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Full Length Research Paper

Environmental lead pollution and contamination in food around Lake Victoria, Kisumu, Kenya

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Exposure to lead (Pb) through food, water, or contaminated air has adverse health impacts that are particularly severe in children. Many countries have outlawed the use of leaded petrol, and enacted policies and regulations limiting lead pollution, and lead levels in foods. However, African countries, including Kenya, have generally been slow in adopting policies and regulatory structures concerning lead pollution. The main objective of this study was to determine lead contamination levels in the environment around Kisumu (Kenya). Lead content in samples of tap water and other surface water ranged from 140 to 260, and 140 to 690 (µg/g), respectively. All the tap water samples had lead content above10 µg/g, the maximum WHO limit for lead in drinking water. The lead content in vegetables and fish ranged between 0.0 to 2.9 and 1.0 to 3.3 (µg/g), respectively. All the fish samples had lead levels above the WHO maximum limit of 0.2 (µg/g). Lead content in soil samples ranged from 0.2 to 3.9 (µg/g). These results indicate that there is considerable risk of lead poisoning from drinking water and eating some foods from these sites.

Key words: Lead, pollution, environment, food safety.

INTRODUCTION

Environmental pollution by lead is a worldwide public health problem, exemplified by elevated blood lead levels among people living in the polluted areas (Makokha, 2004). Lead poisoning has severe adverse health im-pacts, which particularly affect children (WHO, 1995), where it has been specifically linked to neurological, neuro-behavioural and developmental problems, and iron deficiency anaemia, whose prevalence among pregnant women and children in Kenya is very high (IAEA, 1994; Richard et al., 1993; Mwaniki et al., 2001; WHO, 1995; Marcus and Schwartz, 1987).

Worldwide, leaded petrol has been reported to have caused more exposure to lead pollution in human beings than any other single source (Ellen, 1996). Therefore, the USA, all European countries, and many developing countries have outlawed or strictly regulated the use of leaded petrol. In such countries, levels of lead are closely monitored in food and drinking water. The United Nations World Health Organization (WHO) has also given recom-mendations for maximum lead content in foods and water (WHO, 1995; CAC/FAO, 1999).

However, African countries, including Kenya, have been slow in putting in place regulatory structures on leaded products, and leaded petrol is still used in some cases. There is very little data on the magnitude of the contamination levels of lead in the environment and in foods in Kenya. There is also a weak policy and regu-latory frame work for the control of lead pollution in Kenya.

The objective of this study was to determine the extent of lead contamination in soil, water and foods around Kisumu in Kenya, and assess the implication of such con-tamination on food safety.

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Table 1. Lead content in water samples (µg/L).

Sample source (n = 5 for each sample)	Mean Lead	Range
Dunga Beach 200 m inshore	260 ± 46^{bc}	210 - 300
Dunga Beach onshore	470 ± 29^{ab}	440 - 500
River Nyamasaria	650 ± 46^{a}	500 - 690
Tilapia Beach 200 m inshore	150 ± 4^{c}	140 -150
Tilapia Beach onshore	450 ± 19^{ab}	430- 470
Tap water	200 ± 58^{c}	140 -260
WHO maximum limit, drinking water	$\mathbf{10^{d}}$	

Each value is a mean ±SE of five replicate samples, each done in triplicate. Means within columns followed by different letters are significantly different ($p < 0.05$) from each other.

METHODOLOGY

Study area and sampling sites

The study was carried out in the Lake Victoria basin around Kisumu in Kenya. This area has different potential sources of pollution including industrial activity that pollute the lake and rivers and motor vehicle exhaust. Triplicate samples were taken within a radius of 20 km from the Lake in these areas. Water samples were obtained from the Lake itself, River Nyamasaria and from domestic taps. For the lakewater, some samples were taken onshore at the beach, whereas others were taken at least 2 km inshore. Soil samples were obtained from purposively selected sites in the research area. Some sampling sites were next to the highway, where motor vehicle pollution is high, whereas others were obtained at least 2 km from the highway. Some of the foods were obtained from the market, while fish was obtained from the lake, landing sites and the market. Soil and water sampling was done according to the International Atomic Energy Agency (IAEA) protocols (IAEA, 1997).

