

# Pollution Levels from Selected Manual Stone Crushing Units in North Central Nigeria and Their Health Effects

Oladele F. Anjorin<sup>1\*</sup>, Mariam D. Solomon<sup>2</sup>, Jaryum H. Kiri<sup>2</sup>, Jonathan D. Dabak<sup>2</sup>,  
Samuel Y. Gazuwa<sup>2</sup>, Simon G. Mafulul<sup>2</sup>, Raymond I. Daspan<sup>3</sup>, Elizabeth O. Okoh<sup>4</sup>,  
Isaac S. Laka<sup>5</sup>, Jane-Rose Onche<sup>2</sup>, Isa S. Wuti<sup>2</sup>

<sup>1</sup>Department of Physics, University of Jos, Plateau State-Nigeria

<sup>2</sup>Department of Biochemistry, University of Jos, Plateau State-Nigeria

<sup>3</sup>Department of Geology, University of Jos, Plateau State-Nigeria

<sup>4</sup>Department of Community Medicine, University of Jos, Plateau State-Nigeria

<sup>5</sup>Department of Geography, University of Jos, Plateau State-Nigeria

\*Corresponding author: [frankanj@yahoo.com](mailto:frankanj@yahoo.com)

Received May 15, 2023; Revised June 17, 2023; Accepted June 26, 2023

**Abstract Background:** When stones are crushed, the finer dust gets airborne and escapes as fugitive emissions, constituting dust pollution problems in the vicinity with severe adverse effects on the ambient air quality and human health. **Methodology:** In this study, active sampling method was deployed to sample and obtain the ambient concentrations of CO, SO<sub>2</sub>, H<sub>2</sub>S and PM (of sizes 2.5 and 10 microns) in the fugitive emissions from selected manual stone crushing sites in North Central Nigeria. The trapped particles sampled were analysed for particulate-associated heavy metals such as Cd, Co, Cr, Cu, Pb, Mn, Ni, Fe, and Zn by Atomic Absorption Spectrometry (AAS). **Principal Findings:** The observed mean concentration of CO, SO<sub>2</sub> and H<sub>2</sub>S sampled were 0.12 mg/m<sup>3</sup>, 0.06 mg/m<sup>3</sup> and 0.004 mg/m<sup>3</sup>, respectively. The mean concentration of PM<sub>2.5</sub> was observed to be 26.5 µg/m<sup>3</sup> (ranged from 8 µg/m<sup>3</sup> to 70 µg/m<sup>3</sup>) which is about 76.7 % higher than the World Health Organization (WHO) air quality guidelines (15 µg/m<sup>3</sup> for 24- mean for PM<sub>2.5</sub>). The Mean concentration of PM<sub>10</sub> was observed to be 54.36 µg/m<sup>3</sup> (ranged from 17 µg/m<sup>3</sup> to 143 µg/m<sup>3</sup>) which is about 20.8 % higher than the World Health Organization (WHO) air quality guidelines (45 µg/m<sup>3</sup> for 24-mean for PM<sub>10</sub>). AAS analysis revealed that metal-bearing particulates have significant levels of the selected heavy metals except copper that was below detection limit: Cr, Mn, Fe, Pb, Zn, Ni, Cd and Co were respectively, 48.0 mg/m<sup>3</sup>, 82.0 mg/m<sup>3</sup>, 140.0 mg/m<sup>3</sup>, 202.0 mg/m<sup>3</sup>, 34.0 mg/m<sup>3</sup>, 1403.0 mg/m<sup>3</sup>, 21.0 mg/m<sup>3</sup>, 60.0 mg/m<sup>3</sup>. **Conclusion:** All the metals (Pb, Ni and Cd), classified by IARC as carcinogenic in humans (group 1) greatly exceeded on average the annual EU's limits (500, 20, 6 and 5 ng/m<sup>3</sup> respectively).

**Keywords:** fugitive emissions, stones, crushed, manual, ambient air, particles, gaseous pollutants

**Cite This Article:** Oladele F. Anjorin, Mariam D. Solomon, Jaryum H. Kiri, Jonathan D. Dabak, Samuel Y. Gazuwa, Simon G. Mafulul, Raymond I. Daspan, Elizabeth O. Okoh, Isaac S. Laka, Jane-Rose Onche, and Isa S. Wuti, "Pollution Levels from Selected Manual Stone Crushing Units in North Central Nigeria and Their Health Effects." *Journal of Environment Pollution and Human Health*, vol. 11, no. 2 (2023): 37-45. doi: 10.12691/jephh-11-2-3.

## 1. Introduction

According to several researchers, airborne contaminants can lead to respiratory and cardiovascular conditions like bronchitis, cardiac arrhythmia, lung inflammation, lung fibrosis, deep vein thrombosis, and lung cancer [1,2,3,4,5,6]. It has also been noted that these detrimental health effects are caused by particulate matter (PM) and other pollutants like CO and SO<sub>2</sub>. Stone crushing is a rising source of particulate matter emissions in Nigeria, which come in a variety of sizes and chemical compositions. Due to a lack of resources and technical know-how for mechanized stone crushing, manual stone crushing industries are becoming more prevalent and common sights along several highways leading to major

Nigerian cities. Stone crushing has become the main source of income for low income earners in Nigeria.

Despite being extremely time-consuming and frequently dangerous, the technique has gained popularity among many individuals, particularly young people and women, as a favorable pastime in light of the current severe economic crisis and lack of attractive job prospects to address the country's massive unemployment problem. The large health effects from exposure to fugitive emissions from quarry activities are caused by the fact that the persons involved in these activities are frequently in clusters and dispersed inside the microenvironments of rock formations. The lack of information now available regarding the deterioration of air quality caused by these units' operations, accompanying occupational exposures, and potential health effects is a significant downside to this industry in Nigeria.

Notably, size reduction occurs during crushing operations; larger stones and fragmented pieces become too crushed, which leads to the generation of stone dust [7]. The finer dust becomes airborne and escapes as fugitive emissions, creating dust pollution issues nearby that have a serious negative impact on the quality of the surrounding air and human health. These have an effect on the microenvironments' air quality and may cause respiratory illnesses, poor sight, and a decrease in the growth of vegetation. According to [8], stone crushing operations are a significant source of dust generation in the areas close to the facilities and in the communities in those areas. Oxides of sulphur, Oxides of nitrogen, and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) are some factors that are considered for the investigation of ambient air quality within the microenvironments of manually operated stone crushing businesses [9].

