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Assessment of Suspended Particulate Matter (SPM) and Toxicity Potential (TP) of Emissions from Different Power Generating Sets in Ado-Ekiti, Nigeria

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Abstract: *This research investigated the levels of Suspended Particulate Matter (SPM) resulting from the emissions of various power generators in Nigeria. Additionally, the study conducted risk assessments concerning the inhalation of this pollutant from different power generators, and proposed suitable measures to control the emission of SPM linked to the use of power generators. To capture the exhaust from each generator set, a sampling technique was employed. This involved using a sample probe, a filter, and a filter holder to trap the gas emissions in a sequential manner. The concentration of SPM in the air was calculated based on several factors, including the weight difference of the filter paper before and after sampling, the sampling duration, and the flow rate. The concentration of suspended particulate matter for the 16 different generating sets varied from 1413.4 µg/m^3 to 5300 µg/m^3, with an average concentration of 2912.98 µg/m^3. These values surpassed both the World Health Organization (WHO) standard of 50 µg/m^3 and the Nigeria Ambient Air Quality Standard of 250 µg/m^3. The study's findings indicate that power generating sets emit Suspended Particulate Matter (SPM) through their gas exhaust. Moreover, the results demonstrate that the generator samples lacking a galvanized mesh at the gas stream exhaust exhibit significantly higher toxicity potential compared to those with the galvanized mesh. This research established that SPM concentrations were found from the exhaust of different power generating sets.*

Keywords: *Ambient air quality standard, power generating set, SPM, toxicity potential, WHO.*

1. INTRODUCTION

It is widely acknowledged that the economic growth of any nation relies heavily on the availability of electricity. In the modern world, nearly all daily activities depend on electricity. However, it is a well-known problem that the Nigerian power sector operates well below its optimal capacity, resulting in frequent power outages [9]. As a result of the unstable power supply, Nigerians have turned to alternative sources of electricity, such as electric power generators, to fulfill their daily power requirements. When these generators are set on, especially at various locations such as homes, offices and business areas emit pollutants to the environment via the gas exhaust [8]. Maintaining ambient air quality at appropriate levels is one of the greatest challenges facing society today. There are many Maintaining ambient air quality at appropriate levels is one of the greatest challenges facing society today. There are many sources that discharge large amounts of polluting compounds into the atmosphere. Most of the sources are anthropogenic. Natural sources of pollutants may include desert, local sand carried by the wind; sea salt aerosols volcanoes and wild land fires [3] .Other than gaseous compounds, one of the most important pollutants produced by human activities is particulate matter (PM) [1, 2].

In contrast, the emissions from generator exhaust contribute to the overall levels of SPM in the surrounding environment [2] and evaluating the concentration of SPM in the Nigerian environment is essential for assessing the risks involved and predicting appropriate management practices [13]. Given the large demand for electricity in the country, which comes primarily from the manufacturing and suburban sectors, and the unstable, insufficient, and unreachable nature of the national grid supply, there is undoubtedly a strong will to own and operate generators in the country. Nigeria is currently the top importer of generators in Africa and one of the top importers globally, with an annual import cost of US$ 112 million (₦40.3 billion) [8]. Emissions from the exhaust of the generators contribute to the ambient amounts of pollutants polycyclic aromatic hydrocarbon (PAHs) and suspended particulate matter (SPM) [3] and characterization of their concentration in Nigeria environment is significant in order to assess its risks and estimate appropriate management practices [8]. Emission exhaust from generators usage (gasoline and diesel) has also subsidised to increasing levels of chemicals such as particulate matter $PM_{2.5}$ and PM_{10} ($PM_{2.5}$ those fewer than 2.5 µm, PM_{10} comprises particles less than 10 µm in diameter) [13].

