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Investigation of Heavy Metal Pollution Caused by Vehicular Emissions in Roadside Soils in Ile-Ife.

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Abstract
This study determined the concentrations and the variations in the concentrations of heavy metals in roadside soils exposed to regular vehicular emissions in Ile-Ife. The aim was to investigate the levels or extent of heavy metal pollution in roadside soils due to vehicular emissions. Topsoil samples were randomly collected from 10 cm away from each of the seven roadside locations with varying traffic densities. These sites are not industrial areas, and no mechanized farming within any of these locations. Heavy metal concentrations were analyzed using Atomic Absorption Spectrophotometry. Variations in the concentrations of the analyzed metals were compared and analyzed using Analysis of Variance (ANOVA) to test for significant differences in the means, while Duncan's multiple range test was used to separate the means. The concentration of heavy metals in the soils from the study locations revealed that high-traffic areas, particularly location E, exhibited elevated levels of Cu, Zn, and Pb exceeding WHO permissible limits. Lead and cadmium were not detected at location CT. Values obtained from location E were significantly higher ($p \leq 0.05$) than those of the other locations. There was variation in the concentrations of heavy metals across the seven study sites in Ile-Ife. The study revealed that roadside soils of places with high vehicular traffic in Ile-Ife are contaminated with heavy metals and can be injurious to human health. The need for adequate governmental policies in the enforcement of laws against the use of leaded gasoline in refineries is hereby recommended.

Keywords: Concentrations, environmental pollution, heavy metals, human health, roadside soil, vehicular emissions.

Introduction
Environmental pollution has been a major cause for concern in recent decades largely because of its negative impacts on the ecosystems and human health. Environmental pollution is usually classified based on the environment into three major groups: air, water, and land pollution. In modern societies, various forms of pollution, including noise, light, and plastic pollution, have become significant concerns (Nathanson, 2022). Forest fires and active volcanoes are the natural sources of environmental pollution. Pollutants from anthropogenic sources caused by human activities include vehicular emissions, industrial wastes, and agricultural by-products like fertilizers, insecticides, and herbicides (Ediene and Umoetok 2017; Ajayi and Olawole 2018).

Many research studies had been conducted on Lead contamination from automobile emissions in Nigeria. Nriagu *et al.* (1997) observed that the blood lead levels in 87 children, aged 1 to 6 years, in Kaduna State, averaged between 10.6 µg/dl and 30 µg/dl. Lead poisoning is not limited to Nigerian children but also affects adults. The average blood lead levels in adults not exposed to occupational activities in Lagos and Ife are 13 µg/dl, surpassing the threshold limit for adult humans (Ogunsola *et al.*, 1994). In Ibadan, the average lead concentration in the adult blood is 12 µg/dl (Omokhodion and Howard, 1994).

In more recent times, Nigerian investigators have reported a wide range of Pb in the blood of individuals, from less than 15 µg/dL to as high as 275 µg/dL, indicating that there is an increase in average blood lead levels and that quite a number of the population is at risk of high blood lead levels (Ademuyiwa *et al*., 2002; Wright *et al*., 2005; Babalola *et al*., 2007; Osuntogun and Koku, 2007; Arinola *et al*., 2008; Adekunle *et al*., 2009). Elevated lead levels have been found in various foods sold in Nigerian outdoor markets, with concentrations ranging from 0 to 12.5 mg/kg in yam flour (Elubo), 6.5 mg/kg in suya, and 0 to 15.1 mg/kg in dried meat, dried fish, smoked fish, and different beverages (Okoye, 1994; Ikem *et al.*, 2002; Adekunle and Akinyemi, 2004; Nnorom *et al.*, 2005; Maduabuchi *et al.*, 2006). This contamination is largely attributed to the continuous deposition of lead from automobiles and other human activities into urban environments (Nriagu *et al.*, 1997). The Lancet Commission on Pollution and Health documented that pollution was responsible for 9 million premature deaths in 2015, identifying it as the leading environmental cause of disease and mortality (Landrigan *et al.*, 2018). Revised estimates based on data from 2019 confirmed that pollution continues to contribute to approximately 9 million deaths annually, accounting for one-sixth of all global fatalities. While deaths attributed to household air and water pollution have declined, those caused by ambient air pollution and exposure to toxic substances, including lead, have risen. These pollutants, driven by industrial growth and urbanization, have resulted in a 7% increase in deaths since 2015 and over a 66% surge compared to 2000 (Singh *et al*., 2020). Despite the ongoing efforts of UN agencies and other organizations to address this issue, significant advancements in combating pollution remain limited, particularly in low- and middle-income countries (Fuller *et al.*, 2022).

