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Chronological Studies of Traffic Pollution Using Elemental Analysis of Tree Rings: Case Study of Haatso-atomic Road

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ABSTRACT: Mitigation of atmospheric pollution has been a topic of concern over the past decades. In this study, tree rings have been used to reconstruct past climates as well as to assess the effects of recent climatic and environmental changes on tree growth. Vehicular emission is one of the major sources of pollutants in the atmosphere and this study focused on the Haatso-Atomic road which over the years has been a spot for heavy vehicular traffic. Swietenia mahagoni (Mahogany) tree was logged and the rings counted and age determined to be 61 years spanning from 1957 to 2018. X-ray fluorescence (XRF) was used to investigate the presence of the following heavy metals. Heavy metals (Cu, Mn, Zn, Pb, Cd and Ni) which ranged from (3.15—9.84mg/kg), (2.58 – 5.49 mg/kg), (8.18 – 15.78mg/kg), (0.12—0.60 mg/kg), (0.01—0.09 mg/kg) and (0.10 – 0.99 mg/kg) respectively, from vehicular emissions were determined for annual rings spanning from 1957 to 2018 and surprisingly an increasing trend was observed with some the heavy metals exceeding WHO guidelines. Tree growth rates were calculated through ring width measurements and related to annual precipitation data spanning over the sampling period. It was observed that wet seasons correlate with high growth rates of trees while low precipitations seasons related to low or no growth rate of trees.

Keywords: Tree rings, Air pollution, Trace element, Vehicular emission.

INTRODUCTION

In an urban environment, heavy metal pollutants are released from many different anthropogenic sources such as, vehicles, industries, building construction or renovation, waste incineration, agriculture (fertilizers and pesticides etc) (Wajid et al., 2008; Popescu, 2011; Tanvir et al., 2017). This study will focus on emissions from vehicles, which are the most significant and widely recognized sources of pollutant in the atmosphere. Road transport activities over the past decades has increased as a result of world economic growth and improved human welfare (Siyan et al., 2015; Elena et al., 2018). Consequently, the rise of road transport activities causes high levels of pollutant emission which impacts negatively on the environment, especially farmlands, pastures, rivers and residences along heavy vehicular traffic areas and major highways (Oliva & Espinoza, 2007; Lee et al., 2010).

Motor vehicles introduce a number of toxic metals into the atmosphere which are later deposited on roadsides, increasing Pb, Zn, Cr, Ni, S, Fe, Cd and Cu concentrations

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in road dust and vegetation adjacent to the roadside (Lough et al., 2005). Pb comes from the exhaust of vehicles which is attributed to the addition of lead alkyl as an antiknock additive to gasoline to raise octane number of fuel. Zinc also comes from the wear of tires and contains additives in lubricating oils emitted from vehicle exhausts. Copper emissions are also as a result of the wear of brake linings (Vecchi et al., 2007; Abu-Allaban et al., 2003; Garg et al., 2000). At high levels or concentration, these metals can cause serious health risks to humans.

Most air pollution studies in Ghana are based on atmospheric aerosols collected on particulate matter filters (Aboh et al., 2012; Benjamin & Ayatulai Abdul, 2018). This is an active method that gives an idea of trace-element atmospheric pollution only during the sampling time (Kathie et al, 2010). The measurements require sophisticated technical equipment which are generally expensive. In Ghana, it is difficult to use air samplers in remote areas due to lack of electricity. The usefulness of bioindicators such as mosses, tree rings and lichens in determining trace- and heavy-metal concentrations in different geographical areas has been discussed and demonstrated in several studies (Markert, 2003; Tan et al., 2005; Padmo et al., 2003). Mosses and lichens are used because they more readily reflect local changes in heavy-metal deposition and they are also better accumulation indicators (Palmieri et al, 2016). A disadvantage of using mosses and lichens as passive samplers is that their growing range is limited. (Szczepaniak & Biziuk, 2003).