A number of manually operated stone crushing clusters, many of which are found at the base of rock formations, are particularly prevalent in north central Nigeria. A typical cluster can consist of fifteen workers, including women and children, who spend an average of 10 hours each day at the crusher sites. North central Nigeria has a distinctive terrain with enormous rock formations, which contributes to the huge scale of manual stone crushing quarries even though all geographic regions of the nation are home to a variety of rock formations. The microenvironments of the stone crushing sites predispose the workers to a number of occupational hazards, including silicosis, which is brought on by prolonged exposure to particles rich in free silica [8]. This is brought on by the workers' regular exposure to high concentrations of dust brought on by the crushing operations at these sites. According to [10], severe respiratory injuries can result in lung functioning abnormalities that are reversible in some situations but may result in irreparable damage in others, including lung cancer. [11] found that humans' respiratory systems are capable of filtering out big particles. Some tiny particles can still get through, though. 3 million premature deaths worldwide occurred in 2016, according to the World Health Organization (WHO) [6]. Despite the lack of evidence between long-term exposure to coarse particles and mortality, according to [5,12] found that exposure to coarse particles has pro-inflammatory and cytotoxic consequences. Studies by [12-18] and others estimated the impact of PM on human health as well as the associated impact from the chemical composition. These metal-bearing particles may contain As, Cd, Co, Cr (VI), and Ni, which have all been linked to a higher risk of cancer. According to [19], the majority of metals are hazardous and may have serious negative consequences on health, including various cancers. This is due to the finding made by [20] that dust particles differ in size and have a significant surface area, which makes them a great vehicle for the transportation and deposition of heavy metals in the environment.

Fine particulate matter (PM<sub>2.5</sub>, particles with aerodynamic diameters 2.5 µm) has a larger surface area per unit mass than coarse particulate matter, which makes it easier for PM<sub>2.5</sub> to accumulate heavy metals. PM<sub>2.5</sub> is also more dangerous than coarser PM due to its longer residence time in the atmosphere and deeper penetration into the lungs [6]. Many sources that emit heavy metals into the air have been studied and documented in literature, but little research has been done on the heavy metal emissions from

manually crushed stone in Nigeria. Due to the physical processes that create atmospheric particles and the atmospheric processes that regulate the fate and evolution of particle size distributions, the size of atmospheric particles can be related to their sources in the atmosphere. Physical processes, such as the resuspension of soil and road dust, sea spray, agricultural tilling, vehicular abrasion (i.e., tyre and brake wear), and fugitive dust emission from industrial sources, are the main causes of coarse PM (particles with aerodynamic diameters between 2.5 µm and 10 µm) production (IARC, 2015). The sizes of particles span over around five orders of magnitude, from groupings of molecules at the nanoscale (for example) to grains of dust at the scale of tens of micrometers. While it is possible to measure the distribution of particle sizes, most measures only record the mass of particles falling within a given size range. For instance, PM<sub>2.5</sub> refers to PM with aerodynamic diameters of less than 2.5 µm. Other typical size categories include total suspended particles (TSP), ultrafine PM (PM < 0.1 µm), and PM10 (PM < 10 µm).

According to the [21], coarse PM is defined as the fraction having sizes between 2.5 and 10 micrometers. These size classes correspond to size ranges utilized in health research and are pertinent to PM dynamics in the environment and uptake in the human body. According to [22], the presence of heavy metals in urban dust and soils is a significant sign of environmental contamination. Due to the activity of stone crushing in Nigeria, research to determine their levels in the atmosphere is therefore crucial. There aren't many thorough researches on the environmental effects of Nigeria's emissions of metal-bearing particles, particularly those from manual stone crushing.

This research seeks to determine the effects of fugitive emissions from a few chosen groups of manually operated stone crushing locations in north central Nigeria and their heavy metal constituents.

## 2. Materials and Methods

### 2.1. Study Area

The Federal Capital Territory (FCT) of Nigeria and six states in the nation's central region were included in the study. The seven states that make up North Central Nigeria are geographically located in the central belt area of the nation, starting in the west and extending to the confluence of the Rivers Niger and Benue. Benue, Plateau, Nasarawa, Niger, Kogi, and Kwara are the north central states and are situated at an altitude of 115 meters above sea level, as indicated in Figure 1. 80°00' N and 800'0' E DMS are its coordinates (in Degree Minutes Seconds). Its Joint Operation Graphics reference is NC32-14, and its UTM position is LP88. Due to its distance from the equator, its climate, the tropical savanna climate, has a clearly defined rainy season with a single peak known as the summer maximum. With an average annual rainfall of roughly 1,500 mm and a peak rainfall in September, the temperatures range from above 18.54°C to 36.9°C. In total, fourteen sites were chosen at random from these thematic regions shown in Figure 1.



Figure 1. Map showing north central Nigeria

## 2.2. Geology of the Study Area

### 2.2.1. Regional Geology

The Basement Complex and the Younger Granites make up around 50% of Nigeria's entire 935,000km<sup>2</sup> landmass, while the Cretaceous to Recent Sediments (Tertiary & Quaternary), which are in the six (6) primary sedimentary basins of the nation, make up the majority of the other 50%.

- Pre-Cambrian-Lower Palaeozoic rocks of the crystalline Basement complex make up around 50% of Nigeria's total surface area and can be split into three primary geological age regions.
- The Basement Complex in the North-Central region of Nigeria has less than 10% of the Jurassic Younger Granite and the Quaternary Volcanism.
- Sediments from the Cretaceous to Recent Epochs make up around 40%. deposits were made in Nigeria's Middle Benue Trough, Niger Basin, northeastern Chad Basin, and northwesterly Sokoto Basin.

These geological age provinces are distributed differently across the North Central States. Parts of Kwara, Nasarawa, Niger, Benue, Kogi, Plateau State, and the Federal Capital Territory (FCT) include the basement complex rocks. At least four main orogenic cycles of deformation, metamorphism, and remobilization are thought to have had an impact on them: the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-African cycles (600 Ma).

Intense deformation, isoclinal folding, regional metamorphism, and significant migmatization were common characteristics of the first three cycles.

Younger Granite Complexes are made up of a number of unique intrusions that are frequently arranged in a concentric fashion. The complexes' rock types, according to [23], include rhyolites, granites, syenites, and basic rocks. These are typically found in Nasarawa and sections of the Plateau. Rhyolites come in two varieties on the Jos Plateau, the early and late rhyolites. Although they vary in mineralogy and texture, granites are a constant throughout the region. They are predominately granites made composed of riebeckite granite, biotite granites, and the hornblende granite and porphyries group.

