# Geospatial Distribution of Selected Heavy Metal Contaminants in Agricultural Soils in Western Kenya

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**ABSTRACT**

The industrial and technological advancement has resulted in wide distribution of heavy metals in the environment. While arsenic, cadmium (Pb), chromium (Cr), lead (Pb), and mercury (Hg) rank among the priority metals that have high degree of toxicity, essential heavy metals like copper (Cu), zinc (Zn) exert malfunctions in organisms. This study investigated the mean seasonal Pb, Cd, Zn and Cr levels in spatial area in western Kenya in order to ascertain if they were above the recommended background values. The distribution of Pd and Cd on individual farms was also assessed. A total of 25 sites were investigated where an Atomic Absorption Spectrophotometer was used for analysis of the samples. Lead in 11% of soil samples exceeded the range for unpolluted soils of 0.1 to 20 ppm. Soils were found to have optimum to low levels of Cu and Zn, which indicated variability in land use. A positive correlation (r = 0.98, P<0.05) between wet and dry seasons was reported. These findings indicate spatial temporal variation in heavy metals driven by changes in land use patterns and associated changes in climate. While this study has quantified the heavy metal levels in the soil, further studies are required on their bioavailability, environmental and associated health effects.

**Key words:** Heavy metals; Agriculture; Soils; Environment

**INTRODUCTION**

Heavy metals are naturally occurring elements that have a high atomic weight and a density at least 5 times greater than that of water (WHO, 1996). They occur as natural constituents of the earth crust, and are persistent environmental contaminants since they cannot be degraded or destroyed. In rocks, they exist as their ores in different chemical forms, from which they are recovered as minerals, by mineral processing operations (ECM, 2004; Brown et al., 1999; Garbarino et al., 1995). They can be emitted into the environment by both natural and anthropogenic causes. Sources of anthropogenic contamination include the addition of manure, sewage sludge, fertilizers and pesticides to soils, municipal and industrial effluents, and vehicular emissions (GOK, 2002, 2009; Hawkes, 1997; Kachenko and Singh, 2004). Heavy metals such as iron, cobalt, copper, manganese, molybdenum, and zinc are required by living organisms in various concentrations hence are beneficial while other heavy metals such as mercury, plutonium, and lead, have no beneficial function in organisms, and their accumulation over time in the bodies of animals can cause serious health effects.

Bungoma County, located in the western region of Kenya, slopes from the foot of Mt. Elgon from the North where the altitude is over 2000 meters above sea level falling to the lower lying South and South West of altitude 1200 meters. The county has a population of 1,630,934 and an area of 2,069 km² (CIA, 2012). It is evenly distributed with an average population density of 482 persons per square kilometer. There is higher population density in the main urban centers and major factories. These include Webuye town, Nzoia Sugar Company, Bungoma town and Kimilili urban centres. Mumias and Nzoia sugar companies located in Mumias and Webuye respectively serve farmers in the larger Bungoma and Kakamega counties. Cultivation of sugarcane involve application of phosphate fertilizers at the initial stage of planting and top dressing with nitrogen fertilizers at the stage of two to nine months of growth. Farmers also grow other crops (maize, beans, cassava, millet, sweet potatoes and vegetables) beside sugarcane that involve fertilizer, manure and pesticides application. Industrial effluents from the two sugar factories and the pulp industry together with the municipal effluents from Mumias and Webuye urban also characterize these study areas. This study investigated the concentrations of the heavy metals in soils in order to ascertain if they were above the recommended background values for unpolluted environment.



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## MATERIALS AND METHODS

### Sample Collection and Storage

The study was carried out during the months of November 2010 (wet season) and February 2011 (dry season). Soil samples were collected from 25 sites within the agricultural and industrial areas of Webuye and Mumias. There were 5 sites sampled around Mumias town, 11 around Nzoia sugar factory, and 9 around Webuye town. The sites represented commercial vegetable farms and private residential vegetable gardens. Five sites were sampled around Kapkateny as a control. Sampling was done using a stainless steel scoop. Soil was collected over a surface area of 10 cm by 10 cm and a depth of 20 cm. A square cardboard template measuring 10cm by 10cm was used to mark sampling areas. A total of 50 soil samples were collected during both seasons. The samples were stored in clean polythene bags that had been rinsed with distilled water and transported to the laboratory for storage, preparation and analysis. Figure 1, is a map showing sampling areas while Table 1 shows the coordinates of sampling points.

