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Particulate Matter from Motor Vehicles in Nairobi Road Junctions Kenya

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Abstract Motor air pollution has become a problematic issue both within as it contributes to environmental degradation. It is evident that air crises in cities continue to rise partly because of the increasing levels of motor vehicle emissions. With the expansion of the economic base, cities such as Nairobi also expand paving the way for an increase in motor vehicle ownership and use, which lead to higher rates of pollution. Given that exposure to pollutants is harmful to human health, the traffic police are vulnerable because members are constantly uncovered to motor vehicle fumes. The survey interviewed a purposive and non-random stratified sample of 127 police officers, according to their seniority, years of employment and work experience, from the target population of traffic police working in major road junctions within the CBD, Nairobi Kenya. The sampled junctions were Kamukunji, Railways terminal, University way and Uhuru roundabouts. In addition, from the leadership rank, five (5) key informants were also interviewed. Data was collected using self-administered questionnaires. Discussions were held with the key informers. The findings show that there are that the high concentrations of PM2.5 in Nairobi major roundabouts is attributed to vehicular traffic congestion and worsened with poorly maintained and old vehicles. The significantly high values obtained compared to World Health Organization 24 hr guideline of 25 µg m−3 (2000) creates a severe health issues to regular pedestrians and workers around those areas. The study exposes that there are association between fine particulates and motor vehicles (r = 0.93), signifying that vehicular emissions is foremost source of fine particles in the atmosphere.

Keywords: *particulate matters, $PM_{2.5}$, motor vehicle pollution, exposure*

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1. Introduction

Motor vehicle road traffic is a critical basis of destructive discharges of particulate contamination in urban areas of the emergent world, where economic development, combined with an absence of powerful transportation and proper land utilization planning is bringing about expanding motor vehicle proprietorship and traffic overcrowding. These phenomenon and components combine to make air contaminations very high near roads.

Urban development is required to proceed at a fast pace in the creating scene, especially in sub-Saharan Africa [1] as rustic populaces keep on migrating to urban communities looking for business and desires of better living conditions. In the event that nothing is done to diminish discharges and to better arrangement for urbanization, this pattern can be required to additionally worsen effectively genuine air worth issues in sub-Saharan African urban areas and in addition the wellbeing impacts that go with rising population.

Fine particulate matter ($PM_{2.5}$), produced by fuel ignition (e.g., that of engine vehicles) has been connected to an widespread variety of health complication, putting in mind that more than 800,000 passing in urban communities around the globe becomes affected [2]. In any case, little data is available concerning levels of particulate air pollutions which occur in urban inhabitants in Africa. This information crevice blocks health sway appraisals, the improvement of financially savvy methodologies to lessen the health burden because of open air contamination and the capacity to impact urban mode of transport and arranging strategies related to air quality and health.

Motor vehicle discharges incorporate a scope of toxins, including particulate matter (PM). $PM_{2.5}$ is of specific hugeness on the grounds that examination on health impacts in urban regions has shown relationship between both here and now and long haul normal surrounding $PM_{2.5}$ concentrations and an assortment of antagonistic health results. These incorporate expanded post neonatal newborn child mortality and unexpected losses identified with heart and lung maladies.

On account of their little sizes, $PM_{2.5}$ particles can be inhaled into the lungs where they apply antagonistic impacts. In 2005, the World Health Organization (WHO), in acquaintance of known health impacts, set a 24-hour normal rule of 25 µg/m3 and a yearly normal rule of 10 $\mu g/m^3$. $PM_{2.5}$ incorporates dark carbon (BC), or residue, which caused by inadequate burning sources which include diesel and ineffectively modified fuel motors and open flames. Notwithstanding antagonistic wellbeing impacts, BC adds to environmental change.

The city of Nairobi, which is regarded to be most conducive for both economical and good livelihood due to its unique features which include location, geographical attractions for example Nairobi national park and many other carrier opportunities makes Nairobi the most desired destination for various populous both local and international. This phenomenon of rural to urban migration as contributed to high level of population growth in most cities of Kenya. According to KNBS, [3], Nairobi leads with about 3.5 million; Mombasa 1.2 million followed by Kisumu city with about 409000 people.

