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# Determination of PM 10 and PM2.5 Concentration in Ambient Air Samples in Nairobi City, Kenya (2016)

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**Abstract:** ***The greatest threat to human health and welfare in urban environments is air pollution; the population growth in Nairobi has continuously contributed to adverse implication on the transport system and traffic congestion. The increase in population has been one of the key contributing factors to air pollution challenges among others which include; increased vehicle ownership, lack of proper traffic control and management, lack of good road planning and inefficient spatial distribution of land use. The fact is that air pollution has not been given any attention despite being the single most environmental world disaster due to lack of data hence no adequate policies governing the air quality in Kenya. Particulate matter (viz., PM2.5 and PM10) has become one of the principal pollutants, according to recent news on health issues, air pollution related diseases have become a disaster worldwide. Recently, there have been increased cases of the air pollution-related diseases in Kenya. Therefore, this study has determined the concentration and likely health effects of particulate air pollutants. The PM10 and PM2.5 are at high concentrations (repirable particulate matter) above the permissible levels by EPA and EMCA. The main causal factors of PM2.5 and PM10 are untreated industrial emissions, geochemical processes and vehicular emissions. The concentration of PM10 and PM2.5 was established during morning and evenings for three days in a week during the study period. Sampling sites selected were categorized as industrial, controlled (CBD) and residential areas. Minivol air samplers were used for sample collection particulate matter. High concentrations were recorded during the day due to many activities during the day while low concentrations at night. Low concentrations at the weekends were observed compared to week days. The Minivol portable air sampler is an ambient air sampler for particulate matter. The concentrations of respirable particulate matter is above the permissible limits. (EMCA and EPA) while the composition of the particulate lead and aluminum is very high.***

**Keywords:** Respirable particulate matter (RPM), PM10 and PM2.5, Permissible levels

**List of Acronyms and Abbreviations**

| | |
|---|---|
| TEOM | Tapered elemental oscillating Micro-balance |
| ICP-MS | inductively coupled plasma-mass spectrometry |
| ICP-OES | inductive coupled plasma-optical electron spectrometry |
| SEM | Scanning electron microscopy |
| EDS | Energy Dispersion Spectrometry |
| OC | organic carbon |
| EC | Elemental Carbon |
| VOCS | Volatile Organic Compounds |
| NOX | Nitrogen oxides |
| SOX | Sulphur oxides |
| PM | Particulate matter |
| FDMS | Filter Dynamic Measuring System |
| LA-ICP-MS | Laser ablation inductively coupled plasmas mass spectrometer |
| HVS | High Volume Sampler |
| XRF | X-ray florescence |

## 1. Introduction

Air and noise pollution are two undesirable impacts of vehicular traffic, and these are especially important in the urban area. This is a serious health hazard because of the high prevalence of air pollution associated diseases like cancer, asthma, eye problems and respiratory health problems in an urban environment especially in young and elderly. One major cause of the increasing air pollution problem is increased a number of personal vehicles and matatus (privately owned public transportation buses) that are overcrowding the city by creating an environmentally unfriendly and unsafe public transportation option for Nairobi's growing population. High levels of particulate matter have adverse effects on human, including mortality and morbidity caused by altered cardiovascular and respiratory function which is alarming in Kenya today. Most African countries lack air quality regulation. Kenya has recently adapted air quality regulation (2014). The new air quality regulation has got some gaps which require improvement hence this research provides data which can be

used for improvement of the new air quality regulation in the country.

Generally, all type of environmental degradation like water pollution, noise pollution, in Kenya has been given a lot of attention. However, little or nothing has been done regarding air quality. Generally, air quality data and regulations governing air quality are missing in Kenya. This research will provide data which will be used in improving or developing air quality standards, land use and transportation policies. It will also be used to evaluate the existing air quality regulation 2014. This study will contribute data pool in the development of air quality standards of the urban environment in Kenya. It will enable development of an air pollution level map for Nairobi city. The findings of PM10 and PM2.5 concentration and risks posed to public health by particulate air pollutants will be documented. From the new air quality regulations, it will be convenient to determine or to measure its effectiveness and sufficiency from the findings. Finally, the findings of the research will enable the determination of concentration and composition of the ambient air, and one will be able to prospect the impacts on the environment and human health.

## 2. Literature Survey

Particulates are finely divided solids and liquids. The major sources of particulate can be natural or anthropogenic. Particulate matter (PM) can cause a variety of environmental problems, and can also have a significant impact on human health (Zanobetti et al., 2000). A recent report by Brook et al. such events usually lead to increased case of hospitalisation due of coronary artery disease, stroke and other atherosclerotic diseases. In Kenya, major sources of particulate matter can be described to be from transportation, stationary fuel combustion, industrial processes, agriculture and waste. Often, more consideration is given to the organic components of the particulate matter, but inorganic compounds may also be significant from a health point of view, with a paper by Baulig et al., (2004) indicating that copper (and possibly iron) were significant contributors to the oxidative stress caused by fine particulate matter (Baulig et al., 2004; Limbach et al., 2005). One of the key tools selected for detailed investigation of the airborne PM samples is, (2004) showed that the current PM concentration is sufficient to cause an increased risk for cardiovascular events.