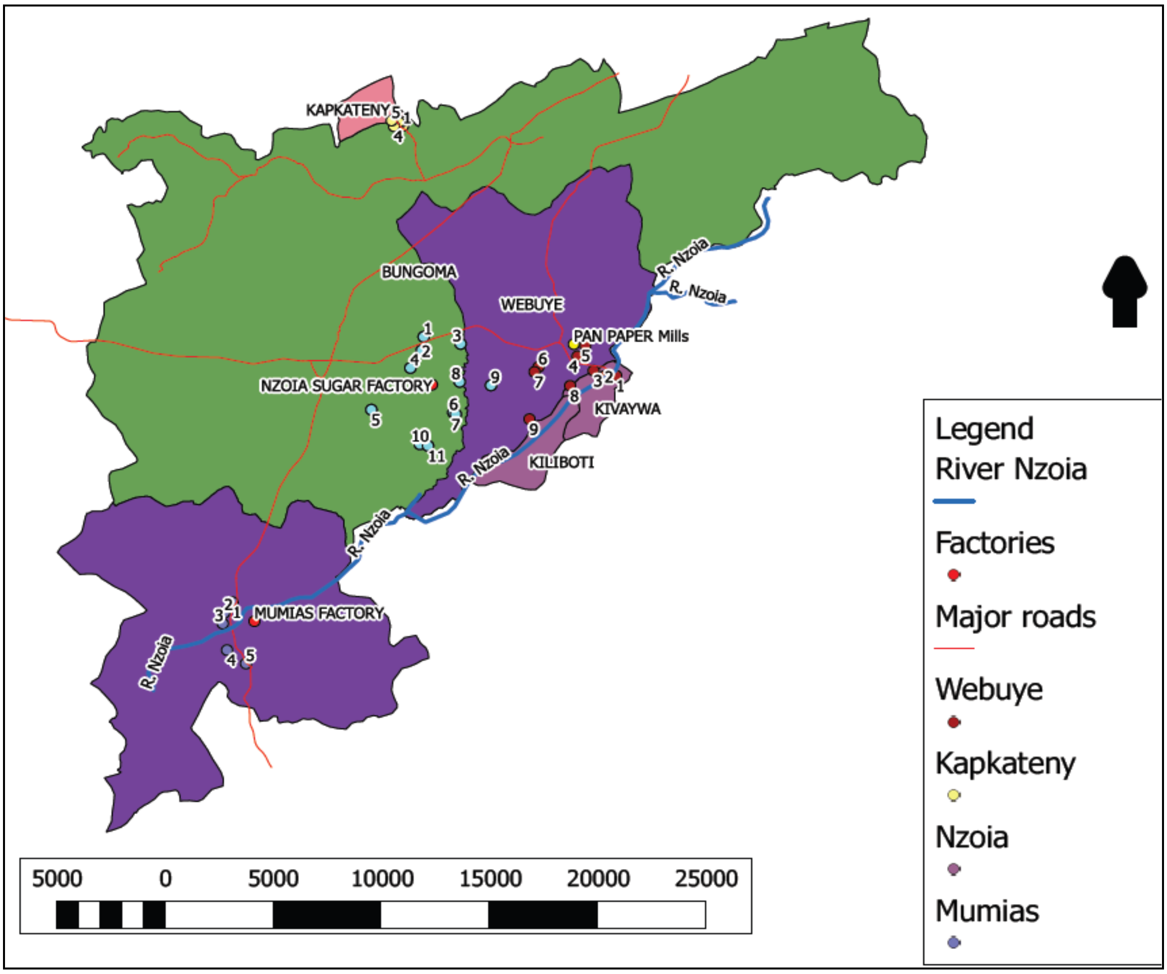


**Figure 1.** Map of study area indicating study sites

**Table 1.** Coordinates of Sampling Points

| Sampling site | Easting | Northing | Site number |
|---|---|---|---|
| Mumias site | 665632.33mE | 42209.18mN | 1 |
| | 664853.31mE | 41187.88mN | 2 |
| | 664720.49mE | 40144.56mN | 3 |
| | 665117.42mE | 37585.45mN | 4 |
| | 666866.24mE | 36285.12mN | 5 |
| Nzoia site | 683308.02Me | 67863.90Mn | 1 |
| | 683135.51Me | 66567.09mN | 2 |
| | 686726.43mE | 67183.42mN | 3 |
| | 682079.74Me | 64857.63mN | 4 |
| | 678469.28Me | 60819.96mN | 5 |
| | 686048.19mE | 60555.49mN | 6 |
| | 686270.45Me | 60373.45mN | 7 |
| | 686635.55mE | 63516.35mN | 8 |
| | 689534.13mE | 63172.74mN | 9 |
| | 682950.03mE | 57482.16mN | 10 |
| | 683709.62mE | 57326.04mN | 11 |
| Webuye site | 701115.99mE | 64109.98mN | 1 |
| | 700054.17mE | 64085.77mN | 2 |
| | 699027.27mE | 64594.48mN | 3 |
| | 697533.04mE | 65988.06mN | 4 |
| | 698265.09mE | 67024.34mN | 5 |
| | 693932.33mE | 64955.08mN | 6 |
| | 693563.41mE | 64476mN | 7 |
| | 696858.71mE | 63131.04mN | 8 |
| | 693095.66mE | 59912.64mN | 9 |

## Sample Preparation and Analysis

Soil samples were air dried at room temperature for 3 days. The dry soils were disaggregated with a porcelain pestle and mortar and passed through a 2 mm sieve. The samples were then oven dried at 105 degrees centigrade for 1 hour, and stored in a dry environment for further analysis.2.500±0.002g each of the samples was accurately weighed and placed into 100 ml beakers to which 20 ml of a mixture of HCl and $HNO_3$ in a ratio of 3:1 (V/V) was added. The mixture was then digested in a hot plate to a transparent liquid digest. The digest were separately cooled, filtered and diluted to 50 ml using deionised water for analysis of Cu, Zn, Cd, Pb and Cr using atomic absorption spectrometer.