A number of studies have shown the ability of trees to take up and incorporate pollutants into their annual growth rings (Nabais et al., 2001; Speer, 2010). Indeed, tree-rings have been used to provide annual records of pollution over decades, tracing pollutants on a spatial and temporal scale in relation to their sources (Cocozza et al., 2016; Danek et al., 2015; Odabasi et al., 2015). In this study, we are interested in vehicular emission chronology recorded in tree rings over the past fifty (50) years at Haatso-Atomic road, in the Greater Accra Region of Ghana. Therefore, concentrations of heavy metals in tree-rings were examined to reflect heavy metals pollution variations and we also examined growth rates of trees in relation to rainfall patterns around the sampling points. This phenomenon is summarized in figure 1, which shows that growth rates are higher in wet seasons than in dry seasons.

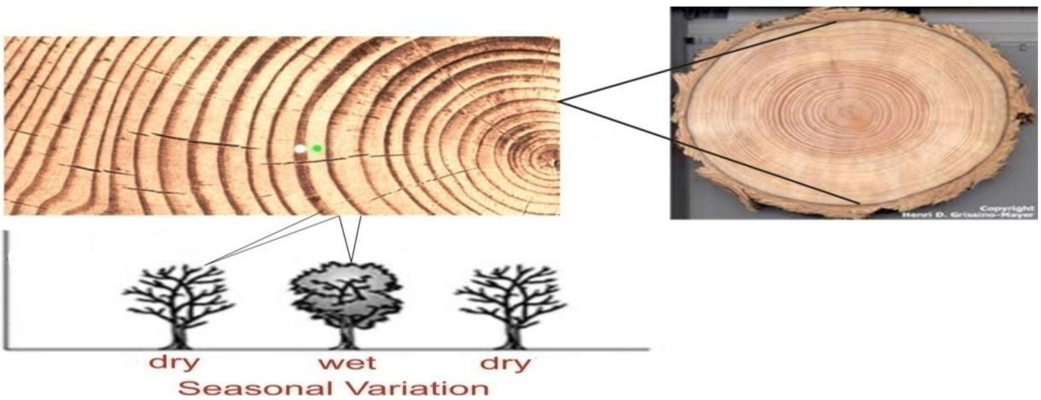

Fig. 1. Schematic showing tree rings growth with respect to seasonal variations (Yorke, & Omotosho, 2010).

MATERIAL AND METHODS

Samples analyzed for this study were taken from Haasto-Atomic road in the Greater Accra Region of Ghana. The Haatso-Atomic road is adjacent to the Ghana Atomic Energy Commission (GAEC), and is located on this coordinate (5° 40′ 9.7″ N, 0° 12′ 27″ W). The road side vegetation in the study area is dominated by Azadirachta indica (Neem tree) and Swietenia mahagoni (Mahogany tree). The area is well suited for the study of pollution effects because of the persistent vehicular traffic on the main road. Figure 2, shows a map of the sampling site, with sampling locations indicated in red circles along the main road.

In 2018, Swietenia mahagoni (mahogany), which is about one meter (1 m) from the main road was logged and cross-sections taken for tree ring analysis. The choice of this tree species was dependent on its ability to produce annual growth rings which is a prerequisite for trees being used as proxies.

Cross-sections of tree samples were dried in the laboratory under supervision. Radial subsections were sampled from these sections and used for energy dispersive x-ray emission analysis and also for growth rate determination. The total length of each radial subsection from the pith to the cortex was measured to the nearest millimeter.

Radial sections of the trees with clear growth ring patterns were electronically scanned, counted and growth widths estimated using image J software. Annual rings cut from the radial cross-sections were analyzed for heavy metal composition using X-ray fluorescence analysis.

RESULTS AND DISCUSIONS

From the tree ring counting analysis performed, 61 annual growth rings were counted. Since the tree was logged in 2018, the age of the tree could be estimated by subtracting 61 from 2018, which gives 1957 as the birth year of the tree analyzed as indicated in Figure 3.