Scanning using X-rays energy dispersed analysis for electron microscopy (SEM/EDS) has already proven to provide information on the morphology, phase and elemental composition of individual particles (Paoletti et al., 2002; Laskin et al., 2006). The elemental composition of the samples can be analysed using laser ablation inductively coupled plasmas mass spectrometer (LA-ICP-MS for in-situ analysis of solid samples). The LA-ICP-MS is able to detect very low elemental concentrations (trace elements) while only requiring minute amounts of the sample. Quantification and characterization of particles are crucial in assessing their impact on the environment and human health. PM10 and pm2.5 is a mixture of various chemical substances and a wide range of particle size distribution resulting from physical and chemical processes that make pm 2.5 and pm10 a difficult to model. Most particles are emitted directly from various industries into the atmosphere while others are formed through different reactions in the air.

Different sources have been found to contribute to pm10 and pm2.5 concentration in the air including meteorological conditions. High volume samplers and a quartz fibre filter are used to collect large particles, e.g., pm 10 PM10 particles. The particle size distribution and their chemical constituents are not considered in the set air quality standards although these properties are significant regarding control strategies and of the health risks associated with PM10.

The fine particles such as pm2.5 are brought by into the atmosphere through the combustion of products as well as the formation of products in the atmosphere from gaseous pollutants as a result of secondary atmospheric chemical reactions. This particle poses a more great health risk than the larger particles since they can easily pass through into the lungs together with harmful chemicals in them that can cause different disease ailments. Apart from the health impacts associated, this particle has a tendency to persist in the air for extended periods resulting in reduced visibility.

In Kenya there no environmental management and coordination Act for Air quality Standards, no policy with regulation on air quality levels, Environmental Management Co-ordination Act (draft air quality, 2008). The general objective of this study is to determine the concentration and composition of PM10 and PM2.5of ambient air in Nairobi city.

## 3. Methodology

Minivol portable air sampler was used in sampling of particulate matter from the selected sites in the Nairobi County. The instrument consists of $PM_{10}$ and $PM_{2.5}$ sampling inlet. The $PM_{10}$ and $PM_{2.5}$ masses on the filter were determined gravimetrically. The filters were conditioned at $20^0$C and 50% relative humidity prior to weighing.

The PM samples collected were subjected to chemical analysis for subsequent determination of chemical composition of the PM. Particles containing the analytes of heavy metals were sampled by drawing known volume of ambient air through filter and then dissolved in $HNO_3$ and $H_2O_2$ by a microwave digester. Inductive coupled plasma-mass spectrometry (ICP-MS) was used to analyze metal content in the sample. The measurement were taken on Sunday, Monday, and Tuesday while others on Friday, Saturday and Sunday twice per selected site in different weather conditions. Before being placed in the sampler, filters were pre-weighed on a high-precision scale in the laboratory to determine the weight of the filter without any dust deposit. The filter was then installed in the sampler. Ambient air was drawn in through the sampler head and filter media by a pump, similar to a vacuum cleaner motor so that airborne particulates were trapped on the filter. After sampling, the filter was returned to the laboratory and

weighed again to determine how much dust was deposited on it. The difference between the two weights divided by the volume of air is the measurement that is used to determine 24-hour concentrations of $PM_{2.5}$ and PM10. Pre-weighed filters were set up for sampling in an office environment. The site operator carefully removed filters from their storage container and placed them in the filter cassette. The filter ID number and date were logged on the data sheets and the filters were covered for transport to the field. In the field the operator checked and recorded the sampler flow rate and elapsed time to complete the data record for the filter that was previously sampled before exchanging the old (now dirty) filter with the new filter. Once the new filter was mounted onto the instrument, the elapsed timer was set to zero and the flow rate re-checked and logged on the log sheets. Exposed filters were taken back to the office where they were stored. Exposed filters were then sent to SGS Kenya laboratory for post sampling weighing and analysis of heavy metals. This process normally took 1-2 days in the mail, and 3-5 days in the lab. This sampling method is not intended to provide data for protecting the public on a daily basis, but rather to document dust problems. The PM samples collected were subjected to analysis for Manganese, Lead, Arsenic, Calcium, Iron Aluminium, chromium, Cadnium and Mercury to determination their concentration during the morning hours and night for both weekends and week days. ICP-OES was used to analyze metal content in the samples.
The filter was weighed before and after use to determine the net weight (mass) gain while the total air volume sampled was determined from the flow rate and the sampling time corrected to EPA standard conditions (25EC and 760NM Hg).The concentration of total particulate matter collected was calculated from the mass of the particles collected divided by the volume of the air sampled. The room conditions were 25EC ± 10EC and relative humidity 50%± 5%.

The filters with the sample were taken back to laboratory and received in manila folders with clearly printed labels. All the filters were weighed and the results recorded on filter weighing form. Note that the weighing was repeated to ascertain the results. The particulate matter concentration was calculated using equation (3.2).

$$PMC = \frac{(W_f \ \& \ W_i \ x \ 10^6)}{V_{std}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

The spatial and temporal heterogeneity in chemical composition of the particle was demonstrated by samples collected day-to-day variation. Different times of the day gave the temporal pattern of the chemical composition of the particles. The measurements from different sites of the county were used to develop the database. The measurements were done in three selected sections of the county each with two monitoring stations totaling to four data set for each monitoring station. The key focus of the study was the spatial and temporal distribution of pm chemical composition. Daily and seasonal concentration of each component for each monitoring station were calculated. Seasons were defined within the three months of data collection. The amount of dust in Nairobi County was measured to determine the levels and concentrations in terms of heavy metals. The monitoring was also used to determine the need to apply palliatives or dust suppressants, which are chemicals that are applied to the road surface to reduce fugitive dust.

## 4. Results and Discussion

### Residential Areas

The PM10 and PM2.5 concentrations were recorded for residential area during the three day monitoring, as follows in figures below in comparison with the EMCA and EPA guidelines.