Numerous colored minerals, including fayalite, hedenbergitic pyroxene, hornblende, arfvedsonite, and

biotite, are found in the hornblende granites and porphyries group. The term "granite porphyry" is used to describe these facies of the hornblende granites, which may take the form of massive plutons with a granite texture within ring dykes [23]. Early ring dykes on the Jos plateau are usually composed of coarse hornblende-biotite-granite or granite porphyry, which is also common as plutons. The most prevalent and common rock types on the Plateau are biotite-granites. They contain a wide range of accessory minerals, including zircon, fluorite and iron oxides, thorite, monazite, and xenotime [24] and they produce some of the largest individual intrusions [23].

Certain regions of Niger, Kogi, Benue, Nassarawa, Plateau, and the FCT have the Cretaceous to recent sediments (Tertiary & Quaternary) that make up the troughs.

### 2.3. Air Quality Monitoring

Using the CW HAT 200 Particulate Sampler, an active sampling tool, the ambient levels of particles with aerodynamic diameters of 2.5  $\mu\text{m}$  and 10  $\mu\text{m}$  were measured in-situ in the quarries. Additionally, using a multi-gas active sampler known as the Altair Multi-gas detector, various gaseous contaminants including CO, SO<sub>2</sub>, and H<sub>2</sub>S were sampled. For the collection and analysis of particles in the PM<sub>2.5</sub> size range, there is no ready-made approach. Since manual stone crushers frequently sit down to complete their responsibilities, these active devices were placed at a distance of only 0.5 to 1.0 meters (50 cm to 50 cm) from the ground levels.

Additionally, these sources were investigated for the heavy metals were present. The dust was collected using a Respirable Dust Sampler, an air check sampler that operates at a flow rate of 5 to 500 ml/min, on Whatman GF/A (size 25.4 cm  $\times$  20.32 cm) filter paper. SKC 224-XR Series Pumps were used with this sampler (Model 224-PCXR8). For three hours at each site, the sampler was positioned on a platform 1.5 m above the ground as shown in Figure 2. Atomic absorption spectrometry (AAS) was used to examine these trapped particle samples for particulate-associated heavy metals such Cd, Co, Cr, Cu, Pb, Mn, Ni, Fe, and Zn. The average sampling time was 3 hours due to the workers' epileptic work patterns, which allowed for breaks for rest, customer service, or complete shutdowns of operations. The sampling that was done during the wet season was similarly limited by the weather. As a result, the sample times for the aforementioned

events were capped at fewer than three hours. Figure 2 shows stone crushing activity being carried out manually.



Figure 2. A Manual Stone Crusher in Operation

## 2.4. Heavy Metal Analysis

Atomic Absorption Spectrometry (ASS) was used to examine the heavy metal components of the particulate emissions from the groups of manually operated stone crushing operations. This calls for the fusion or digestion of powerful acids to dissolve the heavy metals in solution. Because inorganic acids are inexpensive, easily accessible, and the digested solutions have a low salt content, strong acid digestion is perhaps the most often utilized breakdown method for determining the amounts of heavy metals in air pollution.

In a fume hood, 2-3g of filter membrane was weighed into a 250 ml beaker. The tri-acid combination was then added to the beaker, along with 6ml HNO<sub>3</sub>, 3ml HCL, and 1ml HCLO<sub>4</sub>. The sample was heated to a colorless, turbid-free state on a hot plate at 90°C on the fume cup board. With the help of a glass funnel and Whatman filter papers with a pore size of 120mm, the sample was filtered while still warm to allow metals to precipitate into a 50ml volumetric flask. With distilled water from a cleaned bottle, the volume was brought up to the 50ml mark and taken for analysis. UNIFORM PROCEDURE The (AAS) 210VGP Atomic Absorption Spectrophotometer was used for the examination of the chosen heavy metal in accordance with ASTM D1971/D4691.

## 2.5. Statistical Analysis

Using the SPSS software, descriptive statistics of CO, SO<sub>2</sub>, H<sub>2</sub>S, PM<sub>2.5</sub>, and PM<sub>10</sub> sampled in-situ the microenvironments of the chosen quarries were conducted. Additionally, the descriptive statistics of the discovered heavy metals (Cd, Mn, Pb, Cr, Zn, Co, Fe, Ni, and Cu) were obtained using SPSS. Additionally, Microsoft Excel was used to collect the bar charts and display the respective levels of the pollutants across the various quarries.

## 3. Results and Discussion

### 3.1. Rock Types Mined in the North Central States

The manually quarried rocks in FCT, Kwara, and Niger states belong to the Precambrian Basement Complex;

Plateau State has a mix of the Precambrian Basement Complex and the Jurassic Younger Granites; and finally, Benue, Kogi, and Nasarawa States have a mix of the Precambrian Basement Complex and the Cretaceous (Tertiary & Quaternary) types.

The rocks being manually extracted from the Precambrian Basement Complex are migmatites, gneiss, granite gneiss, quartzites, agmatite, leucocratic gneiss (belonging to the Migmatite-Gneiss complex), muscovite granite, quartz diorite, coarse-porphyratic granites, medium-grained granites, and microgranite (all belonging to the Older Granite series). Sandstones, Shales, Ferruginized ironstones, and Ferruginized sandstones were the rock types identified to be crushed at the Cretaceous (Tertiary & Quaternary) sites.

At the Jurassic Younger Granites sites found dominantly in Plateau State, the identified mined rock types are basalts (Tertiary-Quaternary volcanic), rhyolites, ignimbrites, welded tuff, biotite granite, biotite hornblende granite, coarse-grained biotite granite, coarse-grained hornblende biotite granite, hornblende granite, medium-grained hornblende granite, medium-grained aegirine granite, pinkish granite, and pyroxene granites.

