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Research Article

CHRONOLOGICAL STUDIES OF TRAFFIC POLLUTION USING ELEMENTAL ANALYSIS OF TREE RINGS: A 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 – 9.84 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, 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 whiles low precipitations seasons related to low or no growth rate of trees.

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.) (Celik et al., 1995). This study will focus on emissions from vehicles and industries, which are the most significant and widely recognized sources of pollutant in the atmosphere (Oliva and Espinoza., 2007). Road transport activities over the past decades has increased as a result of world economic growth and improved human welfare. Consequently, the rise of road transport activities causes high levels of pollutant emission which impact negatively on the environment, especially farmlands, pastures, rivers and residences along heavy vehicular traffic areas and major highways.

Motor vehicles introduce a few toxic metals into the atmosphere which are later deposited on roadsides, increasing Pb, Zn, Cr, Ni, S, Fe, Cd and Cu concentrations in road dust and vegetation adjacent to the roadside. 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). At high levels or concentration, these metals can cause serious health risks to humans. The prolonged intake of more than 300 mg per day of zinc can lead to disturbance of copper metabolism, causing low copper status, reduced iron function, impaired immune function; can cause abdominal pain, nausea, vomiting, diarrhea, epigastric pain and fatigue (Fosmire, 1990).

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Monitoring of air pollution using bioindicators is emerging as a potentially effective and more economical alternative in performing direct ambient air measurements (Rühling and Tyler., 1968). Most air pollution studies in Ghana are based on atmospheric aerosols collected on particulate matter filters. This is an active method that gives an idea of trace-element atmospheric pollution only during the sampling time. It requires long-term sampling at many sampling sites. The measurements require sophisticated technical equipment which is 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 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. A disadvantage of using mosses and lichens as passive samplers is that their growing range is limited. Mosses and lichens generally do not grow in dry areas, making it difficult to perform studies across different types of biomes or at all sites where air pollution monitoring is needed (e.g. at industrial sites).

Even though mosses and lichens have shown good indication as bio-indicator for air pollution, it cannot be used as proxies for historical environmental information and reconstructing of climate back in time. Air pollutant concentrations are generally higher in tree rings. In this context, tree rings offer a useful tool to interpret historical changes in the atmospheric environment. Trees in temperate and boreal forests form a new wood-growth layer every year (annual ring). The physical and chemical characteristics of the wood cell formed in each particular year reflect the environmental conditions in which the tree grew in that year and can be used to reconstruct past environmental conditions (including climatic conditions and air quality).

In this study we are interested in vehicular emission chronology recorded in tree rings over the past fifty years at Haatso-Atomic, in the Greater Accra Region of Ghana. Tree-ring based climate reconstructions are important in developing and validating climate models for understanding past climate conditions. Therefore, in this study concentrations of heavy metals in tree-rings were examined to reflect heavy metals pollution variations. The study also examined growth rates of trees in relation to rainfall patterns around the sampling points. This phenomenon is summarized in Fig. 1, where growth rates are higher in wet seasons that in dry season.

MATERIALS AND METHODS

Study area and samples

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 roadside 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. Fig. 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.

Preparation of samples

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 for growth rate determination. The total length of each radial subsection from the pith to the cortex was measured to the nearest millimeter.

Samples analysis

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 DISCUSSION

Tree ring counting and growth rates

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 Fig. 3.

From Fig. 4, one can observe a consistent increase in the growth of the tree from 1957 to 1971, after when there was a sudden sharp decline of growth,