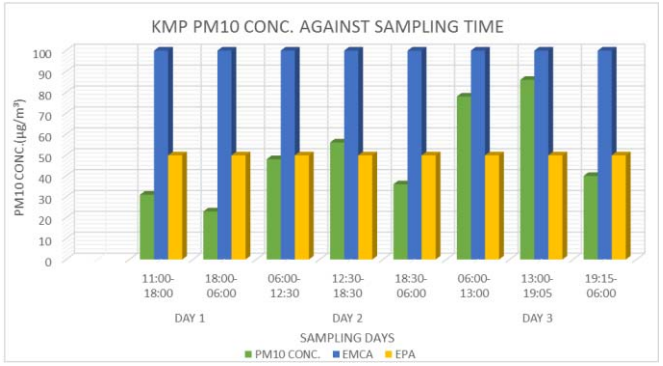


**Figure 1:** PM10 Conc. at KMP residential area

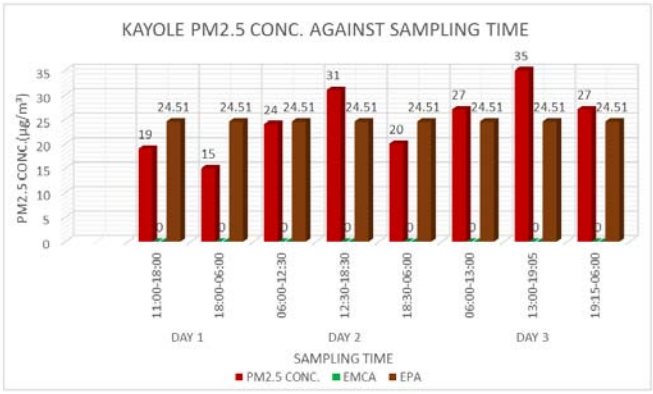


**Figure 2:** PM2.5 at KMP residential area

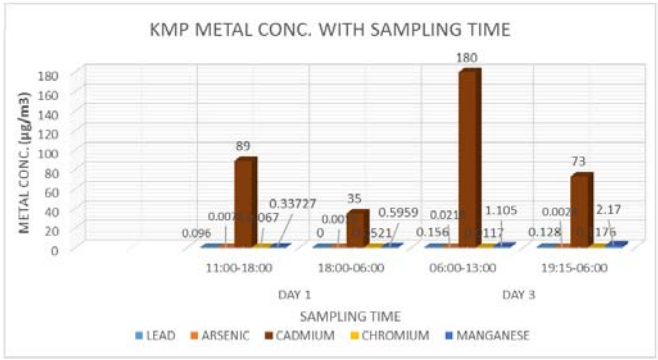


**Figure 3:** Metal concentration at KMP

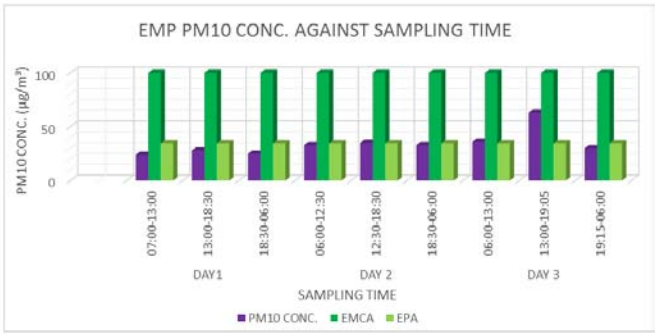


**Figure 4:** PM10 Conc. at EMP residential

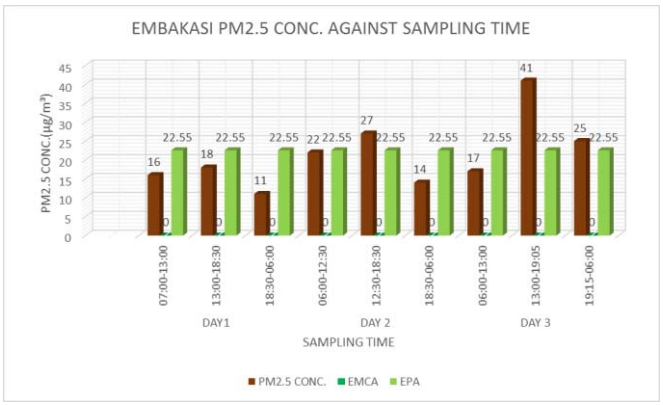


**Figure 5:** PM2.5 Conc. at EMP residential area

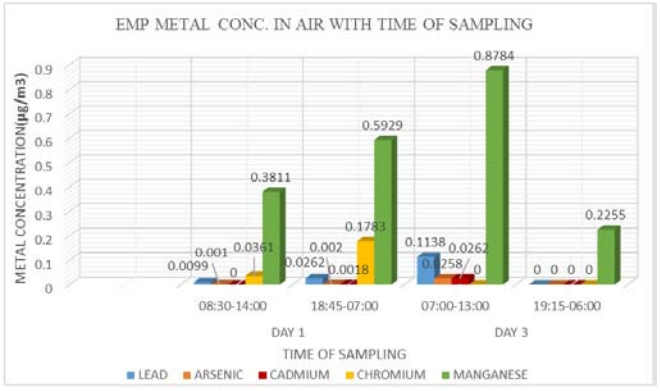


**Figure 6:** Metal Conc. at EMP residential area

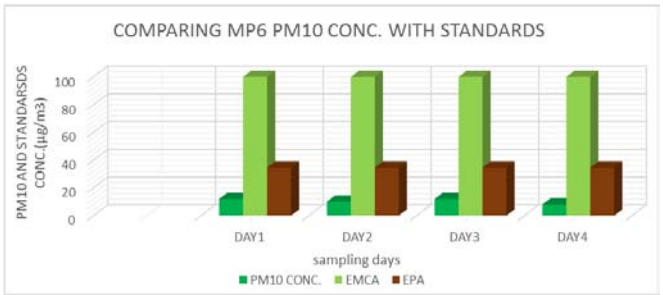


