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Research Article

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Assessment of Particulate Matter Concentration and its Elemental Compositions at Building Construction Site, Owerri City, Nigeria

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Abstract This study considered the assessment of particulate matter (PM) from building construction site in Owerri City with geographical location (5° 29' 0" North, 7° 2' 0" East and elevation of 239ft (73meters) above sea level). PM Sample collection method was by direct deposition under gravity. Neutron Activation Analyses (NAA) of the PM sample revealed the presence of twenty one elements which include sodium (Na), aluminium (Al), calcium (Ca), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), rubidium (Rb), zirconium (Zr), caesium (Cs), cerium (Ce), neodymium (Nd), europium (Eu), terbium (Tb), ytterbium (Yb), hafnium (Hf), tantalum (Ta), titanium (Ti) and thorium (Th). The PM annual mean mass concentration of both sampling points (Construction Site and Residential Area) with values 135.2232 $\mu g/m^3$ and 90.4203$\mu g/m^3$ respectively, exceeded the World Health Organization (WHO) annual limits of 10$\mu g/m^3$ for $PM_{2.5}$ and 20 $\mu g/m^3$ for $PM_{10.}$ WHO reports stated that long-term exposure to very high Concentration of PM may lead to a marked reduction in life expectancy due to aggravated cardiopulmonary and lung cancer mortality. Therefore, knowing the health and environmental hazards associated with PM from construction activities is very important to finding comprehensive control and safety measures for construction workers and individuals who are residing some few meters from construction sites.

Keywords Assessment, Particulate Matter, Concentration, Elemental compositions, construction site

1. Introduction

Man's quest to make life comfortable has resulted in his involvement in so many activities; including construction of buildings, roads, dams, and bridges. This has resulted to the release of microscopic particles into the Earth's atmosphere which directly or indirectly affect his health and the environment in which he lives. Construction industry contributes about 4% of particulate emissions, and is responsible for air, water and soil pollution [1].

The size of these tiny particles ranges between 0.001microns and 100microns in diameter, which are capable of being carried from one portion of the city or region to another, depending on the prevailing meteorological conditions of the environment. The characterization of particulate matter is influenced by meteorological conditions-temperature, humidity, rainfall and wind speed [2].

Construction and renovation activities in office settings can greatly expose building occupants to pollution caused by the release of airborne particulates, biological contaminants, and gases (The National Institute for Occupational Safety and Health) [3, 4]. In the month of February, 2017, Rivers state government shut down a Chinese construction company (CGC) for producing thick black smog from their Asphalt plant [5].

Penetration of particulate matter into the lungs is known to be responsible for many health problems such as asthma, bronchitis and cancer. Research finding also indicated increased cases of Harmattan particulate related hospital admissions for both adults and children [6]. It has also been observed that at construction site, diesel from the diesel engine is the major source of PM_{10} and is referred to as diesel particulate matter (DPM), which is composed of soot, sulphates and silicates, all of which readily combine with other toxins in the atmosphere, increasing the health risks of particle inhalation [1]. World Health Organization has said that PM_{10} measurements are the most commonly used indicator of health hazard, fine particles are able to penetrate deep into the lungs and appear to have the greatest health-damaging potential [7]. As a consequence, the $PM_{2.5}$ standards of 24hour average concentrations requirement was strengthened by United States Environmental Protection Agency(USEPA) in 2006 to not exceed 35 µg/m^3, and maintained the current annual average concentration standard at 15 µg/m^3 [7]. On December 14th, 2012, the U.S. Environmental Protection Agency (EPA) reviewed $PM_{2.5}$ annual limits from 15µg/m^3 to 12µg/m^3 to strengthen her air quality for the protection of public health.

Research studies have shown that outdoor air pollution caused 3 million premature deaths yearly around the world and particulate matter was identified as the biggest culprit [8]. Airborne particulates have been categorized as a Group 1 carcinogen by The International Agency for Research on Cancer [9].

More so, health effects of airborne particulate matter have been identified as being depended on several *factors*, including *particle* dimension, durability, dose, and toxicity of the materials in the *particle* (American Society of Heating, Refrigerating and Air-Conditioning Engineers [10].

Settling Velocity of Particulate Matter Due Gravitational Force

In 1851, George Gabriel Stokes derived an expression, now known as **Stokes' law**, for the frictional force – also called drag force – exerted on spherical objects with very small Reynolds numbers in a viscous fluid.