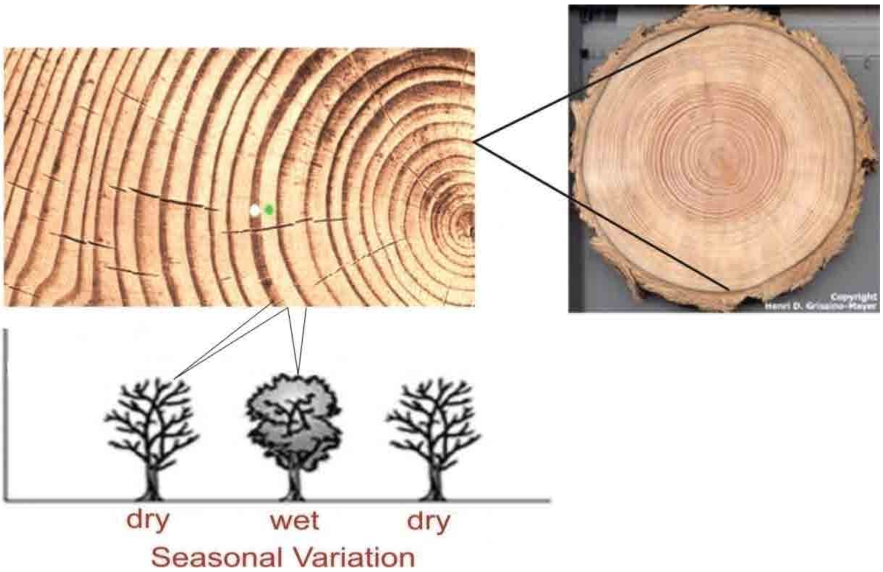

Fig 1. Schematic showing tree rings growth with respect to seasonal variations (Yorke and Omotosho., 2010).

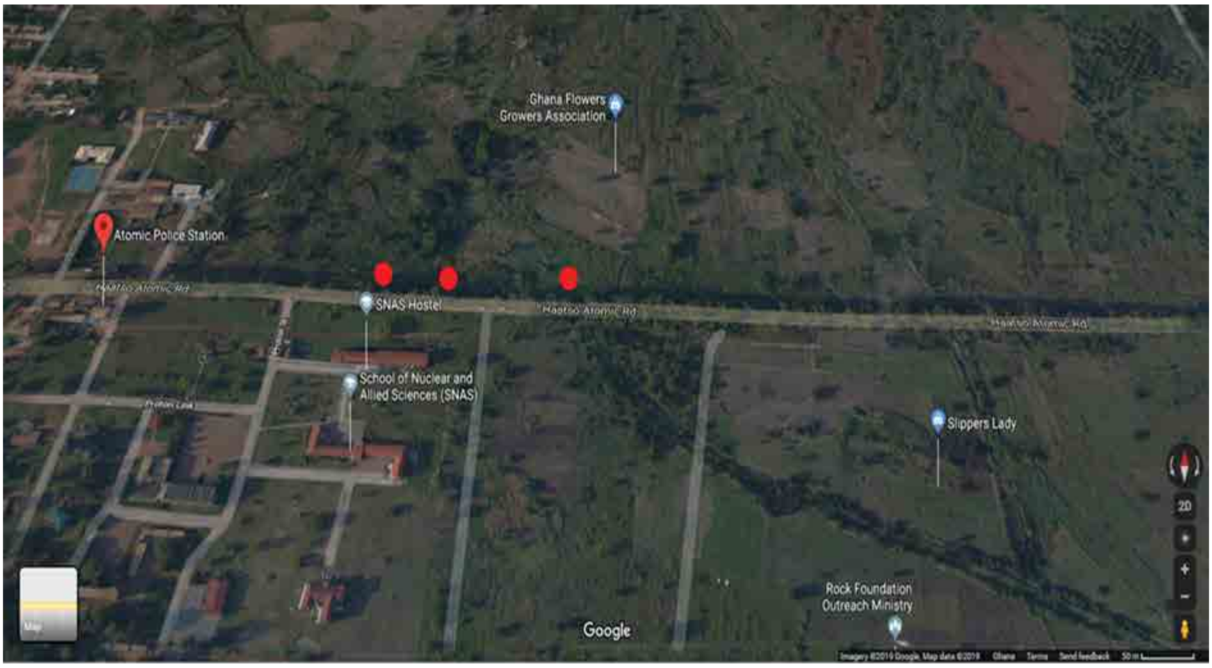

Fig 2. Map showing roadside air quality monitoring site (sampling sites are shown in red circles).

which could be attributed to harsh environmental conditions such as drought which inhibits growth. 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., 8 mm 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. Fig. 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

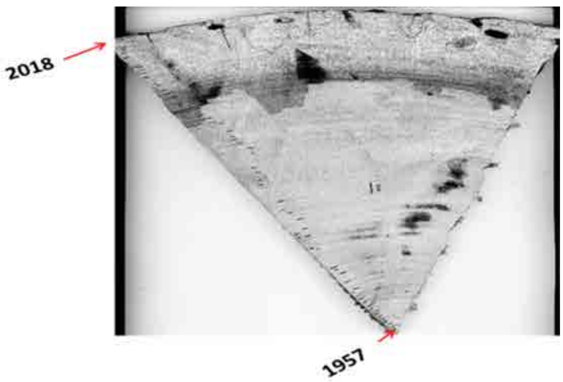

Fig 3. Photograph showing the pith (year the tree was born) and the bark (year the tree was logged).