A 2007 Government appraisal analysis from the Ministry of Roads and Public Works demonstrated that albeit just 15.3% of suburbanites in Nairobi utilize private autos, they represent 36% of vehicles on our city streets. Another 29% of suburbanites utilize *Matatus,* which represent 27% of the vehicles on our streets, while an incredible 47% of the city occupants stroll to their work places, which would be something to be thankful for if separations included were less than 6km. This sadly is not the situation, with a critical number of the low-pay workers remaining in Kayole, Dandora, Roysambu and Kawangware ranges, all of which are more than 10km from Industrial territory.

To mitigate the air pollution menace, the Kenya government has drafted an air quality regulation indicated that, The Environmental Management and Coordination (Air Quality) Regulations, 2008 [4]. This policy has air quality guidelines to be adopted and which are intended to reduce air pollution loadings arising from traffic related activities and other sources. However, emissions contribution to air pollution on road junctions has not been documented. Therefore, this study was to determine the connotation between the categories of vehicles and fuel they use and the level of concentration of particulate matter they contribute in road junctions on Nairobi CBD.

2. Material and Methods

2.1. Study Area

The study was carried out in the city of Nairobi, the capital city and the largest urban centre in Kenya and the one having the highest number of motor vehicles. The city is situated 140 kilometers south of equator and 500 kilometers west of the Indian Ocean at 1°17′S36°49′E. It occupies 696km^2 at an altitude registering 1,661 meters exceeding sea level [5].

Nairobi's western part environs stretches from the Kenyatta National Hospital in the upper south to the UN headquarters at Gigiri outskirts in the north direction covering a distance of about 20 kilometers. The city is centered considering the sixteen sides of the compass on the City Square, located in the Central Business District: enclosed by the Parliament buildings, the Holy Family Cathedral, Nairobi City Hall, Nairobi Law Courts, and the Kenyatta Conference Centre. The city traffic is busy and about over 100 traffic police personnel are deployed almost continuously to man traffic in the most crowded city in east and central Africa manually ignoring the installed traffic lights which operates digitally but poorly non rated [6].

2.2. Entire Study Population

A descriptive exploratory study was targeted the traffic police working within the CBD and its outskirts. Severely congested roundabouts, within the CBD and its outskirts, were selected purposefully for the study. These are the Kamukunji, Railways terminals, University way and Kariokor roundabouts manned by a population of 127 traffic police officers. Self-administered questionnaires were distributed to all the 127 participants. In addition, five (5) senior ranking officers participated in a key informant discussion. All the officers participated in the study. For the proposed study, the researcher enlisted the services of traffic police leaders that is, the Base Commanders to help in the identification of the Traffic police officers according to their seniority of year of employment and work experience. It provided for equal chances of selection of individuals of similar level of experience.

2.3. Research Design and Methodology

The research design involved identifying the roundabouts with high vehicular traffic and which are manned by traffic police officers most of the days of the week from 5.30 AM to 9.30PM. In these roundabouts, measurements were done on each road which links the roundabout. The activities in these roundabouts are largely human and vehicle traffic. Every specific road was measured twice during the period (11th to 19th January, 2016) except University way which was done once. Samples were collected for 8 consecutive hours during each sampling day and interchangeably in time. In the first phase, each sites' measurements was from 6:30 AM to 2:30 PM and from 10:00 AM to 6:00 PM. All filters were analyzed for particulate concentrations.

2.4. Measures of Particulate Matter

Cleaning of Filter Holder Nozzle

Before the start of each sampling, the filter holder nozzle unit was disassembled and properly cleaned using special earpiece wool with ethanol as solvent to clean some particles which could have earlier entrenched inside. This nozzle is left to dry and be assembled again.

Weighing and loading of filters in the nozzle

The filters used in this project were of Teflon type of pore size 2.5 μM. Prior to loading, the filters were carefully weighed using a 100 μg sensitive research analytical balance (Metler Toledo AT 460) avoiding any form of contamination. The filters were each loaded into the sampler holder ready for sampling.

Calibration of BGI personal aerosol sampler

The most critical parameter in aerosol sampling is the air flow rate. The flow meter used was calibrated using a

Standards Gas Flow meter by measuring and comparing readings at different flow rates for linearity test (BGI OMNI 400). Thereafter, the flow meter was used to adjust each loaded BGI aerosol sampler to 4LPM prior to sampling. After sampling, the flow rate meter was also used to determine the final flow rate.