Food and drinking water

Key staple food samples were purchased from the fields and the market places in the study area. The sampling sites were purposively selected to include those next to the highway, where exposure to lead pollution from motor vehicles is presumed to be highest. The food samples included maize, beans, and vegetables. For the food samples, 500 g of each type of food was obtained. Drinking water samples were obtained from the tap, where five 500 ml samples were obtained.

Sampling and sample preparation for foods and drinking water were done according to the IAEA protocols (IAEA, 1997). The specific sampling sites and type of samples taken were as follows:

- Dunga Fish Landing Site: Water samples.
- River Nyamasaria: Water and some soil sample from next to the river, at the point where the river crosses the Kisumu - Nairobi highway.
- Tilapia Beach (Car Wash): Soil, water and some vegetable (amaranthus) samples.
- Kisumu-Nakuru highway: Soil samples from next to the highway, and also from at least 2 km from the highway.
- Kisumu fish market: Vegetable and cereal samples.

Lead determination

Sample pretreatment was done as described in the International Atomic Energy Agency (IAEA) (1997) protocols. In this method, two grams of soil and food samples, and 20 ml of water were digested using concentrated acids (wet ashing). Nitric acid, sulphuric acid, and hypochloric acid were used in the ratio of 2:1:1.

After digestion, the lead in the samples was then determined by spectrophotometry using a *Shimadzu* Atomic Absorption Flame Emission Spectrophotometer Model AA-6200 according to established procedures (AOAC, 1996; Osborne and Voogt, 1978). Commercial lead standards of lead nitrate ($Pb(NO_3)_2$ in 0.1 mol/l. HNO_3) were used as reference (Wako Pure Chemical Industries Ltd., Japan). Each analysis was done in triplicate.

Data analysis

Statistical analysis of data was done using analysis of variance (ANOVA) of the lead levels in soil, water and staple foods from the study areas to reveal correlations between lead levels in the environment with those in food and water. Comparison was made between the lead levels in the samples and the maximum safe limits set by WHO.

RESULTS

Lead content in water

The lead content in the onshore water from Lake Victoria was significantly higher (P 0.05) than in the water obtained at least 200 m inshore at the sampling points of Dunga and Tilapia Beach (Table 1). This is an indication of lead pollution onshore. The water from River Nyamasaria had significantly higher (P 0.05) lead content than the lake water. This is an indication that there was substantial lead pollution along the river course. Lead content in all the water samples from different sources, including tap water, was above the World Health Organization (WHO) maximum safe limits for drinking water of 10 µg/L (Table 1).

Lead content in soil

The lead content in the soil obtained from the roadside was significantly higher ($p < 0.05$) than that of soil samples that were not near the road (Table 2). This is an indication that motor vehicle pollution is a source of lead pollution in these cases. The mean lead levels from the

Table 2. Lead content in soil samples (µg/g).

Sample source (n = 3 for each sample)	Mean	Range
Dunga beach	0.4±0.04^{b}	0.4 – 0.5
River Nyamasaria	0.2±0.00^{b}	0.2 – 0.2
Tilapia beach	0.9±0.42^{ab}	0.3 – 2.6
Roadside	3.3±0.59^{a}	2.7 – 3.9
Maximum safe limits, soil	**0.4^{b}**	

Each value is a mean ±SE of three analyses, each done in triplicate.
Means within columns followed by different letters are significantly different ($p < 0.05$) from each other.

Table 3. Lead content in vegetable samples (µg/g).