PM is a compounded combination of suspended liquid and solid particles categorized into main (particles released directly from source) and subordinate (particles produced through atmospheric reactions with gases) particles. SPMs are launched into the air from a diversity of usual and human caused sources, though the later are common in the municipal and manufacturing areas [2]. Usual sources such as, fine powder, largely subsidises particle matter (vaporisers) of magnitudes >10 µm in measurement, whereas the human caused sources subsidise < 10 µm (categorized lower than PM_{10}) sized particulate matters. Fine particles consist of PM with diameter between 0.1 and 2.5 µm. They justify for the common form of the suspended particles, deposit slowly and leading to a long atmospheric lifecycle of 5-10 days. These particles may infiltrate hollow restricted the air route which may be linked with vulnerable health effects [12].

Therefore, perception of the structure of particulate matter is critical mostly to study that assess healthiness hazard issues. Airborne particulate in relation to suggestion of metallic element having connection with severe opposing well-being effects, including lung diseases, lung tumour, heart viruses, and harm to other body part. Humanity and disease associated with air contamination are mainly due to lethal effects of particulate [4]. PM exposure comes along with diversity of both over time and immediate health implication. Health issues have been linked to PM exposures. Chronic bronchitis, impaired lung function, and even preterm death have all been linked to over time exposures, such as those experienced by those who have lived in high-particle areas for a long time. Momentary openings to particles (hours or days) can transcendently result to lung illness, causing asthma assaults and intense bronchitis, and may likewise prompt respiratory contaminations. Short-term exposures have been linked to heart attacks in heart disease patients [3].

Short-term exposures have not been linked to serious adverse effects in healthy adults or children, though elevated particle levels may temporarily cause minor irritation. When particulate conditions are poor, a person may experience brief symptoms such as irritation of the eyes, nose, and throat, coughing, phlegm, chest tightness, and shortness of breath. During times of high particulate matter pollution, a person with lung disease may not be able to breathe as deeply or as easily as they would normally. They may also experience coughing, chest pain, wheezing, shortness of breath, and unusual fatigue [5]. Particulate matter entering into the body may damage the immune system and reduce the immune capacity of the body through the innate immune system (mucosal system, humoral molecules and innate immune cells) and adaptive immune system (including humoral immunity and cell immunity, cytokines), leading to increased risk of a range of diseases. Some studies found that long-term exposure to particulate matter could do great harm to immune system [31], but few studies evaluated the short-term exposure to particulate matter on immune system.

Currently, the possible mechanisms of particulate matter on immune toxicity include oxidative damage mechanism, apoptosis mechanism and calcium homeostasis disequilibrium mechanism [19]. Although the research on immune toxicity of particles has made some progress, given the diversity of the source and chemical composition of particulate matter and complexity of immune system, the understanding of the mechanism of the immune toxicity of the particulate matter on human beings remains unclear. Since the immune system is widely distributed throughout the body, particles may destroy homeostasis of the immune system and cause immunosuppression or autoimmune diseases. And the effects of particulate matter on various human systems are closely related to its immune toxicity [20]. So in the future, to strengthen the exploration of the immune toxicity of particles in a deeper, more comprehensive way will be helpful to understand the biological mechanism of particles in human body and its effects on human physiological function, so as to provide scientific basis for health hazard assessment of particulate matter [21].