Heavy metals resulting from vehicular traffic follow various pathways, as demonstrated by multiple studies. Johansson *et al.* (2009) reported that over 90% of copper pollutants originated from brake wear, more than 80% of nickel, 40% of zinc, and 90% of lead pollutants come from vehicular emissions. Ndiokwere (1984) estimated that 75% of Pb released from motor vehicle exhaust was in particulate form. Additionally, Zn may be present in vehicle tyres. The gasoline used in automobiles may contain metalloids and metallic elements such as Pb, Cu, Zn, and Cd (Ozaki *et al.*, 2004).

In Nigeria, numerous studies have documented a growing trend in air pollution caused by vehicular emissions, which poses a significant risk to public health (Abam and Unachukwu, 2009). The rapid influx of old and fairly used vehicles into the country in the past few decades has contributed to the traffic congestion observed on most Nigerian roads. This has resulted in an increased concentration of pollutants from vehicular emissions and their associated effects (Ana, 2011). In addition to fuel combustion emissions, tyre wear also contributes to the release of heavy metals such as chromium, Pb, Zn, and Ni (Gupta, 2020). Brake lining wear is associated with the emission of Cr, Ni, and Pb (Muschack, 1990). This process of corrosion, exhaust, wear and tear occurs more frequently in older vehicles, which are prevalent in developing countries due to the widespread use of imported or second-hand cars. Zn is also present as an additive in motor oil, making vehicles an anthropogenic source of zinc pollution (Bai *et al.*, 2009). Ayedun *et al*. (2013) reported that the key issues related to heavy metal pollution in Nigeria include inadequate governmental policies, the proliferation of illegal refineries, and widespread poverty. Others are ignorance and inappropriate prevention and control measures, just to name a few. Additionally, leaded gasoline from illegal refineries, processed with lead alkyls to improve the octane rating, is rampant in Nigeria despite being banned. Measuring the levels of these metals will help to provide basic information that is essential for keeping track of and maintaining soil quality over time, which is vital for environmental impact evaluation, as heavy metal contamination can have severe implications for soil health and the ecosystem.

Identifying areas with higher concentrations of heavy metals is important for public health, as these areas may pose greater risks to the people; hence, this study. The aim of this research was to investigate the extent of heavy metal pollution in roadside soil due to vehicular emissions. The specific objectives were to determine the occurrence, concentrations and variations in the heavy metal concentrations in the roadside soils exposed to regular vehicular emissions across the study areas in Ile-Ife to ascertain which area(s) is/are more affected.

Materials and Methods

The Study Sites

The study sites were roadsides within Ile-Ife, a traditional and ancient city in Southwestern Nigeria, which lies between latitudes 7°28′30” and 7°18′00” North of the Equator and longitudes 4°27′00” and 4°37′30” East of the Greenwich Meridian (Ajayi and Olawale, 2018). The seven study locations, their coordinates and estimated average number of vehicles per day are shown in Table 1. The Obafemi Awolowo University campus bus stop near the fire service office (location A) and OAU campus road 1 gate bus stop (location C) are always very busy, especially when the school is in session. The trailer garage at the old toll gate is an ideal location because of the heavy traffic plying Ibadan road, trailers and heavy trucks also use the place as their parking center (location E). Control, which is CT, was at Tonkere village near the OAU research farm, is very far away from major roads, and it has extremely low human and vehicular activities. Lagere (location D) is a commercial, ever-busy location where vehicles from the north, Akure and Ilesa meet with many junctions from the heart of Ile-Ife and heading towards Mayfair junction where it divides into two main highways called Mayfair Ede road (location F) and Mayfair Ibadan road (location B).