Sample	Mean	Range
Arrow roots	2.9±0.071^{a}	2.2 – 3.6
Onions	2.2±0.00^{b}	2.2
Cowpea leaves	0.4±0.04^{c}	0.0 – 1.6
Amaranthus	2.5±0.029^{b}	1.9 – 2.9
Solanum nigrum	0.2±0.036^{c}	0.2
Fruits (local guava, mango)	0.3±0.025^{c}	0.0 – 1.3
Tomatoes	2.1±0.00^{b}	2.1
WHO maximum limits	**0.3^{c}**	

Each value is a mean ±SE of three analyses done in triplicates. Means within columns followed by different letters are signify-cantly different ($p < 0.05$) from each other.

soil samples obtained from the road side, 3.3 (µg/g) is significantly higher than the maximum safe levels of 0.4 (µg/g), beyond which it is not safe for children to play in, as they run the risk of getting lead contamination from these soils. However, soil samples from Dunga Beach, Tilapia Beach and around River Nyamasaria had lead levels that were not significantly different from the maximum WHO limits. Only the sample from the roadside had significantly higher lead content than the maximum safe limits.

Lead content in vegetables

The vegetable samples obtained from the roadside (amaranthus) had significantly higher ($p < 0.05$) lead concentration than those obtained from the market (Table 3). This is an indication that motor vehicle pollution is a source of lead contamination in such vegetables. The *Solanum nigrum*, cow pea leaves, and local fruits were obtained from a farm, about 5 km from the highway, and hence had relatively low lead concentrations. Onion, tomato and arrow samples were purchased from an open air market, and had lead content above the WHO maximum limits of 0.3 µg/g for vegetables. Amaranthus leaves, obtained from next to the Kisumu-Nairobi highway, had similarly high lead concentrations, most likely due to its close proximity to the highway.

Table 4. Lead content in dry cereal and legume grain samples (µg/g).

Sample	Mean	Range
Maize	0.1±0.02	0.066 – 0.174
Beans	0.2±0.29	0.173 – 0.230
WHO maximum limits (maize, beans)	**0.2**	

Each value is a mean ±SE of three analyses done in triplicate. Means within columns followed by different letters are significantly different ($p < 0.05$) from each other.

Lead content in dry cereal and legume grain

Lead content in dry cereal and legume grain samples is shown in Table 4. Lead content in maize and beans is of particular interest as these are staple foods for many communities in Kenya. The maize and bean samples had low lead content that was within the WHO maximum limits of 0.2 µg/g.

DISCUSSION

Lead concentration in water

The results of this study indicate that there is considerable lead pollution in the water samples, since natural unpolluted water systems usually have low lead levels (UNEP, 2004). One probable source of lead pollution in the lake is the leaching from soils that are found next to busy highways into the water system (USEPA, 2003). Once lead falls onto the soil, it usually attaches to the soil, from where small amounts may leach into rivers and lakes and streams as the soil particles are moved by rainwater (Mahaffey et al., 1982).

Contamination of lead in groundwater may also result from the dissolution of lead from soil and earth crust, where it is usually present in a form of carbonate and hydroxide complex, with varying degree of solubility (WHO, 1995). Such contamination may have contributed to the high lead levels in the River Nyamasaria water samples. It is also possible that in the case of the river water, there was contamination upstream.

For drinking water, lead contamination could be due to use of leaded pipes (Beattie et al., 1972). Leaded solder is also a major cause of lead contamination in drinking water (WHO, 1993). Lead contamination has also been found to be high in water from plastic pipes. The source of lead in plastic pipes is probably lead stearate which is used as a stabilizer in the manufacture of polyvinly plastics.

Lead in soil

The mean lead content in the soil samples lies within typical concentrations of lead in soil. This has been reported to be within the range of 0.5 - 10 µg/g (WHO, 1995). Lead from anthropogenic sources may result in concentrations exceeding 10 000 µg/g. (USEPA, 2003). In particular, soil in or adjacent to lead smelters, lead mines, houses painted with lead paint, orchards treated with lead arsenate, and urban areas where there has been heavy automobile traffic is likely to contain high concentrations of lead. Sources of lead in dust and soil also include lead that falls to the ground from the air, and withering and chipping of lead-based paint from buildings and other structures. Lead in dust may also occur from wind blown soil (USEPA, 2003).