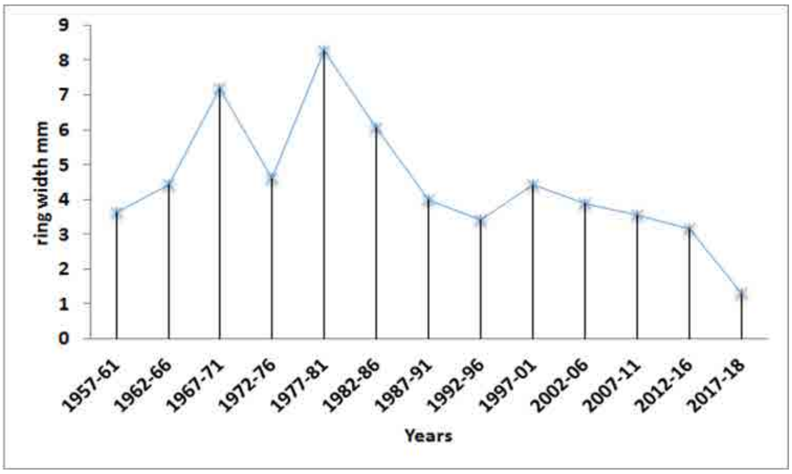

Fig 4. A plot showing tree ring widths averaged over five-year periods.

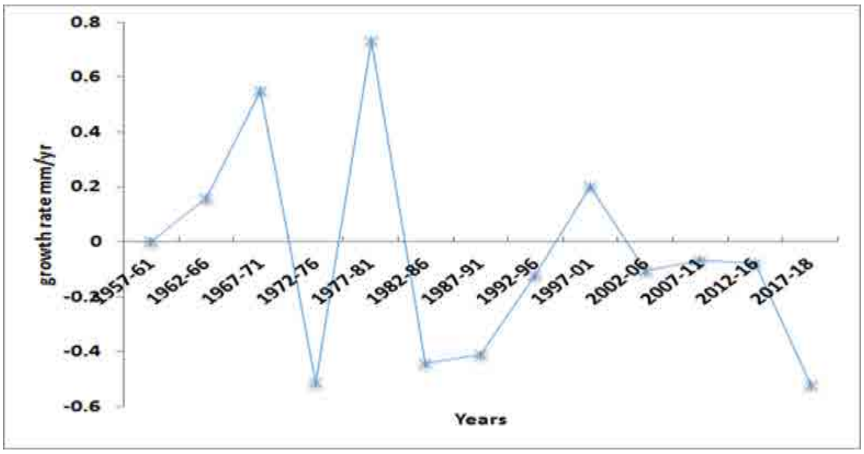

Fig 5. Plot showing growth rates of trees over a 61-year period.

vehicular emission have increased exponentially over the last decades.

Tree ring growth and climate relationship

Tree growth rings were compared with annual wet and dry events recorded by the Metrological Department for Accra. From the Fig. 6, which shows the annual ring width for the tree sample, some years recorded very high growth whiles others experienced a sudden steep dip 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).

Elemental composition of tree rings

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 ranges between 3.15–9.86 mg/kg at Haatso-Atomic road. As the data show in Fig. 7, the concentration of copper started rising at 1957 to 1984, thereafter amount of copper metal fluctuated from 1984-1988 then followed an increase in 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 road where the samples were taken, from literature (Vecchi et al., 2007) Copper and zinc has been definite to be a good indicator of traffic emissions from brake wear and tear matter emissions.