Sampling of $PM_{2.5}$ particulates

Loaded nozzles were affixed onto the metal bar holder and positioned above the ground between one and half meters above the ground and one meter from any adjacent obstruction. The nozzle was then connected to the battery driven pump and sampling done for 8 hours. After each sampling, the loaded filters were carefully removed into clean Petri dishes and kept in a clean environment prior to weighing.

Determination of $PM_{2.5}$ concentrations

The mass determinations of particulates in the loaded filters were achieved by using a same research analytical balance used to weigh filters before loading. Loaded filters were weighed and the new masses noted. The differences in masses of the loaded and unloaded filters gave the particle mass loading. Concentrations of the particulates were acquired by dividing the quantity figure of particulates by the volume of air sucked through the filter during the sampling period as shown in below;

$$\text{Concentration } \left(\mu\text{gM}^{-3}\right) = \frac{Wf - Wi}{V}$$

Where;

W_f-------------------- is the weight of filter after sampling

W_i-------------------- weight of filter before sampling and

V----------------------Volume of air sampled in (M^3).

V is attained by multiplying the flow rate with the period of sampling.

2.5. Data Analysis Results and Discussions

The categories and numbers of motor vehicles recorded on selected Junctions of Nairobi CBD

The CBD vehicle movement and area they dominate veries from one place to the other depending on terms of interest , purpose and reason for that vehicle to enter or pass through CBD Junction, intersection and high way. For this reason the articulated and heavy trucks dominate the wayaiki University way toward uhuru high way toward mombasa road. This scenario is demostrated by reason that much of the tracks transport imported goods from port of Mombasa all the way to neighbouring countries like Ugunda which is termed as land locked country.

The second bunch which demostrate a little number of heavy and articulated vehicles concentrating along kamukunji round about account for goods which are used locally by kenyan populous. These kind of goods are unloaded along Gikomba and Kiriinyaga road for users of second hand clothes and vehicle spares delivery among others goods.

Uhuru high way had the highest number of light good carriers. This light good carriers namely box body does not exceed 4 tonnes. These average carrige does not contribute to high levels of pollution as most vehicles are light and easy to move without use of heavy gears.

Most of the light good vehicle showed dominancy in highway road due to its interlinks between satellite cities which link with CBD. The light goods vehicle operate as normal retail and wholesale business fraternity in and outside city of Nairobi and environs.

The university way roundabout registered the highest number of pick ups and vans. This reason suggest mutiple commercial business which link both satellite towns and the kenyan city and Airport for both perishable goods. Vans mostly in kenya are used to carry light goods for business purpose. So these is the reason for them being dominant in these part of the CBD.

The large cars, 4DW and Jeeps dominated the railways roundabout being the highest compared to other areas. These is entirely attributed by reason that railway roundabout is apivot point for vehicles which ferry senior and subordinate officers in and outside government offices which are located along harambee Avenue which joins Moi avenue and connect railways roundabout.

The most 4WD and large vehicles most of them are owned by government departments and are entirely used for transport purposes. The peak hours of the morning session are most busy for workers being dropped at their work place to execute their daily chores.

In general car and Taxis seem to be evenly distributed within the CBD although uhuru Highway and university highway registered the highest numbers of these category of motor vehicle. This category of vehicle exhibited the evenly used mode of transport although not the best mode of transportation. These is because these small vehicles carry not more than five passangers at one given time.

Small cars uses high volatile gasline and petrol fuel for locomotion. Unlike those heavy vehicles which uses diseal which is less volatile cars in compation pollute less than those which uses diseal. These kind of penomenon explains why University way round about and uhuru round about has large numbers of vehicles yet is the lowest polluter in compration to kamukunji and railway round about.

Kamukunji round about had the highest number of large buses in comparasion to other areas followed by railways roundabout. These penomenon has been attributed by large buses which operate through Jogoo road, Githurai 45, Ngong and rongai bus passanger terminals which contribute to many many buses bring in and out passangers within the CBD environs.

Railways round about registered the highest number of matatus within CBD. These as been attributed to reasons that railways terminals is feed by many matatus operator including the following routes. Kitengela, Machakos, Athi river, Mulolongo, Rongai, Ngong, kawangare, harligum, yaya centre, kibera among other matatu operators which have licence transport licence for diverse routes.

The reason for kamukunji contribiting to high proportinate of particulate matters is because of the high overriding numbers of vehicles which are large buses and matatus dominating in these areas and using diseal fuel which is more pollutant than any other fuel. Most matatus make frequent trips to and frow from these marked junctions for their daily business hence making these ares very polluted.