## Quality Assurance

Quality assurance procedures and precautions were taken to ensure the reliability of the results by minimizing contamination. Glassware were washed thoroughly in alkaline detergent, soaked in 3M nitric acid for 48 hours and rinsed thoroughly in distilled deionised water before use to leach out any trace metal contamination. Plastics were soaked in detergent and rinsed thoroughly in deionised water. Reagents were of analytical grade. Chemicals were obtained from Sigma, Kobian and Aldrich Chemical Company. Deionised water was used for all dissolutions and dilutions. Statistical Analysis

Mean concentrations of elements in soils and their standard deviations for different sites were calculated using data from individual farms. Outlier values from some farms were noted and filtered when calculating the mean of a site. The recorded data were subjected to two-way analysis of variance to assess the influence of different variables on the concentrations of heavy metals. All the statistical analyses were computed using SPSS software version 12.

## RESULTS AND DISCUSSION

Soil samples collected at Mumias, Webuye, Nzoia and Kapkateny during dry and wet seasons were analyzed for Cu, Pb, Cr, Cd and Zn. Tables 2 shows the mean heavy metal levels in geospatial area while table 3 show the distribution of Pb and Cd on individual farms.


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**Table 2.** Seasonal heavy metal levels in spatial area ;( **a**) Wet season (**b**) Dry season (**c**) Correlation between dry and wet seasons.

**(a)**

| Metal (ppm) | Kapkateny | Webuye | Nzoia | Mumias |
|---|---|---|---|---|
| | M±SD | M ±SD | M ±SD | M ±SD |
| Cd | 2.01±0.31 | 1.74±0.90 | 1.77±0.79 | 1.76±0.98 |
| Cu | 60.01±13.6 | 2.52±1.06 | 6.67±2.62 | 6.97±1.16 |
| Zn | 30.04±11.17 | 10.86±4.78 | 16.10±5.17 | 27.72±12.04 |
| Pb | ND | 13.85±4.91 | 11.36±4.01 | 6.17±1.86 |
| Cr | 18.11±7.60 | 26.67±10.04 | 22.09±8.67 | 44.4±22.50 |

**(b)**

| Metal (ppm) | Kapkateny | Webuye | Nzoia | Mumias |
|---|---|---|---|---|
| | M ±SD | M ±SD | M ±SD | M ±SD |
| Cd | 2.47±0.42 | 1.75±0.82 | 1.50±0.67 | 1.95±0.64 |
| Cu | 62.22±14.6 | 2.11±0.87 | 6.78±2.80 | 7.11±1.20 |
| Zn | 33.94±14.17 | 12.80±6.01 | 17.18±5.00 | 28.83±12.07 |
| Pb | ND | 14.80±5.21 | 11.05±4.78 | 6.34±0.84 |
| Cr | 19.14±8.80 | 25.26±8.04 | 19.80±7.90 | 44.0±21.28 |