PM is an important constituent of the atmosphere. The sources of PM can be natural or man-made sources. There are a number of natural sources that inject millions of tons of PM into the atmosphere. They include volcanic eruption, wind and dust storms, forest fire, salt spray, rock debris, reactions between gaseous emissions, and soil erosion. Man-made activities such as fuel combustion, industrial processes, steel industry, petroleum foundries, cement, glass manufacturing industry, smelting and mining operations, fly-ash emissions from power plant, burning of coal, and agricultural refuse also contribute to PM in the atmosphere [22]. PM causes severe physical damage to plants by blocking stomata and its damaging effects are owing to its small diameter and complex composition [14]. PM can cause severe damage to plant growth by direct deposition on the aerial parts and consequent penetration into the plants. Besides, PM can also affect green plants indirectly via soil-root interaction [15]. PM contain trace metals (such as Pb, Cr, and Cd), its deposition on plants significantly contributes to the accumulation of the trace metals in the plants [16]. These trace metals present in the PM contribute to the characteristic toxicity of the PM and it has been reported that PM causes significant damage for plant nitrogen metabolism [17]. PM blocks the stomata pores which result in altered gaseous exchanges, consequently disturbing the plant physiology [18]. Particulate matter is responsible for reduction in visibility. Visibility is principally affected by fine particles that are formed in the atmosphere from gas-phase reactions. Although these particles are not directly visible, carbon dioxide, water vapour, and ozone in increased concentrations change the absorption and transmission characteristics of the atmosphere [28]. Particulate matter can cause damage to materials depending upon its chemical composition and physical state [28]. Particles will soil painted surfaces, clothing, and curtains merely by settling on them. Particulate matter can cause corrosive damage to metals either by intrinsic corrosiveness or by the action of corrosive chemicals absorbed or adsorbed by inert particles. Little is known of the effects of particulate matter in general on vegetation [28]. The combination of particulate matter and other pollutants such as sulphur dioxide may affect plant growth. Coarse particles, such as dust, may be deposited directly onto leaf surfaces and reduce gas exchange, increase leaf surface temperature, and decrease photosynthesis. Toxic particles containing elements such as arsenic or fluorine can fall onto agricultural soils or plants that are ingested by animals and thus can affect the animal's health.

Hence, it is vital, particularly in research focused on assessing health risk factors, to gain a comprehensive understanding of the composition of particulate matter. Particulate matter (PM) is an intrinsic complex combination of suspended solid and liquid particles classified into primary (particles emitted directly from source) and secondary (particles formed through atmospheric reactions with gases) particles [6]. Total Suspended Particles (TSPs) are introduced into the atmosphere from a range of sources, including both natural and human activities (anthropogenic). However, anthropogenic sources are more prevalent in urban and industrial areas [8]. Therefore, the aim of this research work is to assess the potential toxicity present in different power generating set in Nigeria.

2. METHODOLOGY

2.1 Description of Study Area

Ado-Ekiti, located in the southwestern region of Nigeria, serves as the state capital of Ekiti State. This area experiences frequent power supply disruptions, leading to an unstable electricity network. Consequently, power generators are continuously utilized within the city on a daily basis to compensate for the lack of stable power supply. The generators utilized for this study were specifically selected from various locations in Ado-Ekiti, Ekiti State, Nigeria (Figure 1). These locations include Omisanjana Area, Adere Abekoko, and Erifun Poly Road. The diverse generator samples were transported from their respective locations to Afe Babalola University in Ado-Ekiti, where sampling techniques were employed using an active sampler.

Figure 1: Map of Ekiti State showing Ado-Ekiti

Figure 2: Air sampler set up

2.2 Materials for Sampling

The sampling materials are composed of a metallic rod of length 2 m (probe), a filter holder, Whatman filter papers (25 mm), a calibrated personal sampling pump and source of electricity. Sixteen distinct gasoline generator brands were acquired from various households in Ado-Ekiti, Ekiti State, Nigeria. Among these sixteen generators, seven were equipped with galvanized mesh (stainless steel wire to reduce particulate matter emitted by the gasoline engines) housed at the gas exhaust outlet, while the remaining nine did not have such mesh installed. The sixteen generators were sampled for suspended particulate matter.

2.3 Weighing of Filter Papers

Filter papers were equilibrated in a desiccator for 24 hours and weighed before and after sampling using a weighing balance (AE200). To ensure accuracy and consistency, each filter was weighed three times to obtain a stable weight, which was then recorded. The filters were carefully stored in a filter protective. To prevent contamination, all filter handling was conducted using vinyl gloves. This precautionary measure ensured that the filters remained free from any external contaminants during the handling process.