Railways and kamukunji both of them registered the highest number of Motor cyles and Tuk tuk. These was attributed by the fact that middle class people who operate within city stadium are most users of Tuk Tuk to connect to Town CBD after being dropped at city stadium vehicles which enter the famous Muthurwa Market. Muthurwa market stage is not directly connected to CBD so many people about entering town through Muthurwa to avoid walking to their job place.

The motor cycle operators due to fear of county council Askaris does not operate outside there area of Jurisdiction. This is because most of their customers emanate from the Eastland direction who flock at city markets and for small scale business enterprises.

Tuk Tuk in return also uses diseal which also is more polluting than any other kind of fuel. These also contribute to high levels of pollution within Kamukunji area (See Table 1).

Table 1. The categories and numbers of motor vehicles recorded on selected Junctions of Nairobi CBD

Vehicle Category	Kamukunji	Railways	Uhuru Highway	University Way	Grand Total
Light	2745	2055	3525	2862	11187
Light Heavy	1158	1167	2754	2384	7463
Medium	1358	1268	932	620	4178
Heavy	1445	1294	951	633	4323
Very Heavy	62	16	110	303	491
Grand Total	**6768**	**5800**	**8272**	**6802**	**27642**

Table 2. Average particle concentration observed on Nairobi road junctions (μg m-3)

Road junction	Particle concentration (μg m-3)
Kamukunji	124.3
Railways	107.6
Uhuru Highway	68.3
University Way	99.1
Grand Total	**99.8**

Concentration of ambient particulate matter ($PM_{2.5}$) on road junctions in Nairobi

Air particulates ($PM_{2.5}$) were sampled continuously for 8 hour periods during the exercise. The table below shows concentration levels in each site during the sampling periods. (see Table 3 below)

Table 3. concentration of particulate matter ($pm_{2.5}$) on road Junctions in Nairobi City

Road junction	Particle concentration (μg m-3)
Kamukunji	124.3
Railways	107.6
Uhuru Highway	68.3
Uni Way	99.1
Grand Total	99.8

The highest Average particle concentration measured level of $PM_{2.5}$ was 124.3 μg/M^3 observed in River road direction site at Kamukunji and in H. Selassie Muthurwa road at Railways roundabout. State house road (University way roundabout), Center site (H. Selassie roundabout) and stage road (Railway roundabout) registered the lowest levels of 45.0 - 46 μg/M^3. However, concentrations of corresponding sites on different days of measurement were about three time's higher (135.0μg/M^3). The wide variation in the measurements is majorly attributed to the location of the sampling site in the CBD and weather conditions at the time of sampling. On average, Kamukunji and Railways roundabouts registered a mean concentrations ranging from 101 - 144 μg/M^3 and 91 - 135μg/M^3 respectively. These areas are located in CBD with high human and vehicle traffic and the roads are not well paved hence continuous dust re-suspension of dust. On the other hand, H. Selassie and University way roundabouts registered lower concentration values ranging 68 - 109 μg/M^{3}attributed to their locality in CBD, better road and pavement conditions, low human traffic and no dropping and picking passengers at the sites as seen in the other two roundabouts.

The significantly high values achieved compared to World Health Organization 24hr guideline of 25 μg m−3 (2000) stances a severe health issues to regular pedestrians and workers around those areas.

The mean $PM_{2.5}$values obtained in this exercise ranged from 68.0 to144.0 μg/M^3 and correlate with those obtained in a similar study by Kinney et, al., in 2009 [7]. The study which was conducted in the CBD of Nairobi reported mean street values ranging 98.1 to128.7 μg/M^3. This observation may indicate that $PM_{2.5}$ particulate loadings in the air in Nairobi have not changed much over the years although they surpass maximum recommended limit of 25μg m^3, the WHO 24 hour recommendation assessment (2000). This observation of similar results is accredited towards proliferation in the importation and usage of motor vehicles within urban areas which increased from 50 000 units in 2008 to 140 000 units in 2011 [8]. Although there has been progressive improvement of the road network in Nairobi, increased motorized traffic activities lead to severe congestion problems.

In relation to population health, there is a high symptom of potential health hazards for populaces who commute to the built up metropolitan on daily basis and more so the traffic police officers who man the roundabouts for 8hours each day. According to Graeff *et.,al* [9] extreme air contamination contact to many pedestrians takes effect specifically during morning and evening hurry periods of the day.