When a particle is released, it settles due to gravity and the velocity increases. As the velocity increases, the drag also increases which counterbalances the gravitational force. Eventually, when these two forces are equal to each other, i.e. the net force is zero, there is no more acceleration and the velocity reaches a constant value. This is called terminal settling velocity. It is given by equation (5).

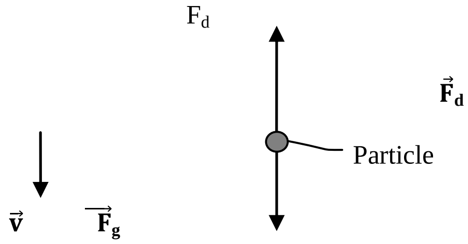
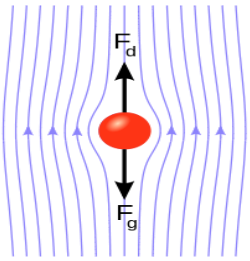


Figure 1

Source: Cotton (2000) [11]



At $t = 0, v = 0, F_d = 0$

$F_d < F_g$,

As v increases, F_d increases

When $F_d = F_g$

$v = v_s$

Where F_d is the upward drag force or friction, F_g is the gravitational force, v is velocity of the particle and v_s is settling velocity

The drag force is given by,

$$F_d = -6\pi\eta rv \quad (1)$$

where η = viscosity of air

r = radius of particle

v = velocity of particle

Gravitational force on the particle is given by,

$$F_g = mg \quad (2)$$

In Stokes' flows, the velocity of the gas in immediate contact with the particle surface is assumed to be the same as the particle velocity. This is termed no-slip condition. Then, for Stokes' flow the force equation becomes,

$$m\frac{d\vec{v}}{dt} = mg - 6\pi\eta rv \quad (3)$$

At settling velocity v_s, we have that

$$\frac{d\vec{v}}{dt} = 0$$

Here, equation (3) becomes

$$6\pi\eta rv = mg$$

$$v_s = \frac{mg}{6\pi\eta rv} \quad (4)$$

If the volume of a spherical particulate matter is $\frac{4}{3}\pi r^3$ and its density is ρ; equation (4) becomes,

$$V_s = \frac{\frac{4}{3}\pi r^3 pg}{6\pi\eta rv}$$

$$v_s = \frac{2r^3 pg}{9\eta} \quad (5)$$

Effects of Particulate Matter Pollution

The effects of particulate matter include:

- Change in the properties of the atmosphere .
- Poor visibility which interferes with aviation
- Climate change due to alteration of solar radiation, wind distribution and temperature
- Formation of fog and precipitation.
- Damage to materials
- Damage to forest or vegetation
- Air pollution causes damage to buildings, monuments, and statues

The Human Lungs and the Size of Particulate Matter

The human lungs are tremendous sponges of blood that act as filters to purify the air we breathe [12]. This filtering process is aided by nasal hairs, nasal turbinates, vocal chords, the cilia of the bronchial epithelium, the sneeze and cough reflexes [12].

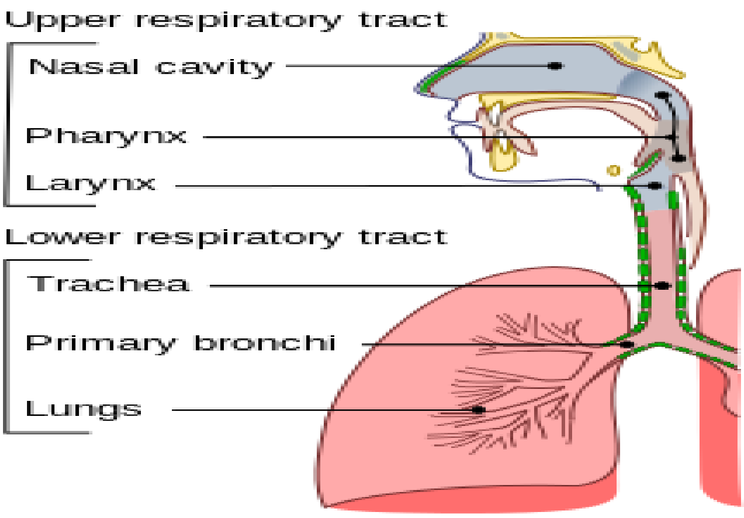


Figure 2: Respiratory Diagram Showing Upper and Lower Respiratory Tracts

Source: Illu conducting passages.sv

Deposition of inhaled particles in the respiratory tract depends on the characteristics of the particle, structure of the airway, and the rate at which the individual breathes [13].