**Figure 7:** MP10 Conc. vs standards at MP6 residential area

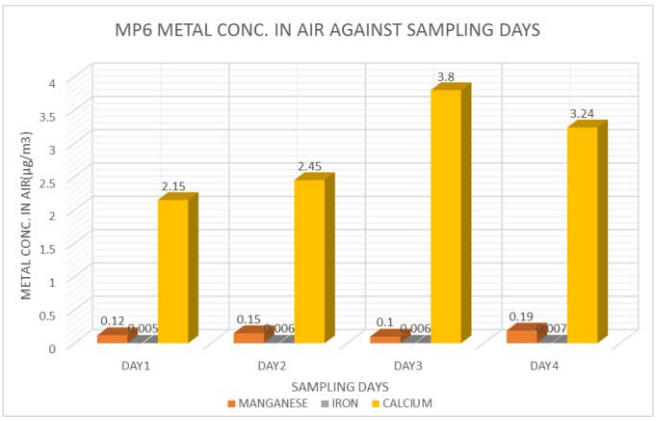


**Figure 8:** Metal Conc. at MP6

**Industrial**

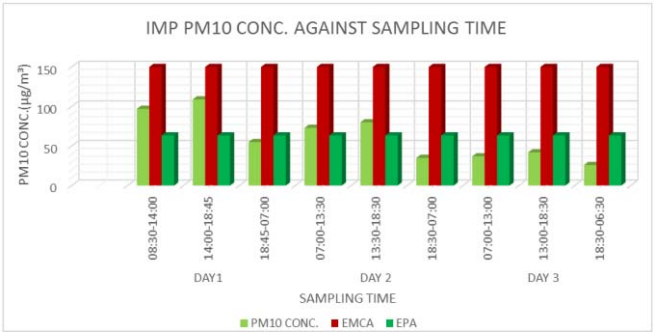


**Figure 9:** PM10 Conc. vs standards at IMP industrial area

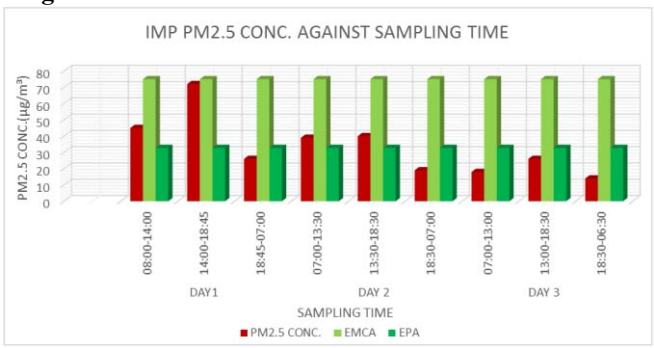


**Figure 10:** PM2.5 Conc. vs standards at IMP industrial area

IMP metal concentrations

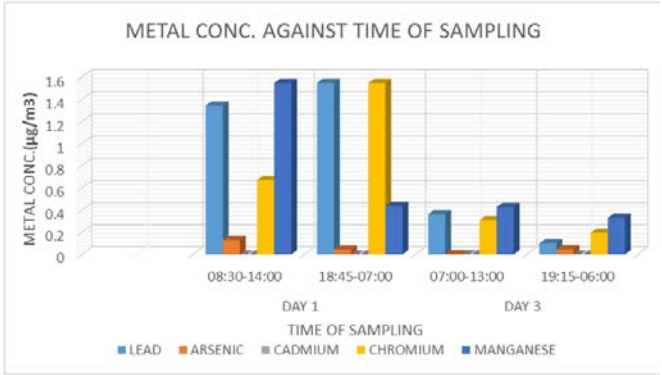


**Figure 11:** Metal Conc. at IMP industrial area

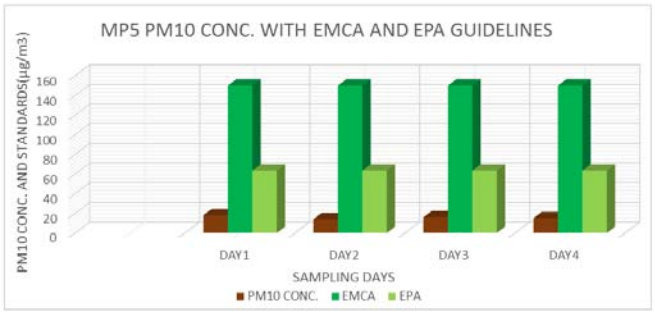


**Figure 12:** PM10 Conc. Vs standards at MP5

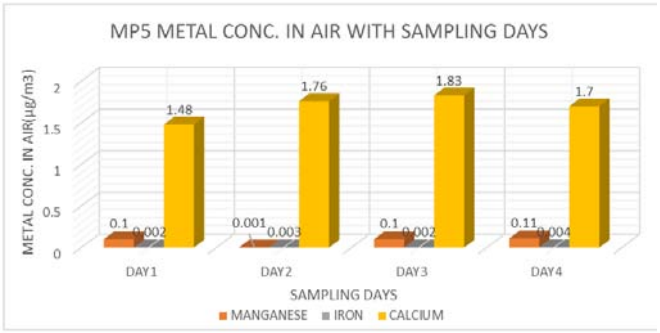


