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Arsenic: A toxic trace element of public health concern in urban roadside soils in Dar es Salaam City

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Abstract

Motor vehicles have been associated with high levels of trace metals in urban soils and the metals are mostly emitted though exhaust emissions, brake pad and tire abrasions. This study reports the levels of arsenic in roadside soils obtained from the surface at a depth of 0-5 cm in the Dares Salaam city which has the highest average daily traffic density in the country. The soils samples were collected at 1 m, 5 m, 15 m, 35 m, 50 m and 150 m distances from the road edge at each sampling site. Results showed that roadside soils were contaminated with arsenic and its levels ranged from 0.03 - 0.65 ppm (mean = 0.23 ppm). The amount of arsenic in the soil at each site decreased exponentially with increasing distance up to 35 m distance from the road edge. The Analysis of Variance (ANOVA) test showed that average arsenic levels in the soils varied significantly with study sites (F = 4.14, p = 0.01, n = 5) while the linear regression between average arsenic in all soil samples and average daily traffic density was statistically insignificant ($r^2 = 0.47$, p = 0.21, n = 5). However, the observed spatial distribution of arsenic with increasing distance from the road edge strongly suggests that arsenic levels above background level in the study sites owe its source from traffic emissions.

Key words: arsenic, automobile, Dar es Salaam, road traffic, soils, trace metals

1. Introduction

The number of vehicles operating in Dar es Salaam, the largest city of all in Tanzania, is 18,711 (52%) out of the 35,718 commercial vehicles licensed in 1998 [1]. The 1989 study reported that the traffic fleet in major arterial roads in Dar es Salaam City ranged between 7,000 to 35,000 in 1990s [2] and currently the traffic fleet is between 80,000 to 150,000 [3,4]. High traffic density increases risks of trace metal pollution of urban air and soils. Some studies have shown that fuels, oils, brake pads and tyres have traces of metals such as As, Cd, Cr, Pb, and Zn which may eventually be released into the environment in the course of operation of vehicles [5-8]. The trace metals emitted from motor vehicles usually end up into roadside soils and streams although some of the particulate metals might remain suspended in the air particularly in a dry season [5,6,9,10]. However, the trace metals deposited into the soils may, in the long run, be absorbed by vegetation and vegetables grown on them [11-15] though the bioavailability of trace metals to plants depends on factors such as soil pH, organic matter content, precipitating agents, and physico-chemical form of the trace metals [15,16]. However, humans are exposed to heavy metals and arsenic absorbed and accumulated by plants through consumption of their edible parts while indirect exposure may occur through consumption of contaminated animal products [17,18]. The chronic exposure risks to trace metals is inevitable due to the fact that vegetables and vegetation growing in urban contaminated soils can uptake and bioaccumulate high levels of Pb, Zn, Cd, Co, Cr, Cu, and As relative to the soil levels [11-14] while some reports showed that tissues and milk from dairy cows fed with contaminated fodder had detectable levels of heavy metals [14,17,19].

Trace metals found in urban roadside soils owe their sources mostly from either the automobile traffic emissions or natural soil formation. We can qualitatively distinguish between trace metals of natural origin from those of motor vehicular origin by establishing the spatial distribution curve of trace metal levels in the roadside soils with increasing distance from the road edge. Exponential decline in the levels of trace metals with distance from the road edge strongly suggests that vehicular emissions are a major source of the trace metals. In addition, the levels of trace metals beyond 50 m from the road edges are usually the lowest and represent the background levels [15]. Some studies have indeed shown that there is an exponential decline in metal concentration with increase in distance from the road edge and most of the metals are deposited within 1-35 m distance from the road edge [20-22]. Although correlation between traffic density and trace metal concentrations in roadside soils or vegetation may exist [13,14,20,23], the relationship may not always be statistically significant. This is because there is a threshold level of heavy metal that must be present above background level in the soil or vegetation for the correlation to be statistically significant [24]. The threshold amounts of trace metals in surface soils may sometimes be affected by soil texture and sampling design because trace metals may not be evenly distributed in the soil core with increasing depth. So, soil samples obtained at 5 cm depth may have higher or lower total trace metal levels than soil samples collected at 10 cm depth depending on the soil texture and organic matter content. Previous studies done in soils and sediments in Dar es Salaam City showed that the surface soil and sediment samples retained higher levels of trace metals than the bottom samples [11,25].