2.4 Air Sampling Procedures for Suspended Particulate Matter

The initial weight of the filter papers was measured and documented. A 25 mm diameter Whatman filter paper was inserted into the filter holder, which was then connected to the probe. The probe, connected to the sampling pump, was positioned at the gas exit of the generator. The generator was turned on for two minutes before sampling commenced. The power factor and frequency of the generators are 1.0 and 50 Hz respectively and the maximum output ranged from 2.5 kW to 3.5 Kw with the existing temperature of 300°C . The air flow rate was 0.0566 m^3/min. The sampling pump was activated to capture and collect the particulate matter on the filter paper. The sampling duration for each sample was set at five minutes. After the sampling duration elapsed, the filter paper was carefully removed from the filter holder and stored in a polyethylene bag. The final weight determinations of the filter papers were conducted using this procedure for all sixteen different generator brands.

The concentration of the particulate matter in the air sampled was determined from the difference in weight of the filter paper after and before sampling [10], the duration of sampling and the flow rate was carried out using Equation 1. The flow rate was determined using 2 cfm sampling pump which is equivalent to 0.0566 m^3/min.

$$\frac{([final\ weight\ (W_f) - initial\ weight\ (W_i)] \times 10^6)}{\text{Volume(V)}} \quad (1)$$

W_f = weight of filter paper after sampling in grams
W_i= weight of filter paper before sampling grams
Volume = flow rate (m^3/min) × sampling period (min)
10^6 = conversion from grams to microgram

2.5 Instruments for Measuring Particulate Matter

There are several instruments for measuring different characteristics of particulate matter. The most important measurements of particles are particle concentration and particle size. In concentration methods, the PM concentration can be in mass (m), number (N) and surface area (S). These instruments are based on different measuring principles, and can be gravimetric, optical, microbalance and electrical charge.

2.5.1 Gravimetric method

In the gravimetric method, the particle mass concentration is determined by weighing the filters before and after the sampling period. Nussbaumer et al. [23] mentioned that the basic method to measure off-line PM mass concentrations, in combustion gases, is the gravimetric sampling in filters. Giechaskiel et al. [26] described that the filter collects PM in all granulometric fractions (nucleation, accumulation, and coarse modes), unless there is a cyclone or impactor to remove larger particles. Nussbaumer et al. [23] cited the use of a set with pre-cyclones, which cut-off is of 10 µm or 2.5 µm, with an option to determine mass concentration.

Particle sampling in filters results in a resolution time of 15 min or more, therefore the identification of fast processes is not possible. However, particles collected in the filter can be analysed chemically as affirmed by Nussbaumer et al. [23]. Determination of PM mass can be altered depending on the conditions of the filter. For this reason, Nussbaumer et al. [23] and Giechaskiel et al. [26] emphasized that the filters are typically packed under controlled conditions of temperature and relative humidity.

The gravimetric method is based on filters and Cascade Impactors. It can collect particles and evaluate their concentration. For more detailed analysis, other techniques are necessary, such as Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). Among the gravimetric instruments for measuring PM mass, [24] mentioned the Cascade Impactor. According to these authors such equipment are most used in the investigation of particle size distribution in mass. Cascade Impactors are frequently used as components of the systems that involve Size Distribution Methods.

3. RESULTS AND DISCUSSIONS

The initial weights of the filters were measured and recorded, and similarly, the final weights of the filters were measured and recorded, as presented in Table 1. Across all the generator brands, an average mean concentration of 2912.98 μg/m^3 was detected, surpassing the World Health Organization (WHO) standard of 50 μg/m^3 [4] and the Nigeria Ambient Air Quality Standard of 250 μg/m^3 [7].