From Figure 4, one can observe a consistent increase in the growth of the tree from 1957 to 1971, after which there was a sudden sharp decline of growth, which could be attributed to harsh environmental conditions such as drought, a typical growth inhibitor. From 1977 to 1980, there was an average growth of the tree which was the highest life-time growth recorded for the tree i.e. 8mm growth. Soon after this growth, there was long period of decline till 2018 when the tree was logged. This prolonged period of decline in growth could only be attributed to harsh seasonal variations or heavy metal pollution from vehicular emission. Figure 5 further shows the growth rate patterns for the tree analyzed over the period of 1957 to 2018. Negative growth was observed in 1974, 1984 and 2018. The negative growth in 2018 indicate vehicular emission have increased exponentially over the last decades.

Fig. 2. Map showing roadside air quality monitoring site (sampling sites are shown in red circles)

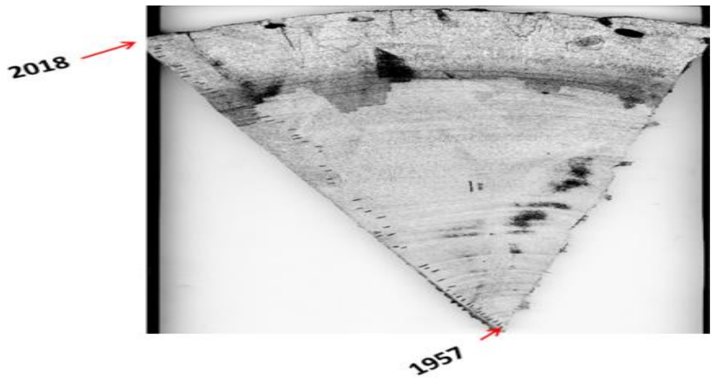

Fig. 3. Photograph showing the pith (year the tree was born) and the bark (year the tree was logged)

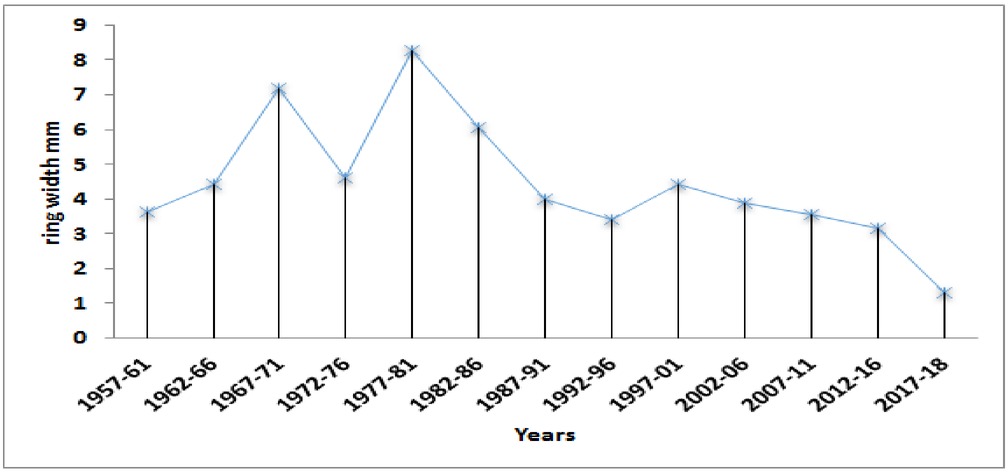

Fig. 4. A plot showing tree ring widths averaged over five-year periods.