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Table 1: The Geographical Locations of each of the Study Sites.

Location Symbol	Locations	Latitude	Longitude	Estimated Average Number of Vehicles Per Day
A	Campus bus-stop	7º29’50” N	4º31’21” E	1320
B	Mayfair, Ibadan road	7º29’21” N	4º31’59” E	1140
C	Campus road 1 gate	7º29’20” N	4º31’56” E	1200
D	Lagere	7º29’12” N	4º32’49” E	1420
E	Old toll gate	7º31’01” N	4º31’23” E	1832
F	Mayfair, Ede road	7º29’38” N	4º29’32” E	1152
CT	Tonkere	7º36’22” N	4º31’23” E	4

The roads coming from Lagos meet those from the east and Benin at Ore junction pass through Ondo to Mayfair to join both Ede road and Ibadan road. These locations were purposely chosen and ideal for this study because there were heavy traffic, no large-scale agricultural activities nearby that will need the use of agricultural chemicals containing heavy metals and no industries near them. Seven research assistants were employed to join the authors for the estimations of the total number of vehicles plying each location per day.

Soil Preparation and digestion of soil samples

Seven topsoil samples (10 cm away from the road at 5 cm deep) were randomly collected using a soil auger from each of the study sites, mixed thoroughly, placed in plastic bags, and properly labeled. The soil samples were mixed thoroughly to achieve a uniform sample. The elemental analysis for heavy metal concentrations in the soil was carried out. For digestion analysis, soil samples were air-dried to remove any residual moisture, sieved by a 2 mm mesh to separate large particles and debris. A mixture of concentrated nitric acid and hydrochloric acid in a 3:1 (aqua regia) was prepared with analar-grade reagents to minimize contamination and guarantee purity in heavy metal analyses. From each site, 1.0 g of the prepared sample was transferred to a digestion flask with 10 ml of the acid mixture and placed on a hot plate under a fume hood. The temperature was gradually raised to 180–220°C and maintained for two hours. Light-colored changes indicate thorough breakdown of organic materials, release of target elements, allowed to cool to room temperature, and diluted with distilled water to 20 ml in a volumetric flask. Analysis was done using atomic absorption spectrophotometry. Blank samples of acid mixture without soil were digested alongside actual samples to monitor potential contamination.

Data Analysis

The mean values of six replicates were used to express all the results. The data obtained from the quantification of heavy metals were analyzed using Analysis of Variance (ANOVA) to compare the means. Means that showed significant differences were further distinguished using the Duncan Multiple Range Test.

Results

Heavy Metal Concentrations in the Study Areas

The result of the chemical analysis of heavy metal concentrations in the soil from all the seven locations revealed the presence of heavy metals (Table 2). Copper concentrations were significantly higher ($p \leq 0.05$) than the WHO upper limit of 12 $mg^{-1}kg$ in locations A and E, but slightly lower in other locations. Zinc concentrations were significantly higher ($p \leq 0.05$) than the WHO standard of 60 $mg^{-1}kg$ in locations A, C, and E. Lead levels were significantly higher ($p \leq 0.05$) than the WHO standard of 10 $mg^{-1}kg$ in locations C and E. Cadmium concentrations were significantly lower ($p \leq 0.05$) than WHO upper threshold acceptable limits (5.0 $mg^{-1}kg$) across all locations. Nickel concentrations were significantly higher ($p \leq 0.05$) than the WHO standard of 5 $mg^{-1}kg$ in all the locations except location CT. Locations A, C and E were particularly notable for their significantly higher ($p \leq 0.05$) levels of heavy metal values than the WHO limits. 3.2 Variations in Heavy Metal Concentrations in the Roadside Soils across the Study

Locations

The variations in heavy metal concentrations ($mg^{-1}kg$) across the experimental locations are illustrated in Figure 1. Heavy metal concentrations across the study locations revealed significant variations, indicating significant differences in the levels of soil contamination. Location E had the highest concentrations of Cu, Zn, and Pb. Nickel, however, was at its peak in location A, while the highest Cd concentration was recorded at location B. Lowest concentrations of these metals (Cu and Ni in location CT, Zn in location F, Pb and Cd in location D, respectively) were recorded. However, Pb and Cd were not detected in the soil from location CT.