**Figure 13:** Metal Conc. at MP5

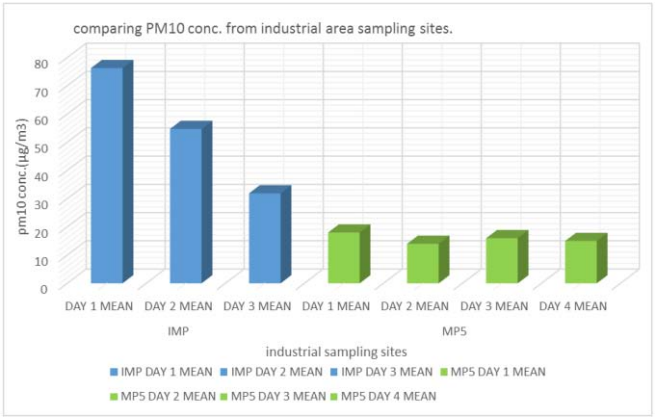


**Figure 14:** PM10 Conc. IMP vs MP5

**CBD (Controlled Area)**

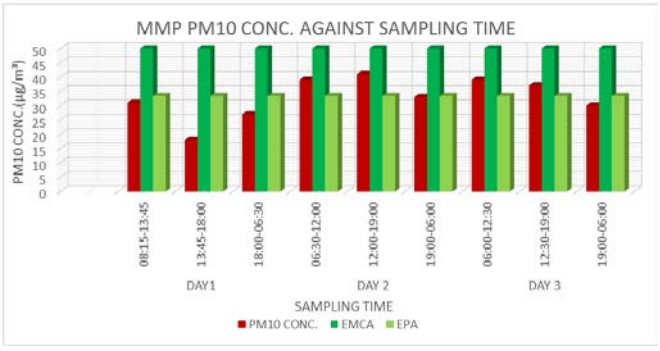


**Figure 15:** PM10 Conc. vs standard at MMP

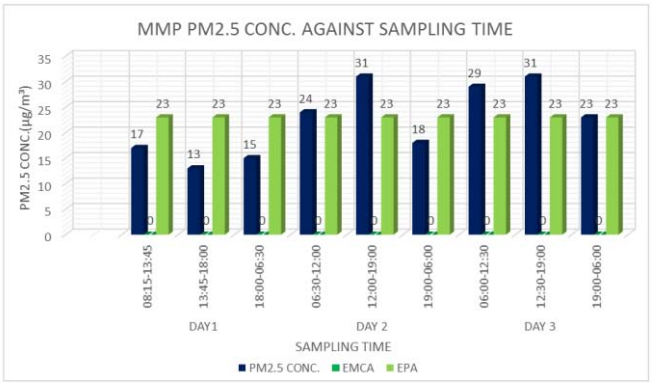


**Figure 16:** PM2.5Conc. Vs standards at MMP

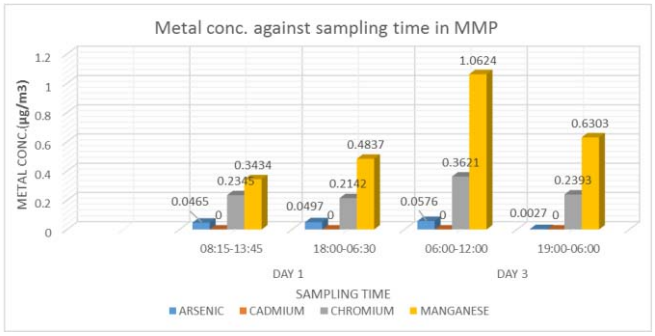


**Figure 17:** Metal Conc. at MMP controlled area

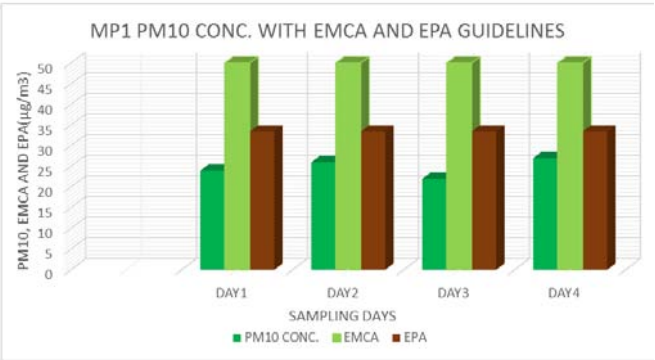


**Figure 18:** PM10 Conc. vs standards at MP1 controlled area

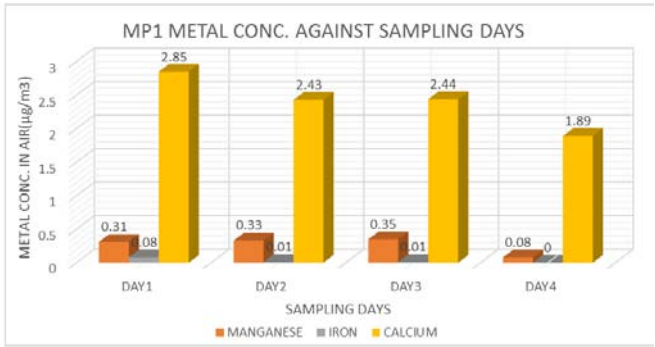


**Figure 19:** Metal Conc. at MP1

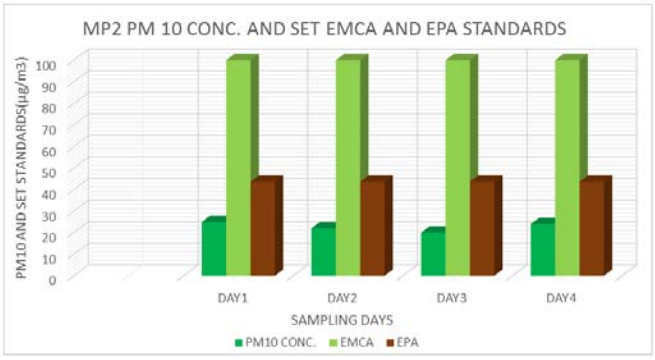