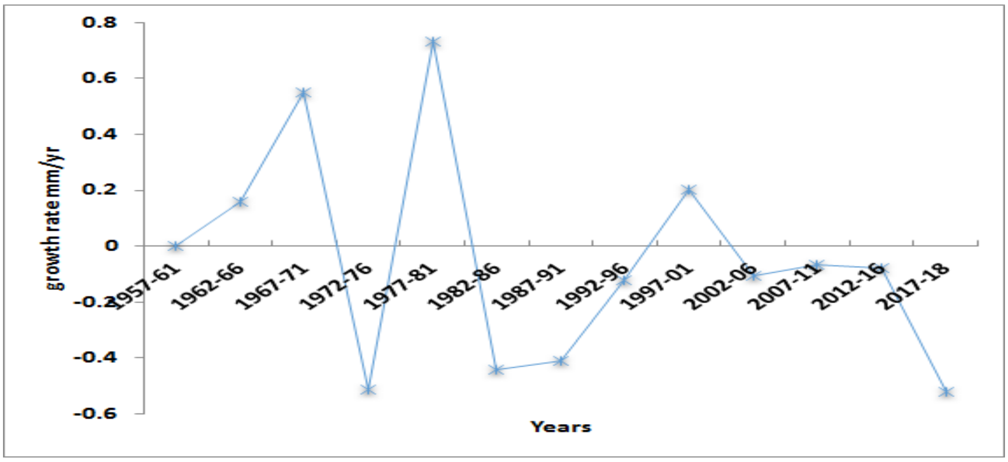

Fig. 5. Plot showing growth rates of trees over a 61-year period

Tree rings' growth were compared with annual wet and dry events recorded by the Metrological Department for Accra.

From the Figure 6, which shows the annual ring width for the tree sample, some years recorded very high growth while others experienced a sudden steep decline in growth. The years 1965, 1968, 1970, 1975, 1979, 1983, 2011 recorded very high growth, which can be attributed to conducive environmental conditions such as enough rainfall during those years. The figure above is used to compare the wet and dry years, in Table 1 (Yorke and Omotosho, 2010).

From X-RF analysis of the annual tree rings, Six (6) elements Cu, Zn, Ni, Mn, Pb and Cd. were identified and quantified.

Copper (Cu) concentrations range between 3.15 – 9.86 mg/kg at Haatso-Atomic road. As the data show in Figure 7, the concentration of copper started increasing from 1957 to 1984, thereafter the amount of copper metal fluctuated from 1984-1988 then followed by an increase in the trend till 2017. The amount of copper, however, reached a peak in 2017 of a value 9.86 mg/kg. The accepted limit of copper for plants is 10 mg/kg recommended by WHO (Zigham Hassan et al 2012). The concentration of copper recorded was below the accepted limit. The consistent increase in the levels of Cu can be attributed to the increase in traffic activities on the stretch of the road where the samples were taken. From literature, Vecchi et al. (2007), Cu and zinc have been identified to be good indicators of traffic emissions from brake wear and tear matter emissions.