Arsenic is a trace element widely found in nature as either arsenides or sulphides and its content in earth’s crust is 1.5-2.0 mg/kg [26]. It is also released into the environment via anthropogenic processes such as combustion of fuels and wearing of car parts. Studies have shown that traces of arsenic are present in fossil fuels, tyres, and brake pads [5,6,27]. The Danish and Dutch studies were the largest in scope and showed that tyres have traces of arsenic and the two studies estimated that amount of arsenic released in the roadside environments were 0.8 kg-As/year and 8 kg/year respectively [5,6]. Some other studies have found that most of the arsenic and other trace metals emitted from motor vehicles end up in the roadside soil, air and water along the highways [5,6 9,10] which raises public health concerns in cities with high motor vehicle traffic.

Arsenic is a potentially toxic trace element to humans and animals though not all forms of arsenic are equally toxic or retained in animal tissues. The inorganic forms of arsenic are generally more toxic than the organic forms but the former can be eliminated from body tissues faster than the latter [26,28]. The public is exposed to arsenic mainly through the use of arsenic-pesticide in agriculture, working in glass ceramics industries, and from consumption of arsenic-contaminated foodstuffs as arsenic is used as an additive in fodder [26]. The presence of arsenic in vehicular emissions raises the risks to human health and WHO reported that chronic human exposure to arsenic may cause serious diseases such as arsenicosis and cancer [26,29].

Despite the fact that number of vehicles operating in Dar es Salaam City has been growing at the rate of more than 3.1% per year since 1989 [30], little is known about the status of arsenic pollution in roadside environment which raises a new public health concern after phasing out leaded gasoline. Thus, the objectives of this work are to determine the spatial distribution of arsenic in the surface soils and establish if there is any significant correlation with annual daily traffic density data available in the literature.

2. Materials and methods

2.1 Soil sampling procedures

The study was conducted in Dar es Salaam city, Tanzania. Sampling sites were established in the selected open spaces that were close to the motorways for which traffic density data were available [31,32]. The samples were collected at the Makongo Secondary School area (Makongo) and the Victoria area (Victoria) along the New Bagamoyo Road. The other samples were collected from the Café Latino area (Café Latino) along the Sam Nujoma Road and from the Radio Tanzania Dar es Salaam (RTD) open space located at the Ubungo-External area (Mabibo) along the Mandela Road. The soil samples were collected at a depth of 0-5 cm depth at 1 m, 5 m, 15 m, 35 m, and 50 m distances from the edge of the road. One set of samples was collected at about 150 m away from the road to obtain background levels of heavy metals in the soil at each study site. The control samples were collected from an open space located at the Lugalo Area-E where there was hardly any traffic (*ca.* < 5 ADT). This site was located at about 1000 m from the edge of the New Bagamoyo Road. Ten soil sub-samples were collected at each distance and these were combined to obtain six composite samples for each study site. The composite samples collected at each study sites were kept in separate clean labeled polyethylene bags and transported to the laboratory in the Department of Chemistry at the University of Dar es Salaam for further treatment.

2.2 Soil sample treatment and analysis

The fresh samples from the field were split into two halves before further treatment in the laboratory. The first half was used for determination of soil pH and electrical conductivity (EC) while it was still fresh from the field. The second half of soil samples was air dried at laboratory temperature for several days and it was used for the determination arsenic content. The dried samples were sieved to remove large coarse particles and roots which were then ground in a clean porcelain mortar. The ground samples were further sieved through a 250 µm-sieve to get the analytical soil samples. The soil samples were digested using the procedure reported in literature [21]. The digested soil samples were kept in clean and labeled plastic bottles until they were further treated for analysis using atomic absorption spectrometer.