**Figure 20:** PM10 Conc. vs standards at MP2

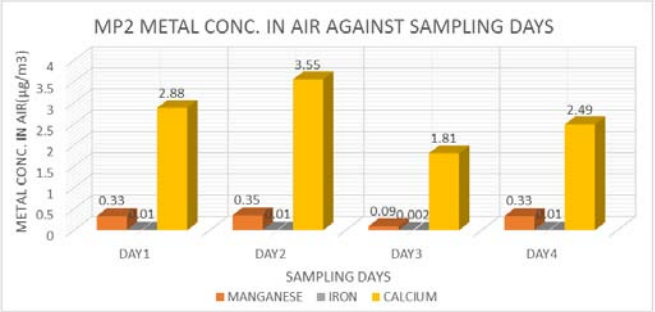


**Figure 21:** Metal conc. at MP2

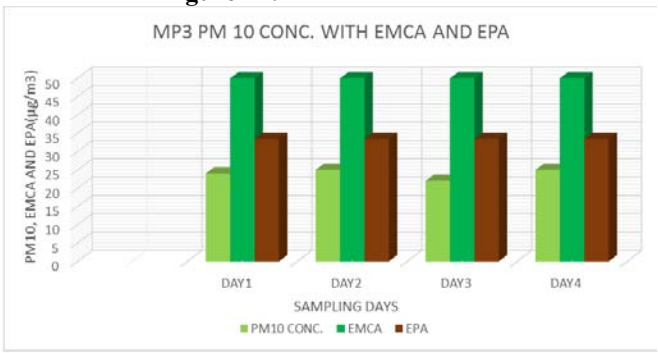


**Figure 22:** PM10 Conc. vs Standards at MP3

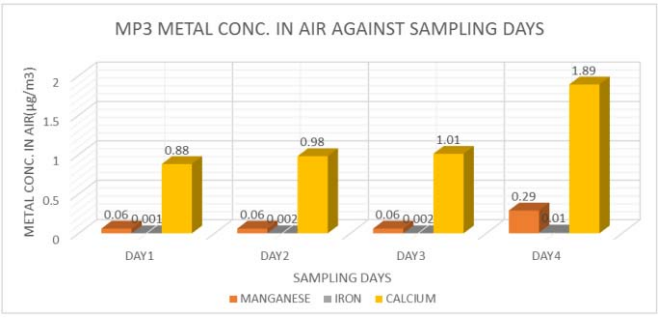


**Figure 23:** Metal Conc. at MP3

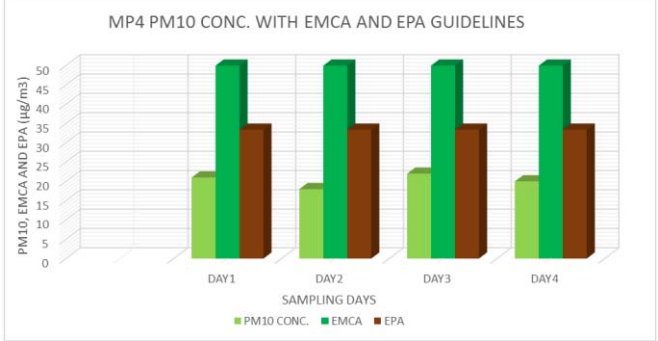


**Figure 24:** PM10 Conc. vs Standards at MP3

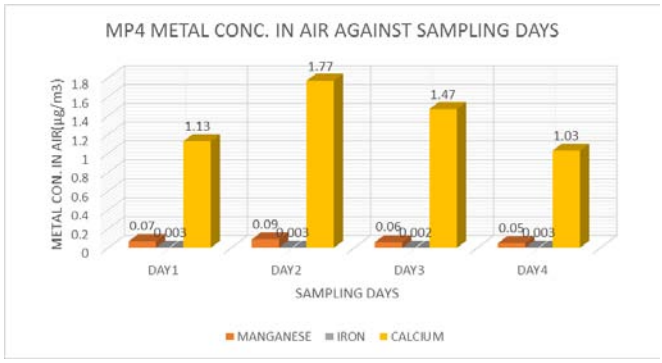


**Figure 25:** Metal Conc. at MP4

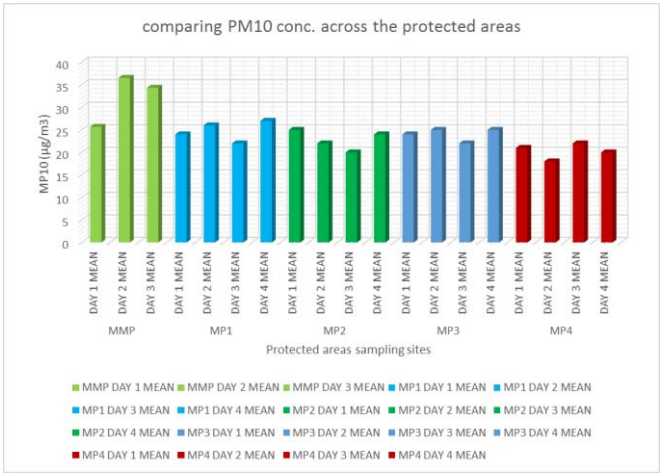


**Figure 26:** PM10 Conc. at controlled areas

Comparing lead levels as recorded from the sampling sites with EMCA and EPA standards.