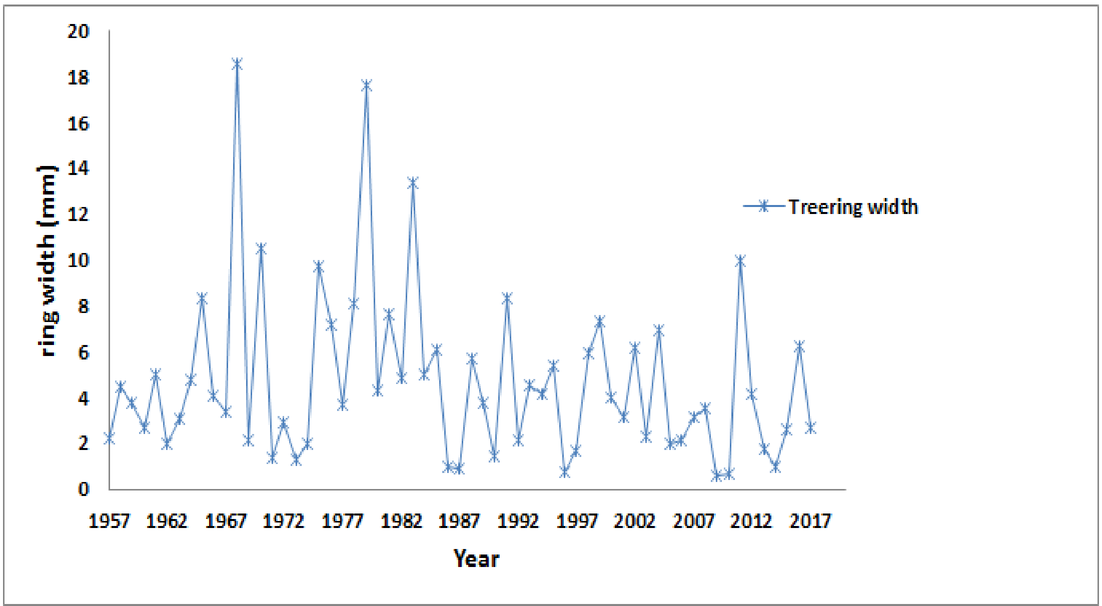

Fig. 6. Illustration of the annual ring width estimated for the tree.

Table 1. Classification into wet and dry rainfall years at Accra (Yorke & Omotosho, 2010)

Accra Rainfall			
1968	Wet year	1976	Dry year
1973	Wet year	1977	Dry year
1974	Wet year	1978	Dry year
1980	Wet year	1983	Dry year
1988	Wet year	1992	Dry year
1991	Wet year	1993	Dry year
1995	Wet year	1994	Dry year
2002	Wet year	1998	Dry year
		2000	Dry year

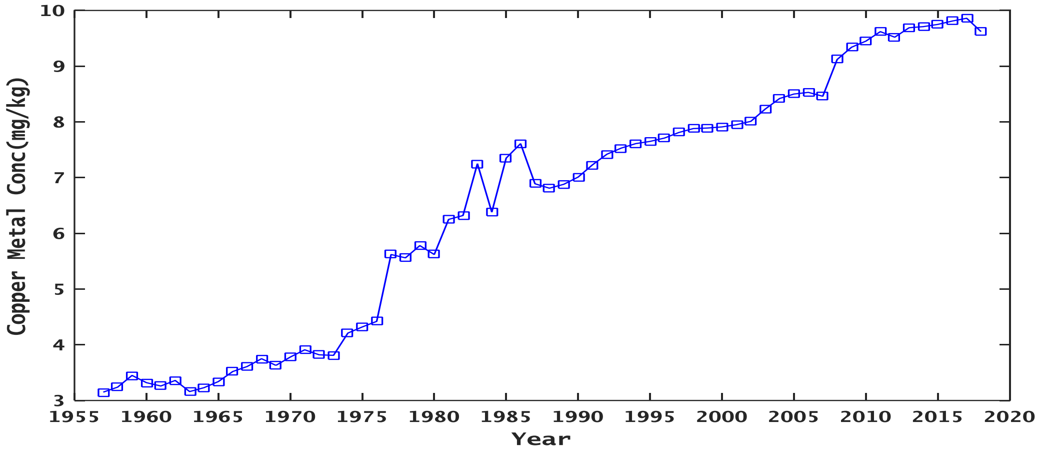

Fig. 7. Copper concentration in Swietenia mahagoni at Haatso-Atomic road

Zinc (Zn) concentrations range between 8.18 – 15.78 mg/kg as shown in Figure 8 below. As the data show, the amount of zinc metal fluctuated from 1964-1999. The highest amount of copper was recorded in 2018, a value of 15.78mg/kg. The zinc values recorded at the site were below the WHO's recommended limit of zinc in plants, that is 50 mg/kg (Afzal Shah et al., 2011). The consistent increase in the levels of Cu can be attributed to the increase in traffic activities on the stretch of road where the samples were taken. From literature, in their study, Talebi & Tavakoli-Ghinani (2008) observed high concentrations of zinc at the south and west areas with higher traffic densities within the city of Isfahan of 220 – 418 ng/m^3.

Cadmium (Cd): there was observed characteristic rise and fall in cadmium from 1957 to 1995 in which cadmium sharply increased and decreased. The highest amount of cadmium is 0.09 mg/kg and recorded in the year 2018. The maximum limit of Cd in plants, recommended by WHO, is 0.02 mg/kg. The presence of cadmium at the sampling site may be accredited to vehicular exhaust emission due to its existence in gasoline and as a result of corrosion of car parts as established by lough et al.(2012). Potential sources of cadmium include vehicular exhaust emissions of tire abrasion; open burning of municipal wastes containing Ni-Cd batteries from vehicles (Awan et al, 2011).