A total of thirty-four (34) distinct rock types were produced by all of these. One hundred percent of the rocks being crushed in Kwara state are metamorphic kinds, represented by gneisses and granite gneisses, according to a subsequent analysis of the distribution of the rocks being crushed in the research region. Similarly, migmatite/migmatite gneisses (69.23%), gneiss (7.69%), porphyroblastic granite gneiss, and granite gneisses (23.07%) make up 100% of the rocks being manually crushed in the FCT. In the state of Benue, volcanic rocks, represented by granites, account for 70% of the rocks being manually crushed. Sedimentary rocks, represented by shales and sandstones, account for 20%. In the state of Kogi, sedimentary rocks made up of ironstone and ferruginous sandstone account for 40% of the manually crushed rocks, while 10% are mostly made up of granite. Metamorphic rocks, represented by gneisses (40%) and quartzite (10%), make up 50% of the manually crushed rocks. The igneous rocks that make up 40.66% of the manually crushed rocks in Nasarawa state are granite, pegmatite, and diorite; the metamorphic rocks that make up 41.66% of the manually crushed rocks are granite gneiss, gneiss, and agmatite; and the sedimentary rocks that make up the remaining 16.66% are ferruginized sandstone. In Niger State, igneous rocks, such as granites, account for 91.66% of the manually crushed rocks, while metamorphic rocks, such as mylonitic amphibolites, account for 7.69%. In Plateau State, igneous plutonic rocks, represented by granites, account for 61.90% of the manually crushed rocks, followed by igneous volcanic rocks, represented by rhyolites, welded tuff, and basalts, at 23.81%, and metamorphic rocks, represented by migmatites, at 41.28%.

### 3.2. Levels of Fugitive Emissions from the Manually Stone Crushing Sites

Manual Crushing is an unmechanized process, hence fugitive emissions are significantly reduced. This is primarily so that only a crusher may work at a given

location, however they may be grouped together with ten or more workers. The potential dangers these sources portend may not lie so much in the volume of the pollutants released as in the way the crushers are positioned; in several recorded instances, the crushers are positioned so that they are facing the fugitive emissions while crushing stone as presented in Figure 2. Due to this, the released particles are now easily able to enter their nasal cavities and enter the lungs. Due to the fact that roughly 90% of stone crushers prefer to work without either nasal masks or eye protection glasses, the risks associated with manually operated stone crushing have grown significantly. The average concentrations of gaseous (CO, SO<sub>2</sub>, and H<sub>2</sub>S) and particulate (PM<sub>2.5</sub> and PM<sub>10</sub>) pollutants were measured in-situ at the 14 manual stone crushing locations chosen from among those in six north central states and the Federal Capital Territory (FCT), and are shown in Table 1. Figure 3 illustrates the considerable sizes and

levels of variation in the observed concentrations of particulates across the selected sites. This supports [25] finding that PM levels fluctuate significantly and depend on the size fraction being considered. The average PM<sub>2.5</sub> concentration was 26.5 µg/m<sup>3</sup> (with a range of 8 µg/m<sup>3</sup> to 70 µg/m<sup>3</sup>), which is approximately 76.7% higher than the World Health Organization's (WHO) air quality standards (15 µg/m<sup>3</sup> for 24-mean for PM<sub>2.5</sub>) [26]. The average PM<sub>10</sub> concentration was found to be 54.36 µg/m<sup>3</sup> (with a range of 17µg/m<sup>3</sup> to 143 µg/m<sup>3</sup>), which is about 20.8% higher than the WHO's air quality recommendations (45 µg/m<sup>3</sup> for the 24-mean for PM<sub>10</sub>). These levels are, however, somewhat below the National Ambient Air Quality Standards (NAAQS) for the United States of America, which are 35 µg/m<sup>3</sup> for PM<sub>2.5</sub> and 150 µg/m<sup>3</sup> for PM<sub>10</sub>, respectively. These showed that PM<sub>2.5</sub> was 24.29% below the NAAQS level for the 24-hour mean and that PM<sub>10</sub> was 63.76% below the NAAQS level for the 24-hour mean.

Table 1. Pollutants' Concentrations from Manual Stone Crushing from selected Quarries in North Central Nigeria

| Sites       | CO                | SO <sub>2</sub> | H <sub>2</sub> S | PM <sub>2.5</sub> | PM <sub>10</sub> | $\frac{PM_{2.5}}{PM_{10}}$ | Cr                | Mn    | Fe    | Pb    | Zn   | Ni     | Cd                     | Cu     | Co     |
|-------------|-------------------|-----------------|------------------|-------------------|------------------|----------------------------|-------------------|-------|-------|-------|------|--------|------------------------|--------|--------|
|             | mg/m <sup>3</sup> |                 |                  | µg/m <sup>3</sup> |                  |                            | mg/m <sup>3</sup> |       |       |       |      |        |                        |        |        |
| ABJ A       | 0.12              | 0.03            | 0.00             | 28                | 58               | 0.48                       | 6.00              | 260.0 | 292.0 | 266.0 | 47.0 | 1079.0 | 4.0                    | N/A    | 1.0    |
| ABJ B       | 0.25              | 0.00            | 0.00             | 33                | 68               | 0.49                       | 86.0              | N/A   | 525.0 | 225.0 | 16.0 | 959.0  | 4.0                    | N/A    | 62.0   |
| ABJ C       | 0.00              | 0.00            | 0.00             | 38                | 68               | 0.56                       | N/A               | N/A   | 26.0  | 243.0 | N/A  | 999.0  | 31.0                   | N/A    | 166.0  |
| NSW A       | 0.00              | 0.05            | 0.00             | 25                | 56               | 0.45                       | N/A               | 30.0  | 436   | 177.0 | N/A  | 1393.0 | 7.0                    | N/A    | N/A    |
| NSW B       | 0.00              | 0.00            | 0.00             | 25                | 52               | 0.48                       | N/A               | 114.0 | N/A   | 183.0 | 18.0 | 1812.0 | 14.0                   | N/A    | 10.0   |
| NSW C       | 0.55              | 0.08            | 0.00             | 70                | 143              | 0.49                       | 22.0              | 223.0 | N/A   | 139.0 | 75.0 | 1560.0 | 38.0                   | N/A    | 61.0   |
| BN A        | 0.00              | 0.00            | 0.00             | 42                | 90               | 0.47                       | 80.0              | 40.0  | N/A   | 415.0 | 77.0 | 41.0   | 37.0                   | N/A    | N/A    |
| BN B        | 0.00              | 0.00            | 0.00             | 30                | 60               | 0.50                       | 38.0              | 50.0  | 180.0 | 295.0 | 68.0 | 451.0  | 4.0                    | N/A    | 53.0   |
| KG A        | 0.00              | 0.00            | 0.00             | 8                 | 17               | 0.47                       | 140.0             | 286.0 | N/A   | 185.0 | 67.0 | 1708.0 | 26.0                   | N/A    | 102.0  |
| NG A        | 0.00              | 0.09            | 0.00             | 18                | 36               | 0.50                       | 120.0             | N/A   | 92.0  | 145.0 | 10.0 | 2085.0 | 30.0                   | N/A    | 175.0  |
| KW A        | 0.00              | 0.00            | 0.00             | 10                | 22               | 0.45                       | 105.0             | 8.0   | N/A   | 169.0 | 42.0 | 1862.0 | 47.0                   | N/A    | 203.0  |
| PL A        | 0.50              | 0.05            | 0.00             | 14                | 31               | 0.45                       | N/A               | N/A   | 234.0 | 134.0 | 55.0 | 2177.0 | 2.0                    | N/A    | N/A    |
| PL B        | 0.00              | 0.05            | 0.00             | 22                | 43               | 0.53                       | 79.0              | N/A   | 55.0  | 160.0 | N/A  | 1815.0 | 26.0                   | N/A    | N/A    |
| PL C        | 0.26              | 0.44            | 0.06             | 8                 | 17               | 0.47                       | N/A               | 137.0 | 116.0 | 93.0  | N/A  | 1705.0 | 20.0                   | N/A    | N/A    |
| Minimum     | 0.00              | 0.00            | 0.00             | 8                 | 17               | 0.45                       | 0.00              | 0.00  | 0.00  | 90.0  | 0.00 | 40.0   | 0.00                   | N/A    | 0.00   |
| Maximum     | 0.55              | 0.44            | 0.056            | 70                | 143              | 0.56                       | 140.0             | 286.0 | 52.0  | 42.0  | 80.0 | 2180.0 | 47.0                   | N/A    | 200.0  |
| Mean        | 0.12              | 0.06            | 0.004            | 26.50             | 54.36            | 0.49                       | 48.0              | 82.0  | 140.0 | 202.0 | 34.0 | 1403.0 | 21.0                   | N/A    | 60.0   |
| St. Dev.    | 0.195             | 0.115           | 0.016            | 14.68             | 33.29            | 0.031                      | 51.0              | 104.0 | 173.0 | 82.0  | 31.0 | 623.0  | 15.0                   | N/A    | 74.0   |
| WHO Sta.    | 4.00              | 0.04            |                  | 15                | 45               |                            |                   |       |       |       |      |        |                        |        |        |
| USAEPA      |                   | 1.31            |                  | 35                | 150              |                            |                   |       |       |       |      |        |                        |        |        |
| OSHA Levels |                   |                 |                  |                   |                  |                            | 0.001             | 5     |       | 0.05  |      | 1      | 5.0 x 10 <sup>-6</sup> | 0.0001 | 0.0001 |
| IDLH        |                   |                 |                  |                   |                  |                            | 250               | 500   |       | 100   |      | 10     | 0.9                    | 100    | 20     |