Zinc (Zn) concentrations range between 8.18–15.78 mg/kg as shown in Fig. 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 15.78 mg/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

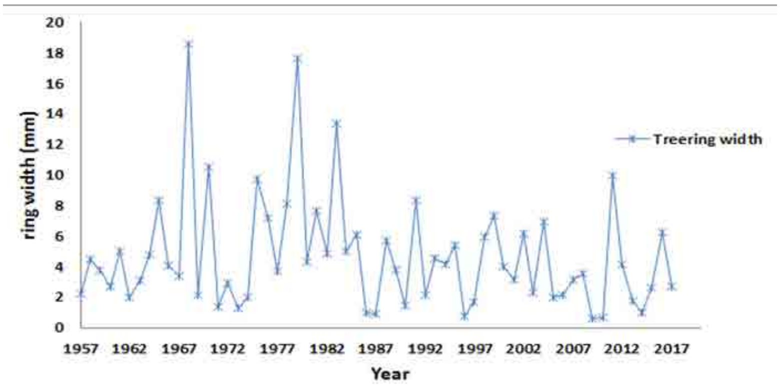

Fig 6. Illustration of the annual ring width estimated for the tree.

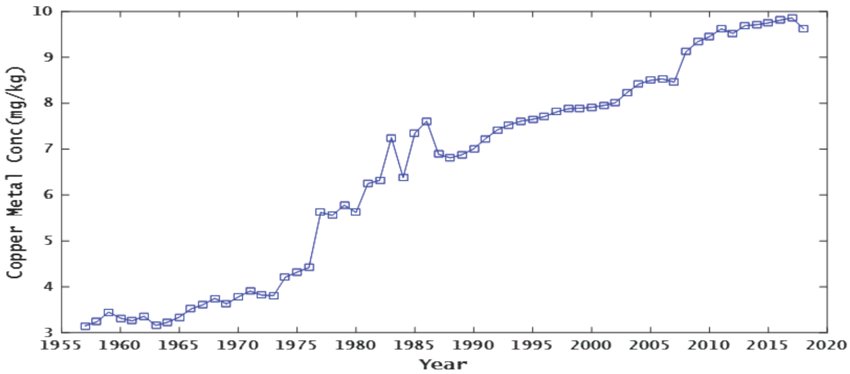

Fig 7. Copper concentration in Swietenia mahagoni at Haatso-Atomic Road.

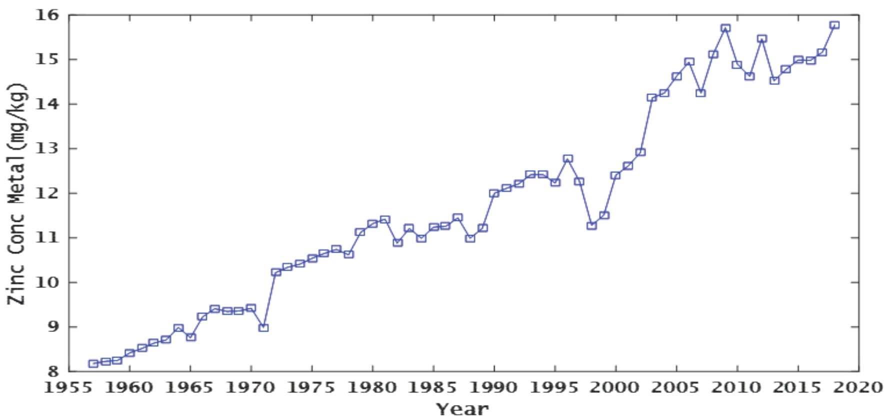

Fig 8. Zinc concentration in Swietenia mahagoni at Haatso-Atomic Road.

Table 1. Classification into wet and dry rainfall years at Accra (Yorke and 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
2004	Wet year	2000	Dry year

be attributed to the increase in traffic activities on the stretch of road where the samples were taken, From literature (Talebi and Tavakoli-Ghinani., 2008) in their study 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 a 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 recorded in the year 2018. The maximum limit of Cd in plants, recommended by WHO, which 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 an effect of corrosion of car parts as established by the European Commission (EC, 2001). Potential sources of cadmium include vehicular exhaust emissions of tyre abrasion; open burning of municipal wastes containing Ni-Cd batteries from vehicles (Awan et al., 2011) (Fig. 9).

Lead (Pb), from Fig. 10 there is a characteristic rise and fall in 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. Before the phase out of leaded fuels, lead concentrations in the ambient air ranged from 2 µg/m^3 to 188 µg/m^3 (2000- 188000 ng/m^3) which was above annual EPA Ghana guideline value of 2.5 µg/m^3. After the phase out of lead in gasoline, lead concentrations ranged from 0–1.97 µg/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 confirms a progressive fading out of leaded fuel.