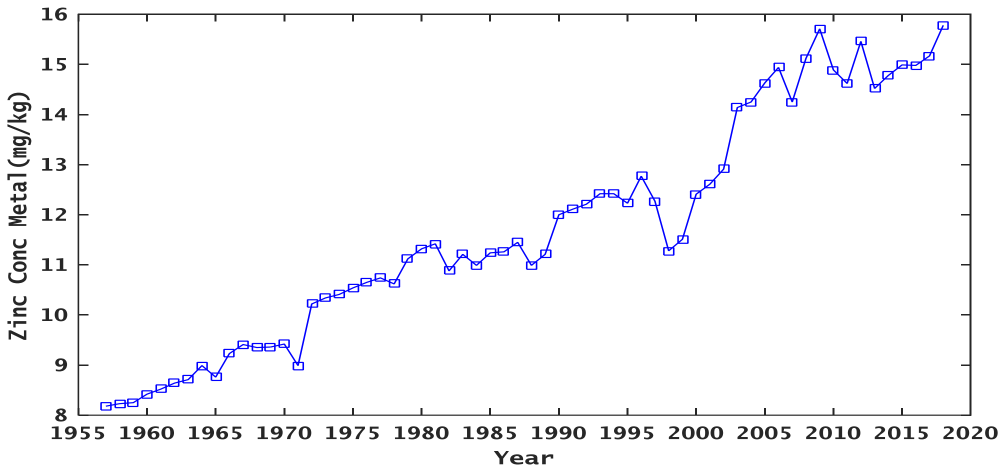

Fig. 8. Zinc Concentration in Swietenia mahagoni at Haatso-Atomic road

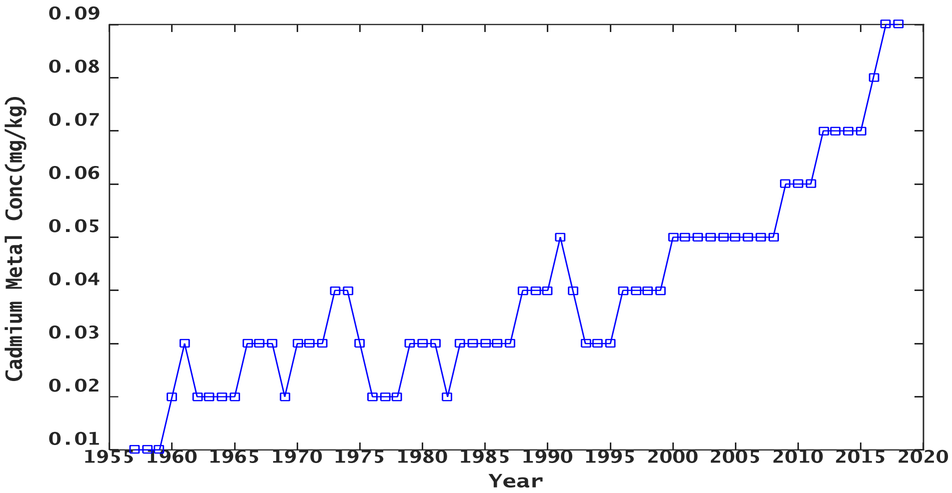

Fig. 9. Cadmium concentration in Swietenia mahagoni at Haatso-Atomic road

Lead (Pb): from Figure 10, there is a characteristic rise and fall in the concentration of lead from 1957 to 1982 in which the concentration trend increased sharply and decreased till 2018. The highest amount of lead of 0.60 mg/kg was recorded in 1986. The maximum limit of lead in plants, recommended by WHO, is 2 mg/kg. Prior to the global phase out of leaded fuels, lead concentrations in ambient air ranged from 2 µg/m^3 to 188 µg/m^3 (2000 − 188000 ng/m^3) which was above the annual Ghana's EPA guideline value of 2.5 µg/m^3. After the phase out of lead in gasoline, lead concentrations ranged from 0 – 1.97µg/m^3 (0 – 1970 ng/m^3) (Nerquaye-Tetteh, 2009). A study conducted by Safo-Adu *et al*. (2014) also revealed low particulate lead levels in the ambient air along the Accra-Tema highway. The low lead levels recorded in this study thus confirm a progressive fading out of leaded fuel.