Association of vehicle size, type of fuel and particle emissions (particle concentration/number of vehicles)

The study done clearly implies that heavy vehicle contributes to higher pollutants when you compare to the light, light heavy and medium motor vehicle categories. Those heavy fuels like diesel are less volatile hence burn slowly causing emission of carbon monoxide in atmosphere and which is most dangerous and greatest cause of mortality. Small vehicles which use high volatile fuel emit less and pollute less in comparison heavy commercial vehicles [10].

According to study it exposes that heavy-duty trucks and light-duty gasoline vehicles emit a range of pollutants. However, their contributions to diverse types of compounds are dependable of the fuel type and capacity of the motor vehicle. Mostly those vehicles like heavy trucks which uses diesel emit more of certain pollutants (e.g., NOx and PM) and contribute disproportionately to the emissions from motor vehicles. Gasoline-powered passenger cars generally emit more other pollutants (e.g., CO, and benzene, a volatile organic compound (VOC) [11].

The enormous common and current cars and trucks are propelled by use of internal combustion engines that burn gasoline or other fossil fuels. The technique of burning gasoline to power cars and trucks contributes to air pollution by releasing a variety of emissions into the atmosphere. Emissions that are released directly into the atmosphere from the tailpipes of cars and trucks are the primary source of vehicular pollution. But motor vehicles also pollute the air during the processes of refueling as part of the fuel evaporates due to its volatile property and from the emissions associated with oil refining and distribution of the fuel they burn although this is dependable on the type of the fuel and its volatile properties (See Figure 1).

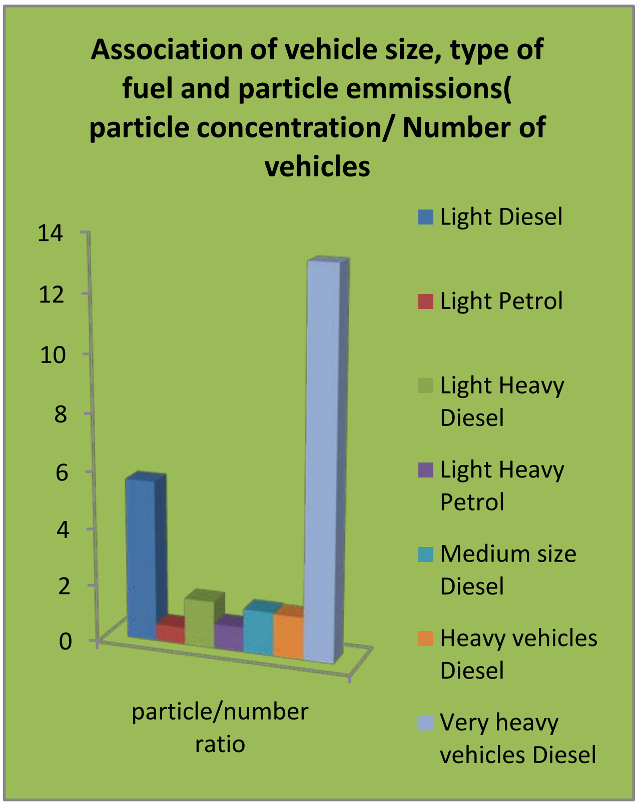

Figure 1. Association of vehicle categories, fuel and particulate matter emissions on Nairobi road junctions

Average particle emmision/ vehicle number ratio observed on selected road junctions of Nairobi CBD

In current study the results showed that Kamukunji had the highest ratio of particle of about 10.6 followed by Railyways , uhuru highway and university way round about which recorded the lowest ratio despite having highest everage numbers of 86.2. These phenomenon is clearly demostrated by the fact that most vehicle which uses university way and uhuru highway were small cars which uses petrol fuel. Small vehicles which use high volatile fuel emit less and pollute less in comparison heavy commercial vehicles [10]. Those heavy fuels like diesel are less volatile hence burn slowly causing emission of carbon monoxide in atmosphere and which is most dangerous and greatest cause of mortality. In this scenario kamukunji had the last heavy vehicles using diseal fuel which is more pollutant to the environment [11]. (See Table 4)

Table 4. Average particle emmision/ vehicle number ratio observed on selected road junctions of Nairobi CBD

Row Labels	Average of Number	Particle/number ratio
Kamukunji	70.5	10.6
Railways	60.4	5.8
Uhuru Highway	70.9	4.8
University Way	86.2	3.2

Comparison of the level of emissions with those reported locally, regionally and globally and the WHO standards

Airborne contamination has escalated by 8% worldwide in the previous five years, with the WHO approximating that it causes 3 million untimely deaths a year, making it one of the top greatest environmental menaces to human health in the contemporary world of humanity.