Discussion

The result of the Atomic Absorption Spectrophotometry of the soil samples from the study locations showed that there was heavy metal contamination in the roadside soil of the study locations, because Cu, Zn, Ni and particularly Pb and Cd were detected in the soils of all
the locations. However, Pb and Cd were not detected in the control site which had extremely little vehicular emission and fewer human activities because of the far distance from the major roads. According to Ali *et al*. (2019), the presence of heavy metals in whatever concentration suggests risk as they can easily accumulate and become toxic over time. Pb exposure is dangerous even at very low concentrations, especially to babies and young children (Ara and Usmani, 2015). The result also revealed that there were variations in the mean concentrations of the heavy metals in the soil across different locations. The mean concentrations of Ni, Cu, Zn and Pb were significantly higher ($p \leq 0.05$) than the permissible limits in location C, which is always busy and rowdy most of the time. This is in line with the reports of many authors (Yahaya *et al*., 2010; Ayedun *et al*., 2013; Ogundele *et al*., 2015; Adedeji *et al*., 2020).

Table 2: Mean Soil Concentrations ($mg^{-1}kg$) of Selected Heavy Metals at the Study Sites with Standard Regulatory Limits.

	Heavy Metals				
Location	**Copper**	**Zinc**	**Lead**	**Cadmium**	**Nickel**
A	14.79^{b}	92.96^{c}	9.99^{c}	0.21^{abc}	9.00^{a}
B	9.43^{e}	37.65^{e}	5.88^{e}	0.23^{a}	7.90^{b}
C	11.77^{c}	120.62^{b}	16.41^{b}	0.18^{bcd}	8.10^{b}
D	9.07^{f}	44.21^{d}	5.86^{e}	0.14^{d}	6.30^{c}
E	48.21^{a}	537.54^{a}	185.09^{a}	0.17^{cd}	6.50^{c}