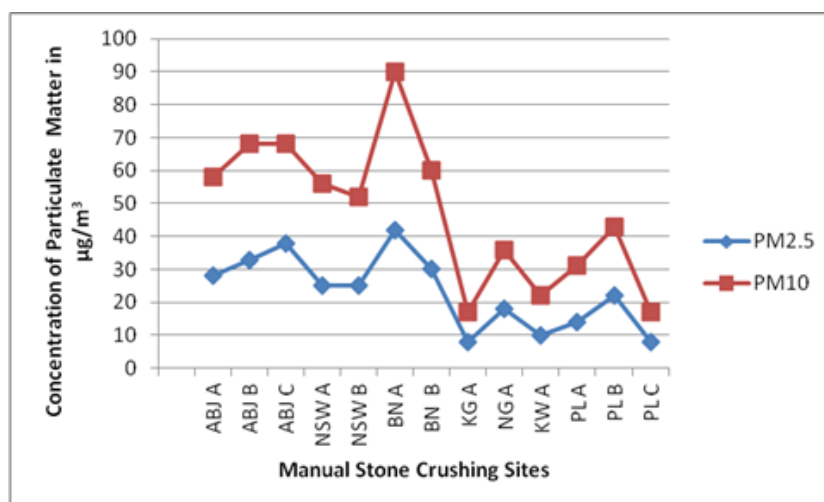


Figure 3. Particulate Levels from Stone Crushing at the selected sites

The ratio of the mean average values of  $PM_{2.5}/PM_{10}$  ranged from 0.45 to 0.56 at the 14 locations monitored across the different states in north central Nigeria where manual stone crushing was carried out, with an estimated mean of 0.49. This falls into the expected range provided by [26]. The estimated range of the annual average values ( $PM_{2.5}/PM_{10}$ ) for the 21 regions examined globally in 2005 is 0.13 to 0.94, according to [27]. It suggests that a significant share of  $PM_{10}$  emissions from manual stone crushing operations. When compared to  $PM_{10}$ ,  $PM_{2.5}$  (particles with aerodynamic dimensions less than  $2.5 \mu m$ ) has a larger surface area per unit mass, making it easier for  $PM_{2.5}$  to accumulate heavy metals. Due to its longer residence period in the atmosphere and deeper lung penetration than coarser PM,  $PM_{2.5}$  is likewise more dangerous [26].

[8]'s evaluation of a group of 50 stone crushing plants in Pammal, a suburb of Chennai, the capital of Tamil Nadu State in India, found that downwind average  $PM_{2.5}$  and  $PM_{10}$  concentrations ranged from  $73$  to  $388 \mu g/m^3$  and  $110$  to  $1200 \mu g/m^3$ , respectively. For  $PM_{2.5}$  and  $PM_{10}$ , the observed downwind average values ranged from  $8$  to  $70 \mu g/m^3$  and  $17$  to  $143 \mu g/m^3$ , respectively. It is 82.0%-89.0% lower than the levels observed by [8] for  $PM_{2.5}$  and 84.5%-88.1% lower than the levels observed by [8] for  $PM_{10}$ . This is clearly significantly lower than the observed concentrations by [8], which were

mechanically operated cluster of stone crushing units. observed downwind average values ranged from  $8$  to  $70 \mu g/m^3$  and  $17$  to  $143 \mu g/m^3$ , respectively.