2.2.1 Soil pH determination

The fresh soil sample from the field was treated for soil pH determination in accordance with the British Society of Soil Science application method C 001 [33]. About five grams of the fresh soil, in duplicate, were weighed in the Mettler analytical balance. The duplicate samples were kept in clean plastic bottles into which 25 mL of distilled water were added. The two samples, in soil-water ratio of 1:5, were shaken for one hour using mechanical shaker. The samples were allowed to settle for five minutes to get the soil slurry. The pH meter was calibrated at pH 4 and pH 7 at room temperature. The pH meter's electrode was dipped into the soil-water extract kept in a small beaker. The pH of soil samples was determined in duplicates.

2.2.2 Soil electrical conductivity

The electrical conductivity was determined by using the fixed soil-water extract method [34). The soil-water extract (1:5) for pH determination was also used for the determination of electrical conductivity of the soil. The Jenway model 4010 electrical conductivity meter was calibrated at room temperature and the electrical conductivity of soil samples were determined in duplicates for each soil sample.

2.2.3 Soil percent organic matter content

The soil organic matter content was determined using the method published in literature [35]. Five grams of each dried and ground soil samples were put into separate pre-weighed crucibles and the soil samples were further dried in the oven at 105 ^{o}C for two hours. The samples were re-weighed in a balance and then ashed in the muffle furnace at 360 ^{o}C for two hours. The crucibles were allowed to cool at room temperature before final weights were measured. The weight of the samples at 105 ^{o}C and 360 ^{o}C were recorded. The percent organic matter (% OM) was calculated according to formula reported in Storer [35].

2.2.4 Determination of total arsenic in the soil samples

The preparations of working standard solutions from stock solution, sample treatment, minimization of interferences in accordance with protocols reported in literature [36]. The total arsenic was determined in digested soil samples using flame atomic absorption spectrophotometer (model GBC 906AA) with hydride generation. The arsenic hollow cathode lamp with 193.7 nm line was used as source of radiation.

3. Results and discussion

The pH of the all soils ranged from 5.97 to 9.72 but there were slight differences across study sites. The Lugalo-Area E had pH ranging from 7.51 to 9.72, Makongo area had pH ranging from 7.60 to 8.05 while at Café Latino area the pH ranged from 5.97 to 8.17. The soil pH at Mabibo area ranged from 6.52 to 8.07 while it ranged from 7.46 to 8.10 at Victoria area. The pH of soils can tell us about the suitability of soils for healthy plant growth and a soil pH above 8.5 will cause most of macronutrients and micronutrients to be unavailable to plants [37]. In this study all the soil samples, except those from Lugalo Area-E, exhibited a normal range of soil pH (6.0 – 8.5). This is a suitable pH range for plant growth [37] and field observation found that the roadside soils in the study areas were also used for cultivating leafy vegetables. Soil samples from the Lugalo-Area E, particularly those from distances between 1 and 5 m from the road edge were basic (pH > 8.5) and would cause most of arsenic to remain in the surface soils.

The electrical conductivity (EC) of the soils ranged from 35.4 - 824 µS/cm in all samples. The highest EC values were recorded in soil samples from Lugalo-Area E, which ranged from 175 - 824 µS/cm, while the lowest EC were recorded at Mabibo area with a range of 35.4 - 139.6 µS/cm. The soil ECs were 211.0-426.0 µS/cm at Makongo area, 124.0-187.0 µS/cm at Café Latino area and 113.7-196.0 µS/cm at Victoria area. Soil EC is related to sodium adsorption ratio (SAR) and they can be used to classify soils. When EC is less than 4000 µS/cm and SAR is less than 13, then the soil is classified as normal and its pH usually ranges from 6.5 - 8.5 [38]. Thus, the soils in the five study areas may be classified normal soils because the average soil ECs were less than 4000 µS/cm and pH ranged between 7.40 and 8.44. The EC may also be used to predict texture of the soil because the model established using large empirical data showed that sands have low EC (*ca.* 3 - 40 µS/cm), silts have medium EC (*ca.* 50 - 300 µS/cm), and clays have the highest EC range (*ca.* 100 - 10,000 µS/cm) [39]. Based on this model, we can infer that the surface soils at Lugalo-Area E (175.0 – 824.0 µS/cm), Makongo area (211.0 – 426.0 µS/cm), Café Latino (124.0 - 187.0 µS/cm), and Victoria area (113.7 - 196.0 µS/cm) had silt-clay soils while Mabibo area had sand-silt soils (35.4-275.0 µS/cm).