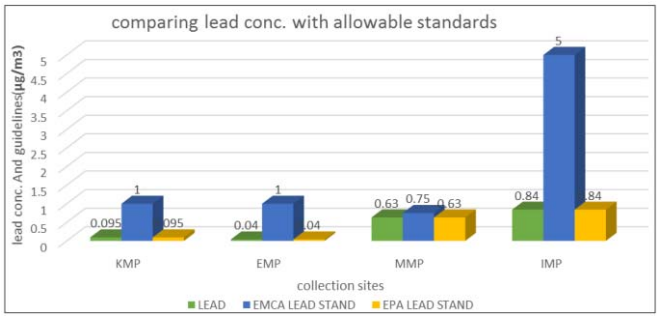


**Figure 27:** Lead Conc. vs Standards

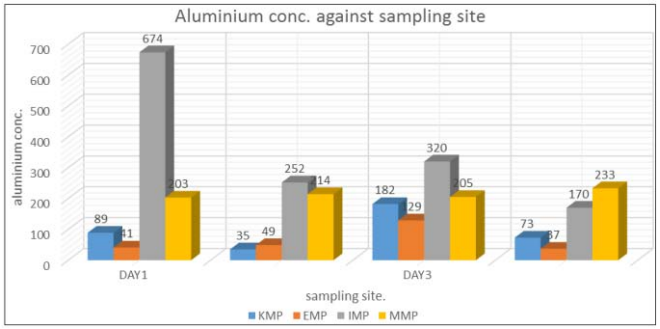


**Figure 28:** Alumnium Conc

The figure below are used to illustrate the comparison of the pm 10 concentrations across the residential areas.

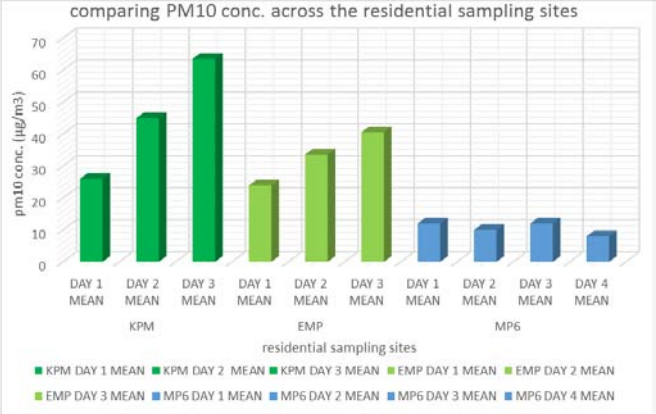


**Figure 29:** PM10 across residential areas

## 5. Discussion

The sites from where the samples were collected were categorized into three, Controlled, residential and industrial areas as stipulated in the Environmental Management Coordination Act. Generally all the four (MMP, MP1, MP3, MP2, and MP4) sites categorized as controlled areas by the Environmental Management Coordination Act (EMCA), the PM2.5 concentration was way far above the permissible levels both by EMCA and EPA. The industrial areas (IMP and MP5) the PM10 and PM2.5 are within EMCA permissible levels but above the EPA guild line values. For the residential areas (KMP, EMP and MP6) the PM10 and PM2.5 slightly above the EPA standards but PM2.5 was above the permissible levels. Both the EPA and EMCA don't provide guide line values for the most of carcinogenic components nor their compounds in particulate matter.

At MMP, the highest level of PM10 was recorded on day 2 afternoon (41µg/m3) with the lowest reported on day 1 afternoon (18µg/m3). Significantly, the highest level of fine particles was recorded on both day 2 and 3 afternoons (31µg/m3) with the lowest recorded on day 1 afternoon (13µg/m3).

Being the central business center, the area is characterized with paved roads and slow moving vehicles meaning that little dust is emitted to the air. The area is also characterized by a huge number of buildings which act as wind breakers and reduce the wind speed hence reducing any significant effect of wind on the concentration of dust particles hence low particle concentration in air.

Pm10 concentrations were above the EPA standards on day 2 morning and afternoon hours and on day 3 morning and afternoon hours in the area. Significantly, the PM2.5 concentrations were fa above the permissible levels by EPA and EMCA standards. The pm2.5 concentrations were significantly high above EMCA standards guideline vales on day 2 (afternoon) and day3 (morning and in the afternoon hours). This shows that this levels were higher than the allowable standards for a commercial center that may lead to adverse impacts on the environment in general and on human health in specific. The highest level of pm10 was recorded on day 4 of sampling followed by day 2 and day 1in MP1. The least level of pm10 was recorded on day 3 of sampling.

The controlled area MP1, MP2, MP3 and MP4 the PM10 recorded was within the permissible levels for both EPA and EMCA, although the metal composition of the PM contained significant amount of manganese, chromium, cadmium and Arsenic which are carcinogenic. The permissible levels of the metallic components or their compounds are not addressed in the regulations both EPA and EMCA.

The metal found in abundance in the sampling sites was Aluminium followed by cadmium, manganese etc. Cadmium is believed to be dispersed into the environment through the air by its mining and smelting as well as by other man-made routes: usage of phosphate fertilizers, presence in sewage sludge, and various industrial uses such as NiCd batteries, plating, pigments and plastics (ATSDR 1999).