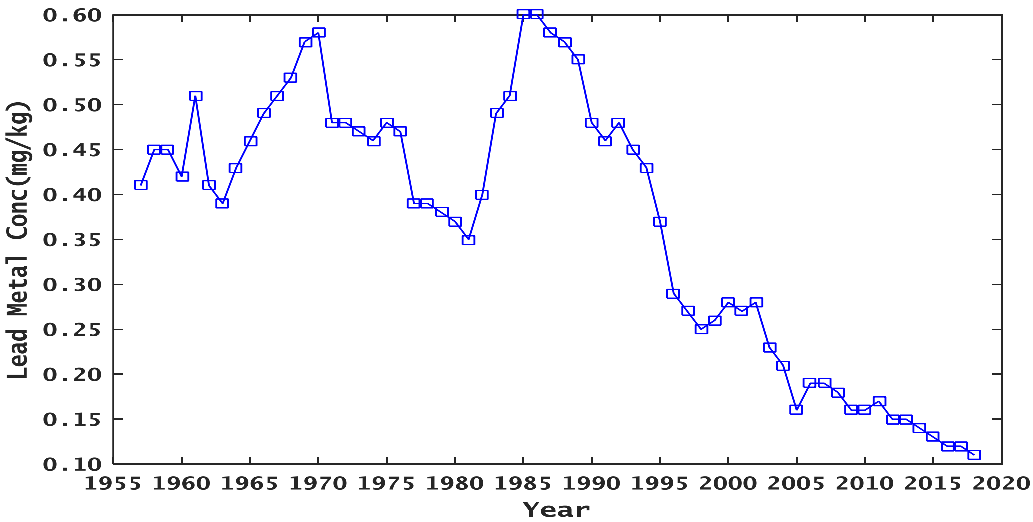

Fig. 10. Lead concentration in Swietenia mahagoni at Haatso-Atomic road

Manganese (Mn) concentration ranges between 5.94 – 2.58 mg/kg as shown the Figure 11. There was a characteristic rise and fall in manganese from 1957 to 2011 in which there was an increase in the trend till 2018. The highest amount of manganese of 5.94 mg/kg was recorded in 2018. The zinc values recorded at the site were above the WHO guideline value of 2.14 mg/kg. Manganese concentrations were predicted to be high due to the Methylcyclopentadienyl Manganese Tricarbonyl (MMT) additive in fuels.

Nickel (Ni) concentration ranges between 8.18 – 15.78 mg/kg as shown the figure 12. As the data show, the amount of nickel increased from 1957-2018. The highest amount of 0.99 mg/kg was recorded in 2018. The nickel value recorded at the site was above the WHO's recommended limit of nickel in plants is 10 mg/kg (Zigham Hassan et al 2012). Potential sources of nickel is open burning of municipal wastes containing Ni-Cd batteries from vehicles (Awan et al, 2011)