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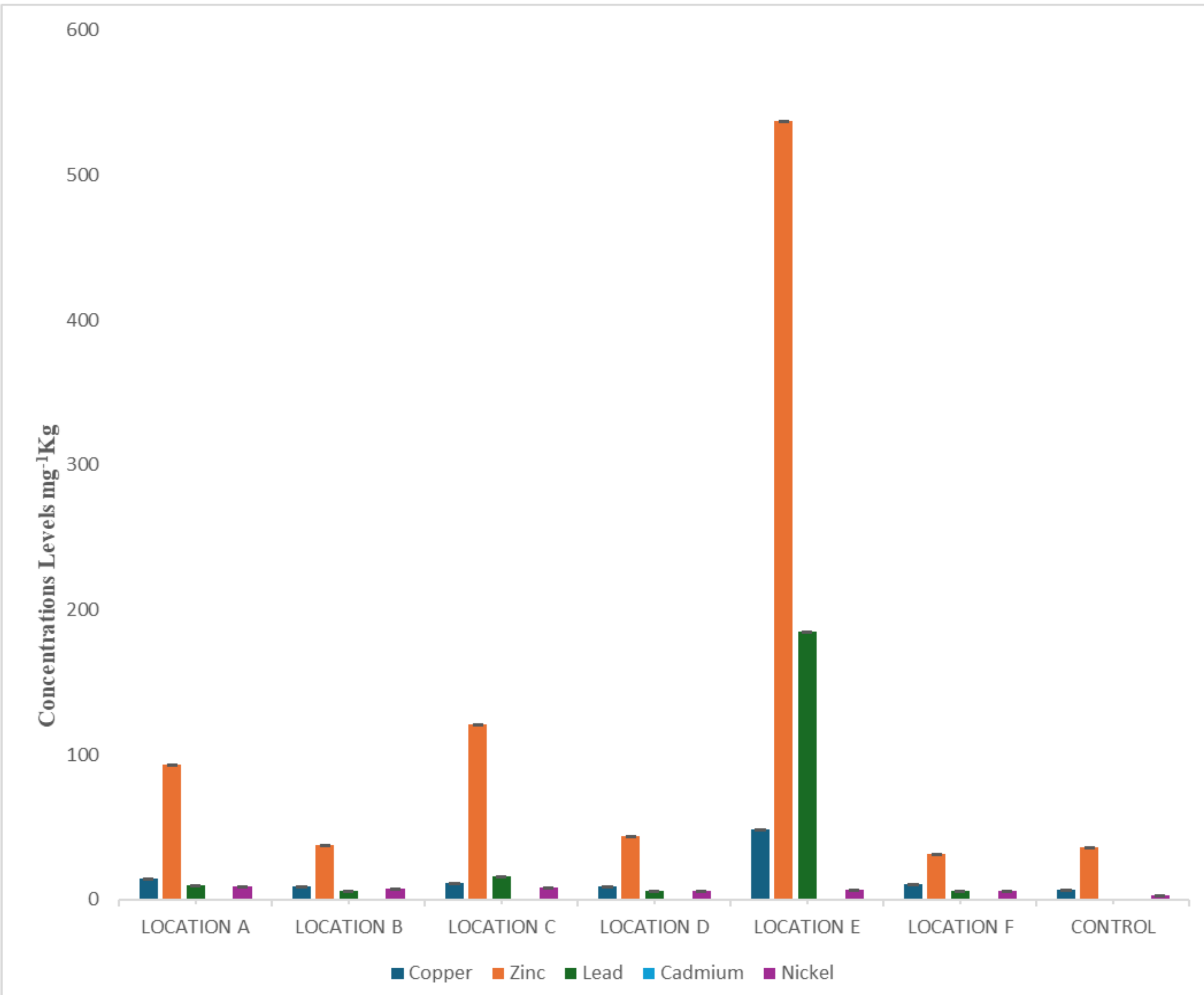
F	10.98^{d}	31.66^{g}	6.38^{d}	0.22^{ab}	5.90^{d}
CT	6.52^{g}	36.28^{f}	0.00^{f}	0.00^{e}	2.80^{e}
WHO*	1.00 – 12.00	12.00 – 60.00	0.30 – 10.00	0.002 - 0.5	0.1 – 5.0
FEPA**	36.00	140.00	85.00	0.80	35.00
USEPA***	63.00 – 140.00	200.00 – 00.00	50.00 – 300.00	1.40 – 39.00	50.00 – 210.0
FAO****	100.00	300.00	100.00	3.00	50.00

Means with different superscripts within the same column are significantly different (p≤0.05) according to Duncan's Multiple Range Test.

Source: **FEPA, 1991; *Ediene and Umoetok, 2017; ***USEPA, 2024; ****FAO – 2024.



Legend: A: Campus bus-stop; B: Mayfair Ibadan road; C: Campus road 1 gate; D: Lagere; E: Old toll gate; F: Mayfair Ede road; CONTROL: Tonkere)

Fig. 1: Variations in Heavy Metal Concentrations across the Study Sites

Similarly, the sources of the heavy metals in the study locations can be linked to vehicular traffic. This is similar to the findings of Odewande and Abimbola (2008) who reported high levels of Cu, Ni, Zn and Pb from vehicular traffic in roadside soils of the Ibadan metropolis, except Cd. Negahban and Mokarram (2021) also reported that the mean concentrations of Pb, Ni, Zn, Cu, and Cd in roadside soils were significantly higher ($p \leq 0.05$) with significant differences in the concentrations of these metals within 5 meters away from the road compared to areas far from urban settlements with less vehicular emissions. In the majority of cases in this study, the concentrations of Pb, Ni, Zn, Cu, and Cd exceeded permissible limits. This may be due to the impact of high traffic volume and transportation on the contamination of roadside soils. Consequently, it is advised not to use these soils for crop cultivation.

The heavy metal contaminations observed in the study locations' soil are similar to the research conducted by Ayedun *et al*. (2013) that the concentration of heavy metals decreased as the sampling distance from the road increased. This can be understood through the work of Morawska *et al*. (2008), who reported that approximately 40% of particulate emissions have diameters greater than 9 µm. Due to their high gravitational settling velocity, these particles quickly settle and are deposited within 10 meters away from the road. Around 20% of the particles have diameters between 1.0 and 9.0 µm and tend to be deposited within 40 meters from the road. About 40% of particles have diameters smaller than 1.0 µm, allowing them to remain suspended in the atmosphere for an extended period and potentially be carried far from the road. Most Cu in vehicular emissions is associated with particles ranging from 1.0 to 10 µm in size (Lough *et al*., 2005), with an average particle size of 6 µm (Sanders *et al*., 2003).