Table 1: Particulate Size and Nasal Regions of Deposition

PM Size	Nasal Regions of deposition
PM > 10 µm	Nasal hair and bends of nasal tract
PM< 10 µm	Wind pipe, tracheobronchial, and pulmonary regions
PM < 2.5 µm	Alveoli

Materials and Methods

The Study Area

Owerri is the capital of Imo state. The geographical coordinates of Owerri city are are $5^{o}\ 29^{'}\ 0^{''}$ North and $7^{o}\ 2^{'}\ 0^{''}$ East; and situated at the hinterland with 239ft (73meters) above sea level.

Sampling Sites

One sampling point was located at a building under construction and another sampling point at a residential building to collect the particulate matter on a monthly basis for a period of 12 months (October, 2017 to September, 2018 month). Orji was the location of the sampling point and is indicated on the map as shown by the red colour in figure 3.

Figure 3: Owerri Satellite map with street view

Source: www.viewphotos.org/nigeria/fat-map-of- Owerri-81-html

Materials

The following materials/Instruments were employed in the measurement of some atmospheric variables (temperature, relative humidity (RH), wind speed and amount of rainfall) and collection of samples of particulate matter (PM). Funnel and Whatman filter paper of 125mm (0.125m).Microprocessor Am-4832 digital anemometer, hygrometer-digital thermometer, rain gauge and digital electronic balance.

Methods

Collection of Samples: The method of particulate matter (PM) sample collection was by direct deposition under gravity using Whatman filter paper placed inside a plastic funnel at a height of 2 meters above the ground. This PM sample was collected on a monthly basis for a period of 12 months. Meteorological variables (wind speed, humidity, temperature and rainfall) were also measured on a daily basis for a period of 12 months.

Elemental Composition Analyses

Elemental components of the samples for each month were analyzed using Neutron Activation Analysis (NAA), **University of Texas, Austin's 1.1 MW TRIGA MARK II Reactor.**

Principles of Neutron Activation Analysis (NAA)

Neutron Activation Analysis (NAA) is one of the most sensitive methods used to measure the concentration of trace amounts of many elements in a variety of sample types and this is made possible for the simple reason that the energy associated with the radiation is characteristic of the radioactive isotope, and hence it is used for element identification i.e., qualitative analysis, while the correlation of the number of gamma rays emitted to the number of atoms present in the sample gives quantitative analysis [14]. Accuracy of Neutron Activation Analysis is within the region of 5% and has relative precision greater 0.1% [15].

Results and Discussion

Table 2 shows PM monthly concentrations and their annual mean for Construction Site and the Residential Area of Owerri City

Table 2: Mass Concentrations of particulate matter samples for Construction site and Residential Area, Owerri City

Month/Year	Construction Site Concentration (μg/m^3)	Residential Area Concentration (μg/m^3)
October, 2017	68.4262	87.97654
November, 2017	127.0772	78.20137
December, 2017	185.7283	107.5269
January, 2018	263.9296	97.75171
February, 2018	146.6276	68.4262
March, 2028	107.5269	68.4262
April, 2018	107.5269	87.97654
May, 2018	146.6276	107.5269
June, 2018	127.0772	107.5269
July, 2018	107.5269	87.97654
August, 2018	136.8524	97.75171
September, 2018	97.75171	87.97654
Annual Mean	135.2232±0.00000917	90.4203±0.0000375