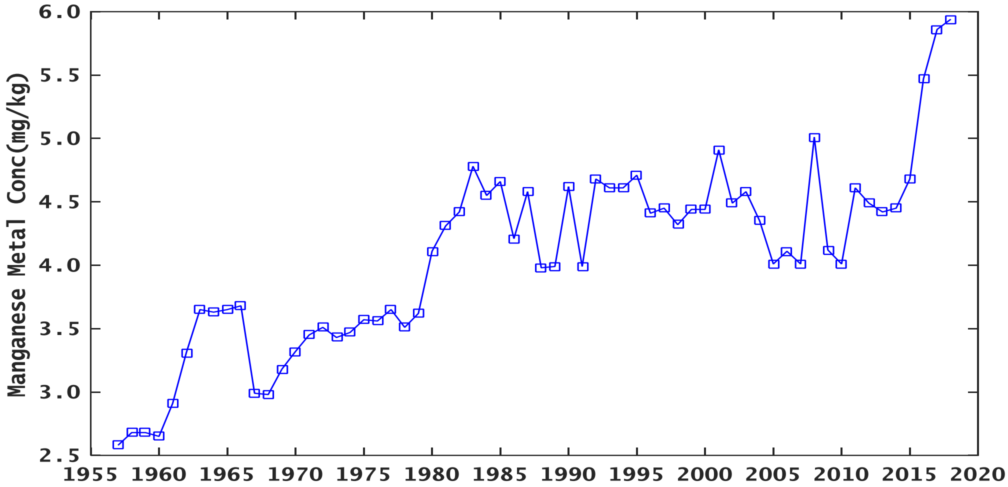

Fig. 11. Manganese concentration in Swietenia mahagoni Haatso-Atomic road

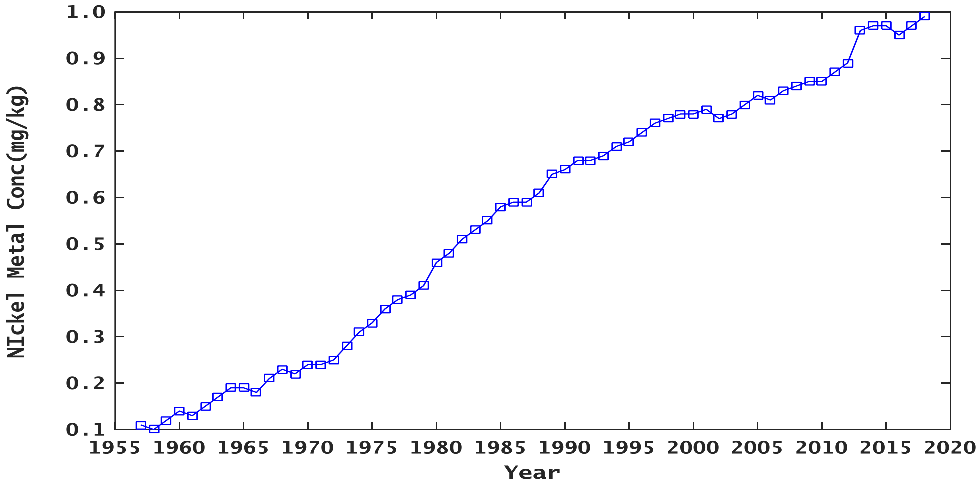

Fig. 12. Nickel concentration in Swietenia mahagoni at Haatso-Atomic road

CONCLUSION

This work investigated elemental composition and ring width of trees (which span from 1957 to 2018) along the Haatso-Atomic road of the Greater Accra region of Ghana. The range of concentrations of heavy metals such as Cu, Mn, Zn, Pb, Cd and Ni resulting from vehicular emissions for annual rings were determined to be (3.15—9.84 mg/kg), (2.58 – 5.49 mg/kg), (8.18 – 15.78 mg/kg), (0.12—0.60 mg/kg), (0.01—0.09 mg/kg) and (0.10 – 0.99 mg/kg) respectively. Surprisingly, an increasing concentration trend was observed for these heavy metals with some concentrations exceeding the WHO guidelines. This study has shown that the levels of almost all of these heavy metals (Zn, Cu, Pb, Mn and Cd) have been increasing exponentially over the past decades. This worrying trend raises lots of concerns and if not halted can have catastrophic effect on the vegetation of the study area. The study also related tree growth rings to annual rainfall patterns and observed that high precipitation (wet seasons) leads to increased growth of tree rings. An average tree-ring growth of 8 mm was recorded which was the highest lifetime growth documented for a tree. Absence of growth of tree rings has been associated with harsh environmental conditions such as drought (dry seasons).

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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