The levels of various gaseous pollutants as CO,  $SO_2$ , and  $H_2S$  were detected in-situ using the Multi-gas Altair 5X Detector. The gaseous emissions throughout the selected quarry sites differ greatly, as seen in Figure 4. However, the mean measured concentrations of CO,  $SO_2$ , and  $H_2S$  for the samples are shown in Table 1 as  $0.12 \text{ mg}/m^3$ ,  $0.06 \text{ mg}/m^3$ , and  $0.004 \text{ mg}/m^3$ , respectively. Additionally, Table 1 shows that the observed mean  $SO_2$  level across these sites ranged from 0.00 to  $0.44 \text{ mg}/m^3$  and was  $0.06 \text{ mg}/m^3$  on average. This is 95.4% lower than the NAAQ Standards yet 33.33% higher than the WHO recommendations. In particular, the mean CO level that was found varied from 0.00 to  $0.55 \text{ mg}/m^3$ , which is 99% below the WHO recommendations. According to Figure 3, CO levels were higher at crushing sites along major highways and at sites where heating by wood fuel occasionally for weakening rocks for later breaking. These sites are ABJ B, NSW C, PLA, and PLC. Generally speaking, low CO concentration levels were sampled (typically below WHO and NAAQ guidelines), with the exception of locations along busy highways with heavy traffic. The levels of  $SO_2$  sampled are not significantly high. However, there are signs that prolonged exposure could result in serious occupational risks.

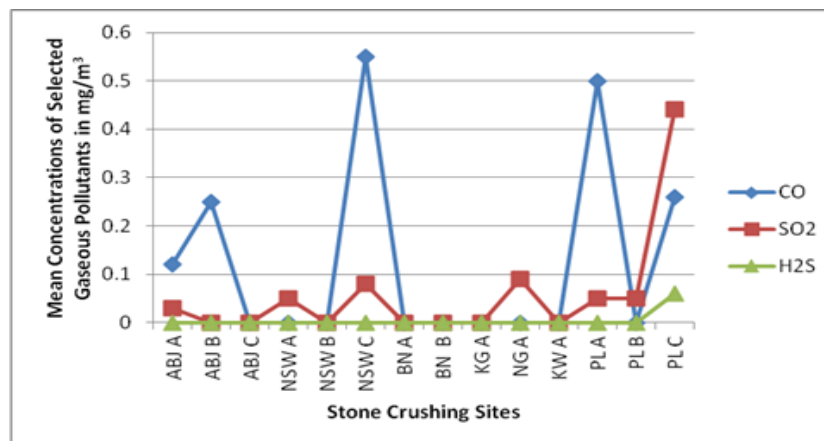


Figure 4. Gaseous emissions from Stone Crushing at the selected sites

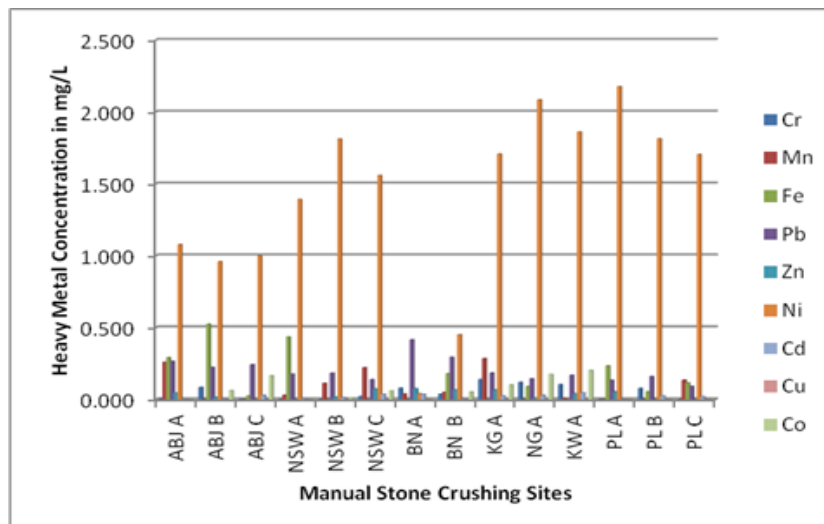


Figure 5. Heavy Metal Concentrations from Stone Crushing at the selected sites

### 3.3. Heavy Metal Assessment

The risk assessment's context plays a significant role in defining the kind of analysis that is most suited in any given circumstance. Due to the requirement to establish the baseline data of emissions from the manual stone crushing activities, site-specific assessments were used in this study. Exposure to metal-containing particles happens almost constantly, in all kinds of microenvironments-even indoors. Table 1 displays the summary information (mean, minimum, and maximum values) for the elemental levels of the selected metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) over the course of the study. Table 1 demonstrates that, with the exception of copper, which was below the detection threshold, the metal-bearing particles have significant quantities of the selected metals. The concentrations of Cr, Mn, Fe, Pb, Zn, Ni, Cd, and Co were 48.0 mg/m<sup>3</sup>, 82.0 mg/m<sup>3</sup>, 140.0 mg/m<sup>3</sup>, 202.0 mg/m<sup>3</sup>, 34.0 mg/m<sup>3</sup>, 1403.0 mg/m<sup>3</sup>, 21.0 mg/m<sup>3</sup>, and 60.0 mg/m<sup>3</sup>, respectively. As seen in Figure 5, both the compositions of the metal-bearing particles and their absolute quantities vary significantly between the measured sites. Nickel, lead, and iron were the metals with the highest amounts of significant emissions, whereas copper had the lowest levels. The compositions of the metal-bearing particles around quarry sites in Nigeria, much less all the places a person may travel, is rarely, if ever, fully described, which makes it difficult to interpret these exposures.

The order of the selected heavy metal sampled and analysed depict Ni as having the highest level (see Figure 5). Fe and Mn, two of the main elements found in the earth's crust, were noteworthy based on their average concentration. In particular, their total made up around 11% of all the trace elements sampled. The yearly EU limits for Pb, Ni, and Cd (500, 20, 6, and 5 ng/m<sup>3</sup>, respectively) were all significantly exceeded by all three metals, which the IARC has designated as group 1 carcinogens in humans. It is important to note that Pb concentrations in all of the samples were many orders of magnitude greater than their limit values. [28] established varied concentrations of heavy metals in the following descending order: Mn > Cr > Cu > Pb > Ni > Cd. However, in this work, concentrations of heavy metals

from manually operated quarry sites in the following descending order: Ni > Pb > Fe > Mn > Co > Cr > Zn > Cd. This provided a better perspective of the impact of these metals.

By comparing these metals' levels to those of Immediate Detrimental to Life and Health (IDLH) values and the Occupational Safety and Health Administration, [29] was able to gain a better understanding of their effects. Figure 6 illustrates that Ni, Pb, Co, and Cd are much higher in this order than the immediate Detrimental to Life and Health (IDLH) values and those of Occupational Safety and Health Administration. To safeguard workers from both acute and chronic exposure scenarios, OSHA defined allowable exposure levels that shouldn't be exceeded during each 8-hour work shift of a 40-hour workweek. According to the metal concentrations observed at the selected crushing locations, manual stone crushers are exposed to unacceptably high quantities of Nickel, Lead, Cobalt, and Cadmium.

