports by Jimoda *et al.* [15] who showed that tyre burning in Nigeria produces substantial quantities of fine particulates capable of degrading air quality and penetrating deep lung tissues. Similar

$PM_{2.5}$-driven AQI deterioration was reported by Narra *et al*. [17] across tyre-handling and tyre-recycling operations in West Africa, confirming that $PM_{2.5}$ pollution is a recurring feature of tyre-related activities in the region.

PM_{10} readings in this study mostly fell within the 'good' category, with fewer occurrences of 'moderate' and 'unhealthy for sensitive groups' ranges. This behaviour closely corresponds with observations by Ikwebe and Bando [16], who noted that although coarse particulates (PM_{10}) are produced during tyre burning, their concentrations are often lower than those of $PM_{2.5}$ due to heavier particle mass and quicker deposition.

4. Conclusion

This study has significantly established that particulate matter and gaseous pollutants (PM_{10}, $PM_{2.5}$, CO, SO_2 and NO_2) are present at varying concentrations in tyre when burnt with NO_2 having the highest concentration well above the recommended safety limit. Also, it was observed from this study that with exception of PM_{10} the other gaseous pollutants and particulate matter exceeded the limit set by WHO [18]. Also, the AQI classification reveals that CO levels were consistently within the 'good' category, showing no major health risks in this dataset. NO_2 was generally safe but showed occasional moderate spikes. SO_2 appeared more frequently in the 'moderate' to 'unhealthy' for Sensitive Groups ranges, reflecting persistent combustion-related emissions. $PM_{2.5}$ posed greater concern, with values in the 'moderate' to 'unhealthy' for Sensitive Groups ranges, indicating potential risks for vulnerable populations. PM_{10} was mostly in the 'good' category. The highest concentration of heavy metals was observed in lead with a concentration of 919.20 mg/kg and all the metals studied exceeded the USEPA [6] limit with exception of zinc. The results emphasize the need for stricter regulatory enforcement, adoption of safer alternatives in the burning of tyres and continuous air quality monitoring to safeguard both human health and ecosystems.

Abbreviations

PM – Particulate Matter
WHO – World Health Organization
JOSTUM – Joseph Sarwuan Tarkaa University, Makurdi
APM – Air Pollution Monitor (APM 460NL Model sampler)
HNO_3 – Nitric Acid
$HClO_3$ – Perchloric Acid
AAS – Atomic Absorption Spectrophotometer
SHESTCO – Sheda Science and Technology Complex
FCT – Federal Capital Territory
Co – Cobalt
Pb – Lead
Cr – Chromium
Ni – Nickel
Cd – Cadmium
Mg – Magnesium
Mn – Manganese
Fe – Iron
Cu – Copper
Zn – Zinc
CO – Carbon (II) oxide
NO_2 – Nitrogen (IV) oxide
SO_2 – Sulfur (IV) oxide
$PM_{2.5}$ – Particulate Matter less than 2.5 micro metre
PM_{10} – Particulate Matter less than 10 micro metre
AQI – Air Quality Index
EPA / USEPA – United States Environmental Protection Agency

Data availability

Data will be made available upon reasonable request from the corresponding author.

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