**(C)**

| Site | r | P- value |
|---|---|---|
| Webuye | 0.99 | 0.001 |
| Nzoia | 0.98 | 0.004 |
| Mumias | 0.99 | 0.001 |
| Kapkateny | 0.99 | 0.009 |

Soils at Webuye had lower copper level (2.52 ppm) compared to Nzoia (6.67 ppm) and Mumias (6.97 ppm), while zinc in soils at Mumias was higher (6.97 ppm) compared to Webuye (2.52 ppm) and Nzoia (6.67 ppm). Previous studies have shown that Cu concentration in the soil is related to the natural variability, the amount released and spatial temporal distribution of the released amounts (Heijerick et al., 2006). The obtained concentration in different locations maybe related to differences in soil types associated with soil use, additional fertilizers and pesticides.

Lead in soils at Webuye (13.85 ppm) was higher compared to Nzoia (11.36 ppm) and Mumias (6.17 ppm) (Table 2). Since the average concentration of Pb in the earth's crust is 13 mg/kg (Brown et al., 1999), the high values obtained at Webuye may have been released from industrial and agricultural applications as well as the urban centre. Cadmium in soils at Webuye (1.74 ppm), Nzoia (1.77 ppm) and Mumias (1.76 ppm) was similar, while chromium was higher at Mumias (44.4 ppm) and lower at Nzoia (22.01 ppm).

Copper and zinc at all the sites were within the recommended background levels of 100 ppm and 250, respectively. Chromium was higher at Mumias (44.0 ppm) and lower at Nzoia (19.80 ppm). Both lead and chromium were not detected in soils at Kapkateny, while copper (62.22 ppm), Zinc (33.94 ppm) and Cd (2.47 ppm) were higher in soils at Kapkateny compared to Webuye, Mumias and Nzoia. Since Kapkateny was our control with minimal agricultural activities and lack any industrial activities, absence of Pb and Cr was investable. Cadmium level on individual farms at Nzoia ranged between 1.67 and 2.67 ppm with 100% of the samples above the recommended background value of 0.5 ppm for the unpolluted environment. Lead ranged between 7.47 and 19.8 ppm and was within the recommended level of 20 ppm for the unpolluted environment.

The elemental concentrations in samples around Webuye shows that all the samples had cadmium levels above the recommended background value of 0.5 ppm. Pb ranged between 4.53 and 16.06 ppm. Elemental concentrations of samples from farms around Mumias showed that sample Msc had a higher lead level (28.46 ppm), which is above the background recommended limit of 20 ppm. All the samples except sample msa had cadmium levels above the recommended limit of 0.5 ppm. At Nzoia, apart from sample nsa and nsg, all other samples had Cd levels above the background recommended limit of 0.5 ppm for the unpolluted environment while Pb concentrations fell within the range of background values for the unpolluted environment. At Webuye, all the samples had cadmium levels above the recommended background value of 0.5 ppm while Lead in soils ranged between 5.1 and 41.3 ppm and Cd (0.6 to 2.9 ppm). All samples at Mumias had cadmium above the recommended limit of 0.5 ppm, with a range of between 0.60 to 2.10 ppm. while only sample msc had lead level above the recommended limit of 20 ppm (Table 3).


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**Table 3.** Distribution of Pb and Cd on individual farms

**Nzoia (Wet season)**

| Sample No. | Nsb | Nsc | Nsd | Nse | Nsf | Nsh | Nsi | Nsj | Nsk | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cd (ppm) | 2.00 | 2.00 | 2.50 | 2.00 | 2.00 | 2.27 | 2.67 | 1.67 | 1.80 | 1.77 | ±0.79 |
| Pb (ppm) | 12.00 | 19.80 | 8.00 | 7.47 | 8.67 | 15.20 | 8.37 | 8.80 | 10.33 | 11.36 | ±4.01 |

**Nzoia (dry season)**

| Sample No. | nsb | nsc | nsd | nse | nsf | nsg | nsh | nsi | nsj | nsk | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cd (ppm) | 1.70 | 2.20 | 2.10 | 2.20 | 1.40 | 0.30 | 1.60 | 2.30 | 1.80 | 1.20 | 1.75 | ±0.68 |
| Pb (ppm) | 14.20 | 17.10 | 5.60 | 8.60 | 6.50 | 19.10 | 13.20 | 7.50 | 12.20 | 11.05 | 11.05 | ±4.78 |