The results from the determination of percent soil organic matter (%OM) showed that the organic matter varied from 3.05% at Mabibo area to 19.10% at Victoria area. Soils that have organic matter less than 2 % or more than 30% at 30 cm depth from the surface have low micronutrients available to plants [38]. Therefore the normal soil organic matter content for healthy plant growth ranges from 2 to 30 % and the typical soil organic matter content is 10 % [40]. The levels of organic matter found in all roadside soil samples are indeed within this range and therefore they may be used for urban agriculture. The field observation found that the roadside reserves in Dar es Salaam City are used for cultivating vegetables and grasses growing on roadside soils are used as animal fodder. Thus, there is high public exposure risk to toxic heavy metals from these practices because the vegetables and grasses may accumulate high levels of arsenic and other toxic metals emitted from car exhaust, brake pad abrasion and tire wearing.

This study focused on levels of total arsenic in roadside soils and results showed that soils were contaminated with arsenic. The levels of arsenic in all surface soil samples ranged from 0.03 - 0.65 ppm (mean = 0.23 ppm). However, there were remarkable differences in the levels of arsenic within study site with respect to increasing distances from the road edge and across study sites which reflects the differences in daily traffic density. The levels of arsenic, in general, decreased gradually from 1 m to 35 m except for Victoria area at which amounts of arsenic in the soil levelled off from 50 m (Figure 1).

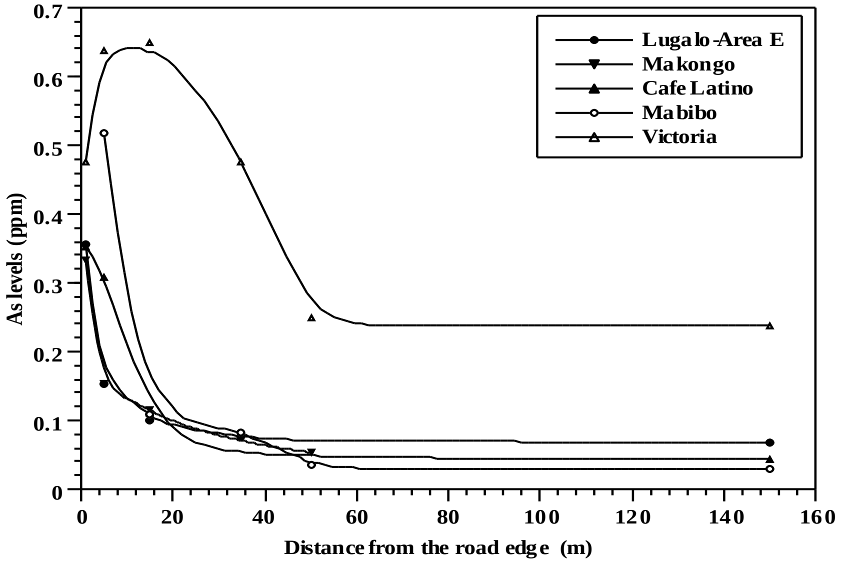

Figure 1: Spatial distribution of arsenic (ppm) in surface soil at each sampling sites

The amounts of arsenic in the soils at 150 m were below 0.1 ppm and represent the background levels of arsenic except for the Victoria area for which the background level was 2.5 ppm (Figure 1). Thus, the background levels of arsenic in all five study sites were below 2.5 ppm which agrees with the typical natural levels of arsenic in surface soil reported in literature [41].The figure also reveals that Victoria area had the highest levels of arsenic and the amounts decreased gradually to 50 m which may suggest that this study site experienced stronger wind movement patterns than the other four study sites.