The fugitive emissions from stone crushing contain non-volatile metals, which have a significant impact on the health of employees who are frequently exposed to them. Even if metals are not the main contributors to particle mass, small-scale industrial operations like stone crushing can be enormous sources of metals that can be detected in the microenvironments of the quarries and the nearby regions [30,31]. By contrasting the measured values with the occupational/industrial limits established by [29] and shown in Table 1, a better understanding of the degree of occupational hazards caused by extensive exposure to metal-bearing particles by manual stone crushers can be obtained. These metals can be identified by other characteristics, such as water solubility (extended to solubility in biological fluids), particle size distribution, and effects on the environment and human health. The majority of metals released during combustion activities, such as the burning of trash or fossil fuels, occur in tiny particles or the fine fraction, which is frequently represented by particles with a diameter of less than 2.5 µm (PM<sub>2.5</sub>). The larger-sized, coarser particles, on the other hand, are the result of mechanical disruption, such as crushing, grinding, the evaporation of sprays, or the suspension of dust from agricultural and building activities.

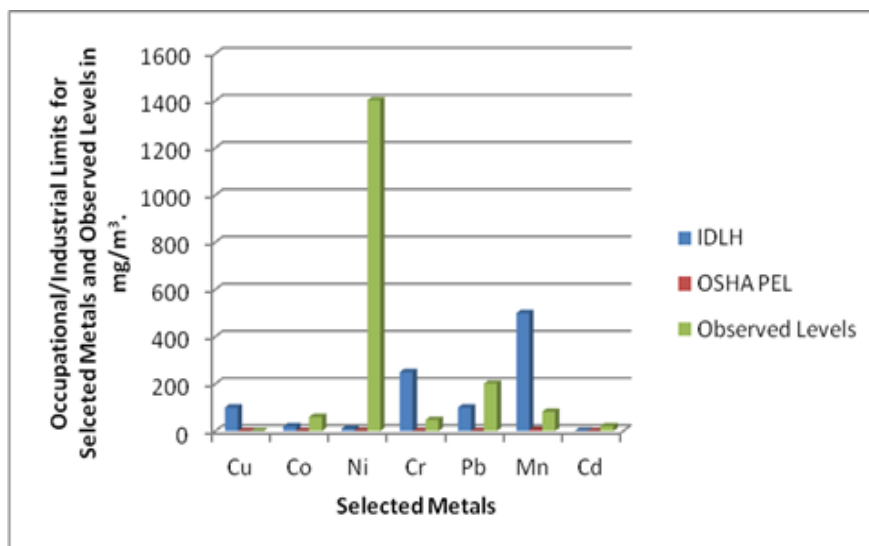


Figure 6. Occupational/Industrial Limits of selected metals and the observed levels

## 4. Conclusion

Different gaseous components (CO, SO<sub>2</sub>, and H<sub>2</sub>S) and particles of sizes 2.5 micron and 10.0 micron (PM<sub>2.5</sub> and PM<sub>10</sub>) were regularly monitored in order to assess outdoor pollution levels as a result of fugitive emissions from manual stone crushing facilities throughout north central Nigeria. In particular, the mean CO levels that was found varied from 0.00 to 0.55 mg/m<sup>3</sup>, which is 99% below the WHO recommendations. According to ABJ B, NSW C, PLA, and PLC, CO levels were greater at crushing facilities near major highways where there were instances of heating rocks with fuel wood to make them more brittle for breaking later. With the exception of locations near congested highways with heavy traffic, low CO concentration levels were often sampled (frequently below WHO and NAAQ guidelines). The observed mean level of SO<sub>2</sub> at these sites ranged from 0.00 to 0.44 mg/m<sup>3</sup>, with a mean value of 0.06 mg/m<sup>3</sup>. This is 95.4% lower than the NAAQ Standards yet 33.33% higher than the WHO recommendations. This demonstrates that even if the mean level of SO<sub>2</sub> is not appreciably high, there are signs that prolonged exposure could result in serious occupational risks. The heavy metal concentrations in manually operated quarry sites were determined in the following order: Ni > Pb > Fe > Mn > Co > Cr > Zn > Cd. The yearly EU limits for Pb, Ni, and Cd (500, 20, 6, and 5 ng/m<sup>3</sup>, respectively) were all significantly exceeded by all three metals, which the IARC has designated as group 1 carcinogens in humans. It is important to note that Pb concentrations in all of the samples were many orders of magnitude greater than their limit values. Even at low quantities, exposure to metals in the microenvironments of the selected quarry sites predisposes the workers to a wide range of adverse consequences on human health, including cancer and damage to important organs.

## Acknowledgements

The research was supported by TETFund National Research Fund (NRF) Code: TETF/DR&D/CE/NRF/STI/36/VOL.1

## Ethical Clearance

Ethical approval was granted by National Health Research Ethics Committee of Nigeria: Approval No. NHREC/01/2007-01/06/2020.

## Conflicts of Interest

Authors declare that they have no conflicts of interest.