Manganese (Mn) concentration ranges between 5.94–2.58 mg/kg as shown the Fig. 11 below. 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

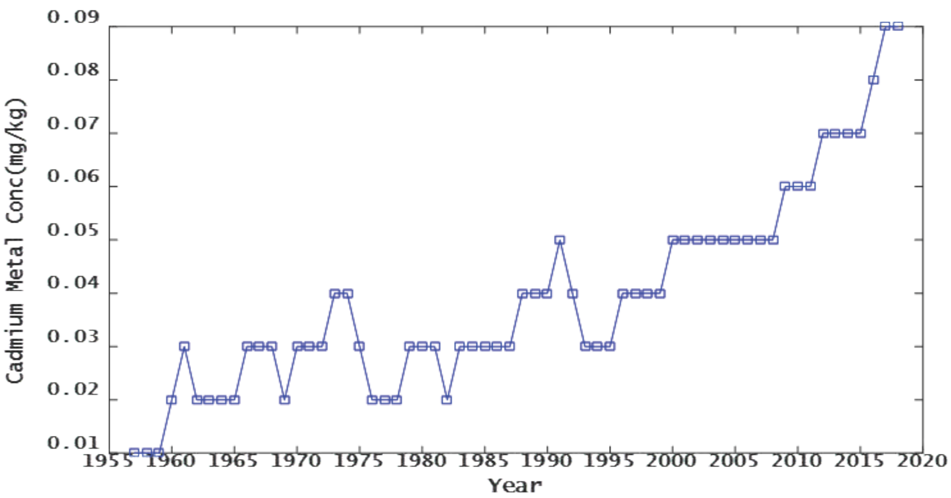

Fig 9. Cadmium concentration in Swietenia mahagoni at Haatso-Atomic Road.

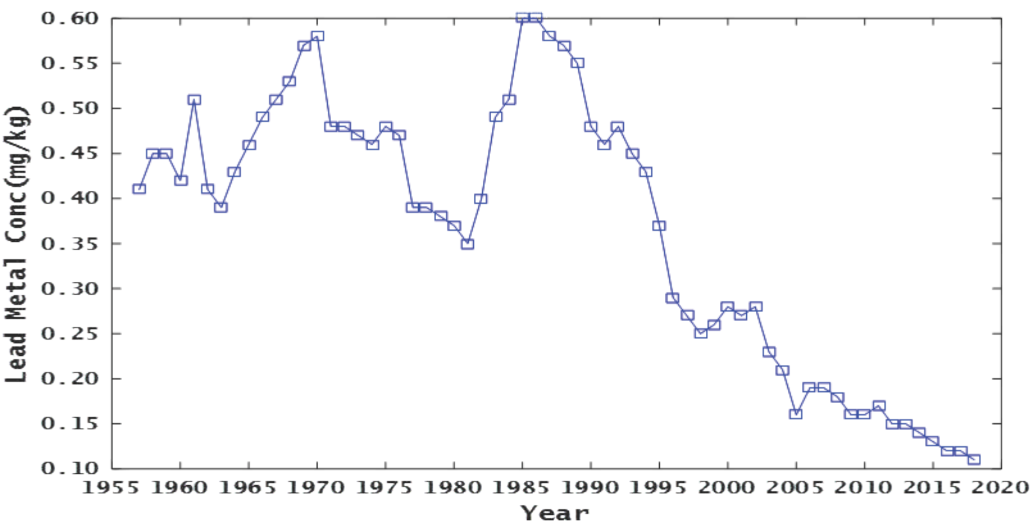

Fig 10. Lead concentration in Swietenia mahagoni at Haatso-Atomic Road.