3. Discussion

In the global selected cities in Africa Nairobi city of Kenya ranked 8th in the category of kampala leading with 104, Cairo Egypt 76,Yaounde Cameroon 49, Johannesburg south Africa 41, Tunis Tunisia 38, Dakar Senegal 34 and Casablanca Morocco 26. All this was above the required WHO standards which is 1.8 micrograms per cubic meters. In the world Nairobi city ranked moderately fair with expected increase of pollutants due raise of pollution and demand for industrial production in most part of the city suburb [12].

The economic growth marks the milestone of most undeveloped and developed countries failure to control levels of pollution. This phenomenon have been contributed the essence of demand for food and other natural Recourses. There are some places in the world that already appear like a human-caused apocalypse aftermath: cities whose ecology in terms of air pollution is so bad that it seems impossible to live there [13].

According to pure earth a non-profitable environmental organization, the most air-polluted city on Earth currently is New Delhi. New Delhi is a city where breathing its air is rather difficult. Owing to consideration of many happening, such as an exponentially increasing populace (New Delhi has reached 25 million people), industrialization, and urbanization regarding coal-fired power plants and thrilling traffic with many cars operated by use of diesel, it is easy to comprehend why New Delhi is recognized as the city with the worst ambient pollution in the world. Pollution has enlarged to an extent that the outdoors in Delhi are correspondingly a gas chamber" [13].

The Iranian city of Zabol stands amongst the other cities as a city with exceedingly bad airborne. Neighboring

Afghanistan, Zabol is ranked by the WHO being one of the utmost contaminated city all over the world. The concentration of detrimental particles in Zabol's air reaches 217 micrograms per cubic meter of air, despite the allowed limit considered safe is only about 60 micrograms. Nowadays, these dusty flying air contaminate the metropolitan atmosphere even more; besides, the loss of environmental protection which has caused a dramatic increase in the amount of respiratory contaminations among citizens: tuberculosis, for instance, have become one of the most severe and common problems of Zabol [14].

Nairobi is among global cities with deadly escalating air pollution levels. For instance over 80 per cent of people living in urban areas that monitor air pollution are uncovered to air quality levels that exceed WHO limits. Although all over the world every populace is affected by this phenomenon, populations in low-income cities are the most impacted. According to the latest urban air quality database by the WHO, 98 per cent of cities in low and middle income countries with a population recording more over 100,000 inhabitants, including Nairobi, do not meet WHO air standards.

WHO was able to compare a total of 795 cities in 67 countries for levels of small and fine particulate matter (PM_{10} and $PM_{2.5}$). During the five-year period, 2008-2013, PM_{10} and $PM_{2.5}$ included pollutants such as sulfate, nitrates and black carbon, which infiltrates deep into the lungs and into the cardiovascular system, posing the greatest risks to human health [15].

In the African region, urban air pollution data remains very scanty. However available data revealed particulate matter (PM) levels are above the median levels of concentration. Ambient air pollution, made of high concentrations of small and fine particulate matter, is the greatest environmental risk to health causing more than three million untimely deaths worldwide every year.

Africa's metropolitan air is especially bad for reasons that few cars are new, the immense majority having been shipped in as secondhand from Japan and Europe with their catalytic converters and air filters dismantled. It is jeopardy for developing countries becoming a dumping ground for the world's old cars - importing vehicles that no longer meet rich countries' pollution standards [19].

4. Conclusion and Recommendations

The number of vehicles and types crossing the road junctions of city of Nairobi CBD were associated with the level of pollution through exhaust emissions. Most vehicles entered the CBD through Kamukunji round about which is characterized by mostly Medium good carries which ferry firm produce to Marigiti market on daily basis. The traffic at this junction consisted of more large and heavy commercial *Matatus*, and Tuk Tuks. Diesel fuelled vehicles observed to be more pollutant than petrol fueled vehicles.

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Competing Interests

The author declares he has no competing interests.

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Ethical Considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the author.

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