## References

- [1] Adar, S.D.; Filigrana, P.A.; Clements, N.; Peel, J.L. Ambient Coarse Particulate Matter and Human Health: A Systematic Review and Meta-Analysis. *Curr. Environ. Health Rep.* 2014, 1, 258-274.
- [2] Bell, M.L.; Ebisu, K.; Peng, R.D.; Walker, J.; Samet, J.M.; Zeger, S.L.; Dominici, F. Seasonal and regional short-term effects of fine particles on hospital admissions in 202 US Counties, 1999–2005. *Am. J. Epidemiol.* 2008, 168, 1301-1310.
- [3] Hänninen, O.; Knol, A.B.; Jantunen, M.; Lim, T.A.; Conrad, A.; Rappolder, M.; Carrer, P.; Fanetti, A.C.; Kim, R.; Buekers, J.; et al. Environmental burden of disease in Europe: Assessing nine risk factors in six countries. *Environ. Health Perspect.* 2014, 122, 439-446.
- [4] Héroux, M.E.; Anderson, H.R.; Atkinson, R.; Brunekreef, B.; Cohen, A.; Forastiere, F.; Hurlley, F.; Katsouyanni, K.; Krewski, D.; Krzyzanowski, M.; et al. Quantifying the Health Impacts of Ambient Air Pollutants: Recommendations of a WHO/Europe Project. *Int. J. Public Health* 2015, 60, 619-627.
- [5] Hoek, G.; Krishnan, R.M.; Beelen, R.; Peters, A.; Ostro, B.; Brunekreef, B.; Kaufman, J.D. Long-term air pollution exposure and cardio-respiratory mortality: A review. *Environ. Health* 2013, 12, 43.
- [6] World Health Organization (WHO). *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*; World Health Organization: Geneva, Switzerland, 2016; 121p, ISBN 978 92 4 151135 1.
- [7] Himanshu M. Padhy, Pranati Mishra, Sadasiba Rout and Babita Kumari. 2020, Dust Pollution in Stone Crusher Units in and Around Khurda, Orissa, India. *Int J Recent Sci Res.* 11(05), pp. 38705-38708.
- [8] Sivacoumar R.; Jayabalou R.; Swarnalatha S.; and Balakrishnan K., (2014). Particulate Matter from Stone Crushing Industry: Size Distribution and Health Effects. *Occupational Safety; Health Hazards: India.* 10:1061/(ASCE)0733-9372(2006)132:3(405).
- [9] Chougule A.C., Chougule P.A., Kumbhoje C.K. (2017). Effect of Stone Crusher on Ambient Air Quality. *International Research Journal of Engineering and Technology (IRJET)*. Volume: 04 Issue: 07.
- [10] Mathur, M.L., and Choudhary R.C. (1996). "Mortality experience of sand stone quarry workers of Jodhpur district." *Lung India*, XIV(2), 66-68.
- [11] Central Pollution Control Board (CPCB). (1998). "National ambient air quality standards. Air (Prevention and Control of Pollution) Act S.O.384(E), New Delhi, India.
- [12] Romanazzi, V.; Casazza, M.; Malandrino, M.; Maurino, V.; Piano, A.; Schilirò, T.G.; Gilli, G. PM10 size distribution of metals and environmental-sanitary risk analysis in the city of Torino. *Chemosphere* 2014, 112, 210–216. [CrossRef] [PubMed].
- [13] Li, H.; Wang, J.; Wang, Q.G.; Qian, X.; Qian, Y.; Yang, M.; Li, F.; Lu, H.; Wang, C. Chemical fractionation of arsenic and heavy metals in fine particle matter and its implications for risk assessment: A case study in Nanjing, China. *Atmos. Environ.* 2015, 103, 339-346.
- [14] Lyu, Y.; Zhang, K.; Chai, F.; Cheng, T.; Yang, Q.; Zheng, Z.; Li, X. Atmospheric size-resolved trace elements in a city affected by non-ferrous metal smelting: Indications of respiratory deposition and health risk. *Environ. Pollut.* 2017, 224, 559-571.
- [15] Pinto, E.; Soares, C.; Couto, C.M.; Almeida, A. Trace Elements in Ambient Air at Porto Metropolitan Area-Checking for Compliance with New European Union (EU) Air Quality Standards. *J. Toxicol. Environ. Health A* 2015, 78, 848-859.
- [16] Samek, L. Overall human mortality and morbidity due to exposure to air pollution. *IJOMEH* 2016, 29, 417-426.
- [17] Singh, D.K.; Gupta, T. Source apportionment and risk assessment of PM1 bound trace metals collected during foggy and non-foggy episodes at a representative site in the Indo-Gangetic plain. *Sci. Total Environ.* 2016, 550, 80-94.
- [18] Niu, L.; Ye, H.; Xu, C.; Yao, Y.; Liu, W. Highly time- and size resolved finger print analysis and risk assessment of airborne elements in a megacity in the Yangtze River Delta, China. *Chemosphere* 2015, 119, 112-121.
- [19] Bello, S.; Muhammad, B.G.; Bature, B. Total Excess Lifetime Cancer Risk Estimation from Enhanced Heavy Metals Concentrations Resulting from Tailings in Katsina Steel Rolling Mill, Nigeria. *J. Mater. Sci. Eng.* 2017, 6, 338.
- [20] Benhaddya, M.L.; Boukhelkhal, A.; Halis, Y.; Hadjel, M. Human health risks associated with metals from urban soil and road dust in an oilfield area of South eastern Algeria. *Arch. Environ. Contam. Toxicol.* 2016, 70, 556-571.
- [21] IARC (2015). *Outdoor Air Pollution: IARC Monographs on the Evaluation of Carcinogenic Risks to humans 2015*; 109: 35-109.
- [22] Yadav, I.C.; Devi, N.L.; Singh, V.K.; Li, J.; Zhang, G. Spatial distribution, source analysis, and health risk assessment of heavy

- metals Contamination in house dust and surfaces oil from four major cities of Nepal. *Chemosphere* 2019, 218, 1100-1113.
- [23] Macleod, W.N., Turner, D.C., and Wright, E.P. (1971): The Geology of Jos-Plateau, Vol.1 General Geology. Geol. Surv. Of Nigeria. Bul1 No 32.
- [24] Turner, M.G. (1989). Landscape Ecology: The Effect of Pattern on Process. *Annual Review of Ecology and Systematics*, 20, 171-197.
- [25] Seinfeld JH, Pandis S (2006). *Atmospheric chemistry and physics*. 2nd ed. Hoboken (NJ): John Wiley.
- [26] World Health Organization (WHO). Health Risks of Particulate Matter from Long-Range Transboundary Air Pollution; WHO Regional Office for Europe, 2006.
- [27] Brauer M, Amann M, Burnett RT, Cohen A, Dentener F, Ezzati M et al. (2012). Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. *Environ Sci Technol*, 46(2): 652-60.
- [28] Tang,R.; Ma, K.; Zhang ,Y .; Mao ,Q. The spatial characteristics and pollution levels of metals in urban street dust of Beijing, China. *Appl. Geochem.* 2013, 35, 88-98.
- [29] Andrea Geiger and John Cooper, Draft APPENDIX C- Overview of Airborne Metals Regulations, Exposure Limits, Health Effects, and Contemporary Research. 2010.
- [30] Schauer JJ, Lough GC, Shafer MM, Christensen WF, Arndt MF, DeMinter JT et al. (2006). Characterization of metals emitted from motor vehicles. *Res Rep Health Eff Inst*, 133(133): 1-76, discussion 77-88.
- [31] Snyder DC, Schauer JJ, Gross DS, Turner JR (2009b). Estimating the contribution of point sources to atmospheric metals using single-particle mass spectrometry. *Atmos Environ*, 43(26): 4033-42.



© The Author(s) 2023. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).