The most important sources of airborne cadmium are smelters. Other sources of airborne cadmium include burning fossil fuels such as coal or oil and incineration of municipal waste such as plastics and nickel-cadmium batteries (which can be deposited as solid waste) (Sahmoun et al. 2005). Cadmium also escapes into the air from iron and steel production facilities.

For the Nairobi residential areas sampled, the reported results from KMP can be attributed to presence of sewage sludge within the estate and open burning solid waste coming mainly from Dandora and from households. Manganese is released to the environment from industrial emissions, fossil fuel combustion. Almost 80% of industrial emissions of manganese are attributable to iron and steel production facilities (EPA 2003a). Manganese may also be released to the environment through the use of MMT as a gasoline additive. Manganese adsorbed to particulate matter in air can be classified by the size of the particles. Fuel combustion from households' activities and vehicular emission from fuel additives are the major sources of manganese in KMP.

In EMP, Aluminium was the only metal significantly detected in the total inhalable dust. The highest level was reported on a Tuesday afternoon. Other metals detected with significant values were manganese and chromium. Aluminum is the most abundant metal in the earth's crust and it is widely distributed. It is a very reactive element and is never found as the free metal in nature. For the metal concentrations in MP6, calcium was the most noticeable metal and was recorded highest in the four days of sampling. It was highest in day 3 of sampling followed by day 4 and was lowest in day 1. Iron was the least recorded in air in Kitengela.

In industrial area estate, Aluminium was the first metal detected in the air in IMP followed by manganese and lead. Being an industrial area, it is associated with different types of industries. This therefore leads to significant increase in metallic compounds in the inhalable air.

In MP5 industrial area round about, calcium was the highest recorded in air with day 3 leading in the levels followed by day 2. Iron was the least recorded in all the four sampling days in the area with manganese recorded in low levels.

Significantly in the commercial/protected areas sampled, Aluminium was the highest detected in the air in MMP. The highest level was reported on a Tuesday afternoon. Other metals detected with significant values were manganese lead and chromium.

From the MP1, the highest metal was recorded on day 1 which was calcium followed by day 3 and day 2. The least level of calcium was recorded in day 4 of sampling. The least metal that was noted in air from the site was iron.

From MP2 Pangani round about, calcium was the highest metal recorded in the air followed by manganese with the least being lead. In average, the highest metal concentration was recorded in day 2 of sampling.

Highest metal recorded in air from MP3 Old Nation Round About was calcium with day 4 leading in the level followed by day 3 down to day 1. The metals levels increased progressively from day 1 up to day 4. Lead was the least recorded in the air from the site.
In MP4 Ngara area, the most recorded metal was calcium with highest levels recorded in day 2 followed by manganese and finally lead.

Understanding the composition of ambient air organic and inorganic particulate matter is essential in predicting its effects on air quality and public health. Speciation and quantification is very crucial in determining the effects.
The set standards both EPA and EMCA have no guide lines values for Aluminium standards in the ambient air. This shows that the Aluminium emitters are not aware of what levels are allowed in the environment which may lead to high concentration impacting negatively on the environment and on human health. The same case happens with most of the inorganic materials and metals in which they are not specified in the standards. This can lead to adverse impacts including different diseases caused by inhaling the respirable particulate matter (<10µm) with high levels of the metals on the Nairobi city dwellers.

Breathing high levels of chromium can cause irritation to the nose, such as runny nose and nosebleeds. Ingesting large amounts of chromium can cause stomach upsets and ulcers, seizures, and kidney and liver damage. Skin contact with certain chromium compounds can cause skin ulcers. Some people are extremely sensitive to chromium and can have allergic reactions consisting of severe redness and swelling of the skin. One form of chromium compound can increase the risk of lung cancer (the EPA classifies it in air as a human carcinogen). The most sensitive system, particularly in children, is the central nervous system (which includes the brain). At hazardous levels, lead compounds can decrease reaction time; cause weakness in fingers, wrists, or ankles; and affect the memory. Lead and mercury in air also can cause anemia, stomach problems, and high blood pressure.

## 6. Conclusions

There was exceedance for both EMCA and EPA regulatory limits for respirable particulate matter (inhalable dust) mostly in the controlled areas (CBD). There are two guideline values for residential areas in the EMCA (first schedule and sixth schedule as controlled areas). Main source of dust in residential areas is emission from unpaved roads and vehicular emissions form fuel combustion. Also, the concentration is contributed from the neighboring industrial area with the fact that the residential areas are located near the industrial areas. The highest mean concentrations of dust particles were recorded in IMP as shown in the graph of means with the lowest in the MMP. Also, the residential areas are located north east of the industrial area which was the wind direction at the industrial areas hence carrying some dust particles from the industrial areas to the residential area. Presence of lead and Arsenic has worse adverse impact on human healthan than when

## 7. Recommendations

Revision and improvement of EPA and National (EMCA) policies governing the air ambient airquality as soon as possible. High levels of respirable particulate matter (<10) in the cities it's a threat to human health in the future. The regulations should provide guideline values for the carcinogenic and other toxic elements and compound in the repirable particulate matter (<10µm). Industries should develop techniques for the safe disposal of cadmium-containing wastes and effluents.

Promote effective measures to increase recycling of cadmium and to restrict non-recyclable uses. Reduce cadmium exposure by, for instance, improving working conditions in the non-ferrous smelting industry and disseminating information on the proper use of fertilizers (which sometimes contain high levels of cadmium). Raise global awareness on the importance of minimizing waste discharges of metals into the air.

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