The concentrations of Cu and Zn in the control site soil were significantly ($p \leq 0.05$) higher than the WHO limit. This could have been a result of agricultural activities in the area a long time ago (Gimeno-García *et al*., 1996). Vehicular emissions could not have been the source, as the location is very far away from the major roads. According to Swaileh *et al.* (2004), soil contamination near roads due to traffic activities generally does not exceed a distance of 20 meters from the road. Also, at location CT, Pb and Cd were not detected at all while Ni was within the permissible limits. This suggests that the control site has minimal heavy metal contamination, as the more harmful and carcinogenic metals, like Cd and Pb, were not detected, just as stated by Ayedun *et al*. (2013). In locations C and E, the mean concentrations of Cu, Zn, Pb and Ni were significantly higher ($p \leq 0.05$) than the recommended safe limits. This is different from Pal and Roy (2021), who reported that most locations fall within safe ranges, except for some elevated values for certain areas. Similar to their work, Cd concentrations in this study fall within safe limits in all the locations, indicating no significant concern in this regard. The result of this work is also similar to Mbah and Arikwe (2010) who reported that it is necessary to identify the areas with higher concentrations of heavy metals for public health.

However, it is important to note that location E is particularly striking compared to the other locations, as the mean concentrations of Pb, Cu and Zn in that location were significantly higher ($p \leq 0.05$) than those found in the other locations. This is most likely due to its exposure to very heavy vehicular traffic with high vehicular emissions compared to other sites, being a major link between Ife and Ibadan routes.

Additionally, it is a trailer park which makes it more exposed to a greater amount of gaseous emissions from trailers and trucks using diesel as fuel. This finding agrees with that of Adedeji *et al*. (2020), who observed that the soil contamination with Cu, Pb, and Zn at the trailer park was extremely high and the total health risk assessments showed that children are at the greatest risk, both in terms of general health hazards and potential cancer risk. The elevated levels of Pb contamination observed in location E, which was significantly higher than the WHO permissible limits, suggest a significant environmental concern. The likely source of this contamination is vehicular emissions. Lead is a very toxic heavy metal even in very low concentrations, especially in children. It is toxic to both plants and animals and poses serious health risks, including neurological damage, developmental delays in children, and various other systemic effects. Unlike some other heavy metals, lead has no known beneficial role in biological systems, making any presence of it in the environment a particular concern (Raghunath *et al.*, 1999; Rahman and Singh, 2019).

Furthermore, the locations with the lowest concentrations of each heavy metal (location B for Cu, location F for Zn, CT for Ni, location D for Cd and Pb) indicate relatively lower levels of pollution. This may be attributed to the fact that CT is not exposed to vehicular emissions, B, D, and F are relatively newer roads as they were recently renovated, thus the heavy metal accumulation was minimal. These findings emphasized the importance of enforcing the ban on leaded gasoline and discouraging farms along major motor roadsides.

Conclusion

This study revealed that there is a major risk of Cu, Zn, Ni, Cd and Pb contaminations of the roadside soils of the experimental locations. The observed values were beyond the permissible limits for soils which calls for immediate remediation actions. While those that were still within safe limits call for continuous monitoring as heavy metals are not degradable, they would accumulate over time if the sources of these metals are not controlled. A comparison between the control location and the other sites indicates that the sources of these contaminants are anthropogenic and primarily would have come from vehicular emissions of heavy vehicular traffic, and tyre wear.

Consequently, the street dust in these areas could be contaminated with heavy metals, posing a health risk through inhalation and consumption of affected crops. Farming in these regions also poses a risk, as crops can absorb the metals from the soil. Hence, agricultural activities along heavy vehicular highways and vehicle parks should be discouraged. Also, there is a need for adequate governmental policies and strict enforcement of laws against illegal refineries and the production of leaded gasoline.

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