Variation in lead soil content may also be due to historical factors such as past traffic congestion, industry and the type of soil. Of these, traffic, and its associated use of leaded petrol, has played the most important role in determining where lead is found in city and rural soils (UNEP, 2000). Leaded petrol has been in use in Kenya up to 2006. Studies done in the USA revealed that inner city areas had more lead pollution than outlying areas (Xintaras, 1992). Urban areas such as Kisumu experience more traffic and rural areas. Such areas with historically high traffic volume are susceptible to lead pollution from leaded petrol that may have settled out into the soil or clung to buildings and is consequently washed into the surrounding soil. High soil-lead levels mean that residents and their children in such areas face a health threat of lead poisoning from soil (UNEP, 2000). Children are particularly at risk. In a study in the USA, where 78% of homes had soil-lead levels higher than 0.5 µg/g, it was estimated that a child eating only half a gram of soil would ingest 250 µg of lead, almost twice the maximum intake limit per day. Mahaffey et al., (1982) established that children in rural areas had blood lead concentration of 13.9 µg/dl, while those from cities with populations less than one million had values of 16.5 µg/dl of blood. Those from cities with a population greater than one million had lead concentration of 18 µg/dl of blood with those from inner cities having lead concentration of 20 µg/dl of blood.

Lead content in foods

Lead in vegetables

The results of lead in some vegetables are consistent with those obtained in some other studies, such as that by Leelhaphunt et al. (1994), where they found lead levels of 2.1 µg/g in tomatoes purchased from Thailand markets. However, the lead levels in vegetables in this study is much higher than those reported by Denmark National Food Agency (Benko et al., 1995). This may be due to the successful phasing out of leaded gasoline in the European countries.

When leaded fuel is burned, it emits very fine particles of lead into the air, where they may settle on vegetables as they are vended along the streets and next to busy highways. Some of the particles settle on soil where they later contaminate the food when the dust is blown by wind (UNEP, 2000).

Other investigations have also reported high levels of lead content in vegetables sampled near major highways (Tyroller, 1988). Perhaps, not surprisingly, there is good correlation between average traffic counts and average soil and plant lead content at sites close to the roadside. An inverse relationship between distance from the road and lead content has been observed in various soils and vegetables (Tyroller,1988). In Japan, Muramatsu et al. (1994) found lead concentrations of 2.3 and 2.4 µg/g in spinach-stew and 1.2 µg/g in cabbage.

Lead content in dry maize and beans

The lead levels in the grain samples are below the maximum WHO limits, and comparable to those observed in other studies. This may have been partly due to the fact that most of these grains are brought from rural areas, where the risk for lead pollution is low. Yang et al. (1994), reported that cereals in China had lead levels of 0.06 µg/g. In Denmark, the National Food Agency established lead levels of 0.03 µg/g in cereals (National Food Agency of Denmark, 1992; Andersen et al., 1996). Another study by Urieta et al. (1996) found mean lead levels of 0.02 µg/g in cereals from Spain. In the United Kingdom, Ysart (1994) reported mean lead levels of 0.02 µg/ g in cereal products. In Poland, Krelowska-Kula (1991) found lead levels of 0.07 µg/g in cereals. In Japan Muramatsu et al. (1994) , established lead concentrations of 0.05 µg/g in wheat and rice.

Conclusions

Lead contamination in tap water, and some vegetables was above the WHO maximum limits and may pose a risk for lead poisoning to consumers. The lead content in soil samples from near the roadside was consistently higher than that obtained further from the roadside, indicating motor vehicle pollution is a source of lead pollution. Such high lead levels in soil poses risk for lead poisoning, particularly to children who play in such soils. The lead content was also higher in vegetables grown near the roadside in comparison to that grown away from the roadside, indicating that motor vehicle pollution is a source of lead contamination in foods. The lead content in maize and beans, which are among the main staple foods in Kenya, was below the maximum WHO limits. Routine monitoring of lead levels in the environment and food samples needs to be established in Kenya, since these levels may change with time.

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