The average levels of arsenic in soil samples at Lugalo Area-E (control site) and Makongo area were closer to each other (Figure 2) despite the fact that Lugalo Area-E had by far lower traffic density than Makongo area [31]. Since Lugalo Area-E had undisturbed soil with vegetation cover, the plants might have absorbed and accumulated traces of natural arsenic over the years. The old leaves, grasses, and the branches may eventually be decomposed by microbes releasing the trace elements into the surface soils (0-5 cm depth). However, most of the arsenic released might be retained on the surface soils in the presence of organic matter at around neutral pH. Thus, the arsenic levels at the Lugalo Area-E may be exclusively associated to natural sources because arsenic fell from 0.36 at 1 m to 0.15 ppm at 5 m and then showed irregular variation to 150 m.

Figure 2, on the other hand, shows that the average arsenic levels increased gradually from Makong area to Victoria area in the order: Makongo area < Café Latino area < Mabibo area < Victoria area. Although the traffic density at Mabibo area, which is located along the Mandela Road, is relatively higher than that at Café Latino along the Sam Nujoma Road and Makongo area along the New Bagamoyo Road [31,32], the average arsenic does not differ much (Figure 2). That might be associated with research design and physical parameters that might influence distribution of arsenic content in the soils and calculation of average level of arsenic at each study site included data from samples at 50, 100, 150 m as well. This study collected samples from surface soils at 0-5 cm depth. However, the retention of arsenic in this layer might not be as high as we expected because the surface soil samples from Mabibo area had lower average organic matter contents (3.5%) than Café Latino and Makongo area (6.1%). Arsenic may not form very stable complexes with organic matter in the surface soils and that is why we think that most of arsenic moved beyond the depth of 0-5 cm.

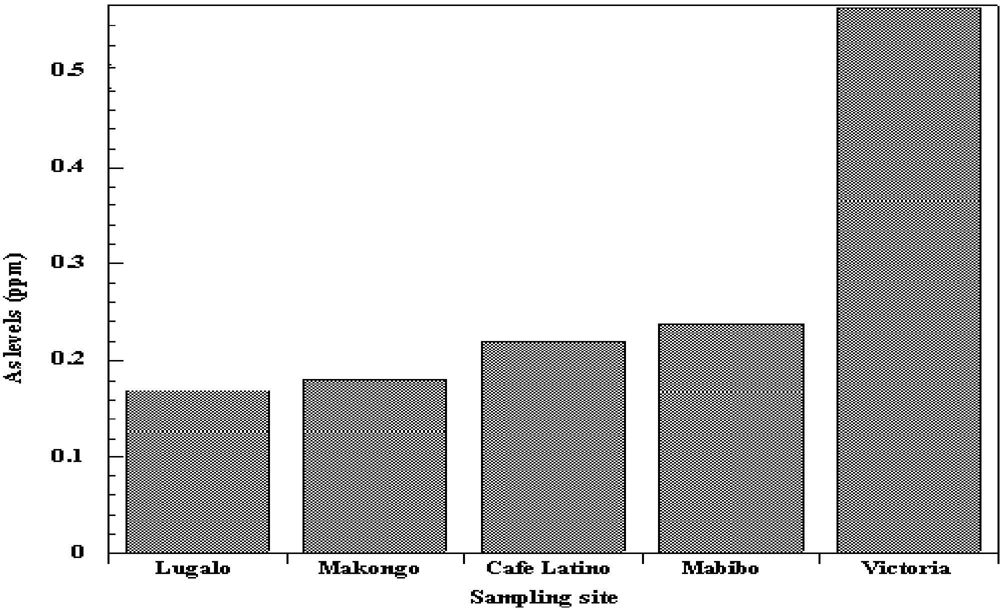

Figure 2: The average arsenic (ppm) in soil samples from 1 m to 35 m at each sampling site