Table1. Suspended particulate matter concentration

Samples	Final weight (g)	Initial weight (g)	Diff	10^6	Diff*10^6	Volume (m^3)	Concentration (μg/m^3)
GEN A	0.0465	0.0458	0.0007	1000000	700	0.283	2473.49
GEN B	0.0436	0.0432	0.0004	1000000	400	0.283	1413.42
GEN C	0.0459	0.0447	0.0012	1000000	1200	0.283	4240.28
GEN D	0.0462	0.0458	0.0004	1000000	400	0.283	1413.42
GEN E	0.0445	0.0430	0.0015	1000000	1500	0.283	5300.35
GEN F	0.0410	0.0404	0.0006	1000000	600	0.283	2120.14
GEN G	0.0429	0.0420	0.0009	1000000	900	0.283	3180.21
GEN H	0.0476	0.0460	0.0016	1000000	1600	0.283	5653.71
GEN I	0.0440	0.0437	0.0003	1000000	300	0.283	1060.07
GEN J	0.0453	0.0449	0.0004	1000000	400	0.283	1413.42
GEN K	0.0441	0.0435	0.0006	1000000	600	0.283	2120.14
GEN L	0.0465	0.0461	0.0004	1000000	400	0.283	1413.42
GEN M	0.0449	0.0438	0.0011	1000000	1100	0.283	3886.92
GEN N	0.0467	0.0452	0.0015	1000000	1500	0.283	5300.35
GEN O	0.0440	0.0431	0.0009	1000000	900	0.283	3180.21
GEN P	0.0457	0.0451	0.0006	1000000	690	0.283	2438.16
						mean average	2912.98

Key: GEN A --------- P represent different brands of generator used.

Due to regular exposure to suspended particulate matter (SPM) emitted from power generating set exhaust, there is a potential impact on human health [1]. To assess this impact, Toxicity Potentials (TP) were calculated using Equation 2.

$$TP = \frac{\textit{The mas concentration of the total suspended particulate}}{\textit{The statutory limit suits for ambient particulate matter concentration}(\frac{250ug}{m^3})} \quad (2)$$

The findings were reported in Table 2, which displayed the Toxicity Potentials (TP). The TP values ranged from 4.2 to 22.6, surpassing the acceptable limit (1). Furthermore, it was observed that the generators equipped with a galvanized mesh ranged from 4.2 to 9.9 as shown in Table 2 have the lowest TP values compared to the generators without such a mesh ranged from 15.5 to 22.6 which have the highest TP values. The toxicity potential of SPM from power generating station in Yenogoa fall within the range of 2.64 to 6.50 [3]. The health implication of this includes: vomiting, eye and skin irritation, swelling [5].

Table 2: Toxicity potential of the 16 different power generating sets

Samples	Concentration (μg/m^3)	Statutory limit suits (μg/m^3)	TP
GEN A	2473.49	250	9.9
GEN B	1413.43	250	5.7
GEN C	4240.28	250	16.9
GEN D	1413.43	250	5.7
GEN E	5300.35	250	21.2
GEN F	2120.14	250	8.5
GEN G	3180.21	250	12.7
GEN H	5653.71	250	22.6
GEN I	1060.07	250	4.2
GEN J	1413.43	250	5.7

Samples	Concentration (μg/m^3)	Statutory limit suits (μg/m^3)	TP
GEN K	2120.14	250	8.5
GEN L	1413.43	250	5.7
GEN M	3886.93	250	15.5
GEN N	5300.35	250	21.2
GEN O	3180.21	250	12.7
GEN P	2438.16	250	9.8

4. CONCLUSION

The toxicity potential of SPM calculated for all 16 different generating sets ranged between 4-23 which exceed a unitary permissible limit by WHO and USEPA. The average mean concentration of SPM which is 2912.9 μg/m^3 of all 16 different generating sets exceed WHO and the Nigeria Ambient Air Quality Standard of 50 μgm^3 and 250 μg/m^3 respectively. The presence of galvanized mesh in some generator sets show a lower value in term of potential risk compare to non-galvanized mesh at gas exhaust.

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