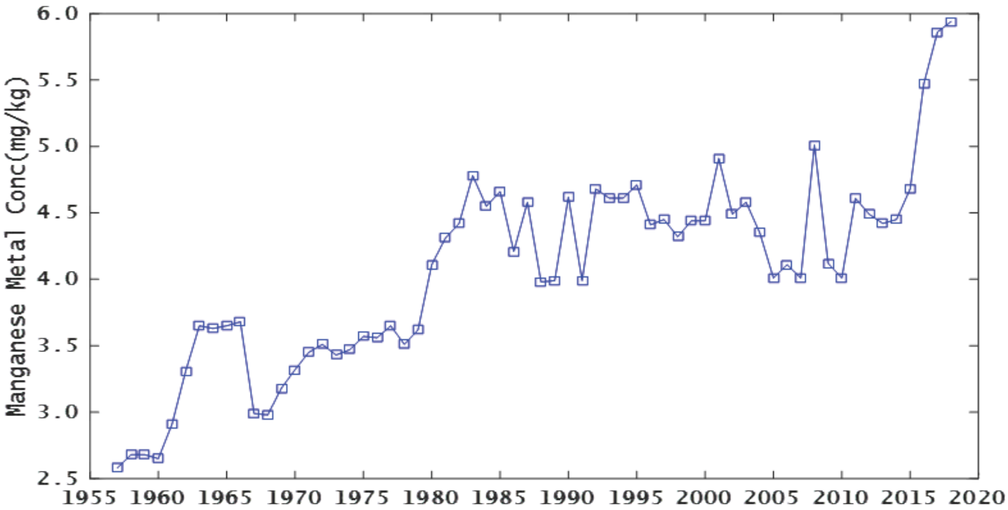

Fig 11. Manganese concentration in Swietenia mahagoni Haatso-Atomic Road.

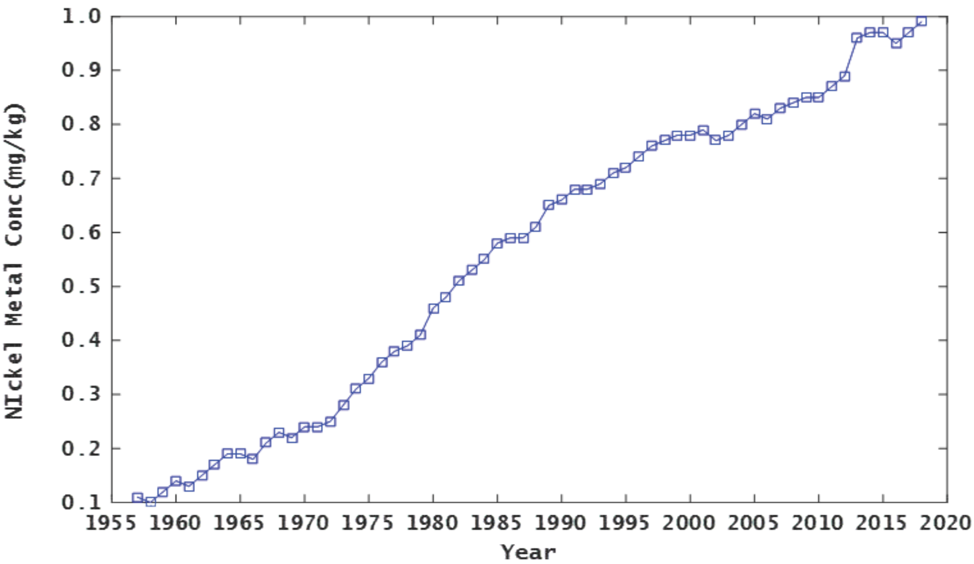

Fig 12. Nickel concentration in Swietenia mahagoni at Haatso-Atomic Road.

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 Fig. 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 recommended limit of nickel in plants is 10 mg/kg (Zigham Hassan et al., 2012). Potential sources of nickel are open burning of municipal wastes containing Ni-Cd batteries from vehicles (Awan et al., 2011).

CONCLUSION

Tree rings have been used as proxies to establish pollution chronology from vehicular emission into the atmosphere for a period spanning from 1957 to 2018. Tree growth rings have been related to annual rainfall patterns. From this study, high precipitation (wet seasons) has been linked to increased growth of tree rings. No growth of tree rings has also been linked to harsh environmental conditions such as drought (dry seasons).

Pollution trends from vehicular emissions, which contribute to the increase of Zinc, Copper, Lead, Manganese and Cadmium in the atmosphere, have been determined over a period from 1957 to 2018. A worrying trend observed for almost all the heavy metals as the levels of these metals have been increasing exponentially over the past decades. This raises lots of concerns because if this trend is not halted, it can disturb the study area as some heavy metals recorded values which exceed the WHO guidelines on the limits of these metals.

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