The Analysis of Variance test [42] was used to analyse the variation of soil arsenic levels with respect to sampling sites at 95% confidence limit. The test showed that arsenic levels in the soils exhibited very significant variations among study sites (F = 4.14, p = 0.01, n = 5). Nonetheless, the variation in average arsenic levels in the roadside soils was the most significant between any of the study site with Victoria area. The Victoria area had the highest average daily traffic density and the site had silt-clay soils with the highest organic matter content. Silt-clay soils at Victoria area which had the highest organic matter content (19.10%) and pH (7.45-8.10) might have played a great role in retaining arsenic in surface soils (0-5 cm). Further, linear regression analysis was performed to find out if there was any correlation between arsenic levels and annual average daily traffic (ADT) data available in literature [31,32]. The test revealed that the levels of arsenic in the soils showed insignificant correlation with average daily traffic density (r^2 = 0.47, p = 0.21, n = 5) when average values of arsenic included background data at each study site. However, the ADT and mean arsenic levels showed linear correlation though it was significant at 95% confidence interval (r^2 = 0.91, p = 0.05, n = 4) when average values of arsenic excluded background levels (50-150 m) and control site that had insignificant ADT. Arsenic, being a metalloid, cannot easily be held in the top surface soil layer of 0 - 5 cm depth used for sampling in this study where pH is less than 8.5. That might have contributed to the observed insignificant correlation between ADT and average soil arsenic. Since the annual average daily traffic data were around ten thousands, there is a threshold level of arsenic that must be present in the soil for the correlation to be linear and statistically significant. We might have missed the threshold levels of arsenic in the soils because we did not collect soil samples at larger depths of about 0-10 cm or 0-15 cm. Arsenic, being a metalloid, may easily move down the soil profile in soils with low pH and organic matter. The lack of statistically significant correlation, however, does not necessarily mean that vehicles are not the primary sources of arsenic in roadside soils in Dar es Salaam city. This is because the graph of arsenic levels against distance from the road edge showed that arsenic levels in roadside soils declined exponentially with distance from the road edge (Figure 1). This may not be a mere coincidence rather the observed distribution pattern tells us that arsenic emitted from vehicle fleets is blown by wind movement to the roadside soils and is mostly deposited within 1-35 m distances. However, if the study area experiences strong seasonal winds, arsenic in traffic emissions may be blown against gravity as far as 35 m from the road edge before levelling off beyond 50 m. Thus the background levels of arsenic for Victoria area may be obtained at 50-150 m while background levels for other four study sites may be obtained at 35- 150 m (Figure 1).

Although total arsenic levels in most of the surface soil samples were below 2.5 ppm which is typical background level [39], we cannot ignore public exposure risks to arsenic associated with motor vehicle emissions based on observation we made in the study area. During the field surveys we noted that the roadside open spaces are used by street vendors to conduct pet businesses and urban famers to grow vegetables or sell the grasses as fodder. The Amaranths (*Amaranthus spp.*) are the most popular leafy vegetables cultivated in the roadside open spaces of the highways in Dar es Salaam city and studies showed that leafy vegetable gardening in Dar es Salaam contributes to total income of the poor households accrued from urban farming [43-46]. However, the Amaranths are well known for bioaccumulating heavy metals and [47-49] and arsenic [50,51]. Thus the public might, unknowingly, be exposed to arsenic from consumption of the vegetable. The grasses growing in roadside open spaces is used as fodder for domesticated dairy cows [43,52] and a previous work done in the same study sites found that roadside grasses were contaminated with of trace metals emitted from motor vehicles [11]. Therefore, the public might also be at potential risks of exposure to arsenic through consumption of beef and milk from dairy cows fed with contaminated roadside grasses in Dar es Salaam city.

Conclusions

This study found that the roadside soils in Dar es Salaam City were contaminated with arsenic. The amounts arsenic decreased gradually with increasing distance to 35-50 m from the road edge. This observation strongly suggests that most of arsenic found in the roadside soils owes its source from the passing motor vehicles. However, correlation analysis showed that there was no significant relationship between average arsenic in roadside soils and annual daily traffic density. The weak correlation may be attributed to sampling design and behaviour of arsenic in soils with low organic matter content at pH of 7-8. Although Tanzania has phased out the use of tetraethyl lead in gasoline in 2005, the public may still be susceptible to chronic exposure to air-borne or food-borne arsenic in cities with high daily traffic density. We call for detailed studies to investigate the distribution of arsenic with soil depth; determine contents of arsenic in fuels, tires and brake pads marketed in Tanzania; determine levels of arsenic in ambient air and vegetables in Dar es Salaam city. The studies will create sufficient data base that can be used to predict the extent of public health exposure risks to arsenic from inhalation of contaminated air or consumption of vegetable grown in roadside side soils.

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