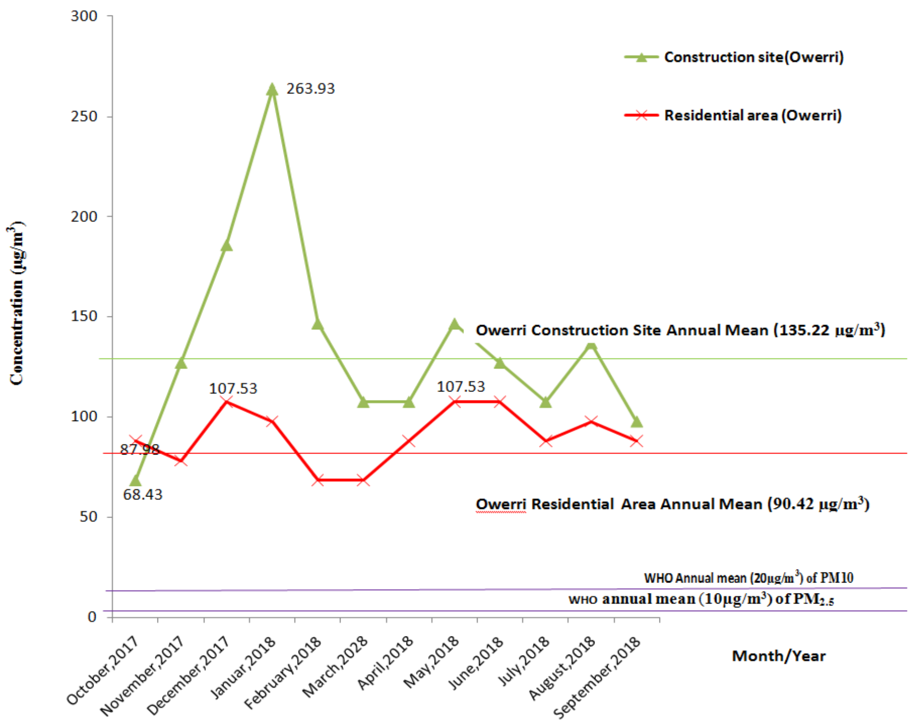


Figure 4: Graph of PM mass concentration for Construction Site and Residential Area

The above figure 4 represents particulate matter concentration of a Construction Site and Residential Area of Owerri City. Comparing the PM concentration of the Construction Site with that of Residential Area, the monthly PM mass concentration of Construction Site is higher than that of the Residential Area, except the month of October, 2017 where the mass concentration of Construction Site and Residential Area are 68.4262μg/m^3 and 87.97654 μg/m^3 respectively. These points are shown clearly with Green and Red colour curves in figure 4. More so, the annual mean mass concentration of the Construction Site is higher than that of the Residential Area with the values 135.2232 μg/m^3 and 90.4203μg/m^3 respectively. These values are shown with two Green and Red horizontal lines while that of the two purple horizontal lines down the graph represent WHO established annual limits for $PM_{2.5}$ and PM_{10}. The PM annual mean mass concentration of both sampling points (Construction Site and Residential Area) exceeded the World Health Organization (WHO) annual limits of 10 μg/m^3 for $PM_{2.5}$ and 20 μg/m^3 for PM_{10}; European Commission (EC) of 25 μg/m^3 for $PM_{\mathbf{2.5}}$ and 40 μg/m^3 for $Pm_{\mathbf{10}}$; and United States Environmental Protection Agency (USEPA) of 12 μg/m^3 for $PM_{\mathbf{2.5}}$ respectively.

Elemental Components of the Particulate Mater

The Neutron Activation Analyses of the PM samples revealed the presence of twenty one elements which include sodium (Na), aluminium (Al), calcium (Ca), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), rubidium (Rb), zirconium (Zr), caesium (Cs), cerium (Ce), neodymium (Nd), europium (Eu), terbium (Tb), ytterbium (Yb), hafnium (Hf), tantalum (Ta), titanium (Ti) and thorium (Th).

Health Implication of Result

The implication is that, these PM concentrations have reached their deleterious levels.

Conclusion

The PM annual mean mass concentration of both sampling points (Construction Site and Residential Area) with values 135.2232 μg/m^3 and 90.4203μg/m^3 respectively, exceeded the World Health Organization (WHO) annual limits of 10μg/m^3 for $PM_{2.5}$ and 20 μg/m^3 for $PM_{10.}$ WHO reports stated that long-term exposure to very high Concentration of PM may lead to a marked reduction in life expectancy due to aggravated cardiopulmonary and lung cancer mortality. All the aforementioned elements in the PM sample, as revealed by NAA analyses, none of them exist without posing any mild or severe health and environmental problems. For instance, research studies have shown a link between aluminium(Al) accumulation in the brain and Alzheimer's disease (a degenerative disorder of the brain that leads to dementia), and Parkinson disease (a gradual nervous disorder characterized by symptoms of trembling hands, lifeless face, monotone voice, and a slow shuffling walk). Inhalation of calcium and their compounds are known for causing, cough and sneezing; pain and swelling of the throat and degeneration of chronic bronchitis Therefore, knowing the health and environmental hazards associated with construction activities is very important to finding comprehensive control and safety measures for construction workers and individuals who are residing some few meters from construction sites.

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