**Mumias (Wet Season)**

| Sample No. | Msa | Msb | Msd | Mse | Msc | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|
| Cd (ppm) | bdl | 2.20 | 2.20 | 2.20 | 2.20 | 1.77 | ±0.79 |
| Pb (ppm) | 4.47 | 5.40 | 6.00 | 8.80 | 28.46 | 11.36 | ±4.01 |

**Mumias (dry season)**

| Sample No. | Msa | Msb | Msd | Mse | Msc | Mean | Std. Dev |
|---|---|---|---|---|---|---|---|
| Cd (ppm) | 0.90 | 1.40 | 2.10 | 0.60 | 1.80 | 1.95 | ±0.647 |
| Pb (ppm) | 5.10 | 16.30 | 12.30 | 18.20 | 41.30 | 11.64 | ±11.63 |

**Webuye (dry season)**

| Sample No. | Wsa | Wsb | Wsc | wse | wsd | wsf | wsj | wsp | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|---|---|---|
| Cd (ppm) | 0.90 | 1.40 | 2.10 | 0.60 | 1.80 | 2.90 | 2.80 | 1.50 | 1.75 | ±0.82 |
| Pb (ppm) | 5.10 | 16.30 | 12.30 | 18.20 | 41.30 | 13.50 | 23.40 | 14.20 | 17.74 | ±10.09 |

**Webuye (Wet season)**

| Sample No. | Wsa | Wsb | Wsc | Wse | Wsf | Wsj | Wsp | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|---|---|
| Cd (ppm) | 1.80 | 2.50 | 2.40 | 0.40 | 2.00 | 2.20 | 2.20 | 1.77 | ±0.79 |
| Pb (ppm) | 4.53 | 14.50 | 15.80 | 16.06 | 10.33 | 21.60 | 14.60 | 11.36 | ±4.01 |

It is worth noting that 97% of the samples in this study had cadmium level exceeding the range for unpolluted environment of 0.5 ppm. Lead in eleven percent of soil samples exceeded the range for unpolluted soils of 0.1 to 20 ppm. Cadmium and lead in these soils may be derived from both natural and anthropogenic sources. In comparison, Omwoma et al. (2010) also reported elevated levels of heavy metals in the soils in top soil samples from Nzoia sugarcane farms in Western Kenya with mean concentrations (mg $kg^{-1}$ dry weight) of 142.38, 59.12, 73.35, 116.27, 409.84 (dry season) and 144.22, 50.29, 72.14, 158.81, 368.83 (wet season) for Cr, Pb, Cu, Zn and Fe, respectively, compared with a control soil sample from an adjacent field where fertilizers are not applied having mean concentrations of 117.27, 61.87, 63.68, 123.49, 282.93 (dry season) 108.00, 50.68, 66.10, 114.23, 167.01 (wet season), respectively. The use of cadmium-containing fertilizers and sewage sludge is most often the primary reason for the increase in the cadmium content of soils over the last 20 to 30 years in Europe (Jensen and Bro-Rasmussen, 1992). Continuous application of fertilizer with a high rate of triple super-phosphate (1,175 kg P-ha-1·year$^{-1}$) for a period of 36 years resulted in a 14-fold increase in cadmium content of surface soils (Singh, 1994). Cadmium in agricultural soils is likewise relatively immobile under normal conditions, but could become more mobile under certain conditions such as increased soil acidity and its cadmium level may be enhanced by the usage of phosphate fertilizers, manure or sewage sludge (Eggenberger and Waber, 1998; Cook and Morrow, 1995). Land is the ultimate repository for lead, and lead released to air and water ultimately is deposited in soil or sediment. Nearly all forms of lead that are released to soil from anthropogenic sources, such as $PbSO_4$, $PbCO_3$, PbS, $Pb(OH)_2$, $PbCrO_4$, and PbClBr, are transformed by chemical and biotic processes to adsorbed forms in soil. The transformation process involves the formation of lead complexes with binding sites on clay minerals, humic acid and other organic matter, and hydrous iron oxides (Chaney, 1993; Chuan et al., 1996; Sauve et al., 1997). Generally, the poisoning effects of heavy metals are due to their interference with the normal body biochemistry in the metabolic processes. When ingested, in the acid medium of the stomach, they are converted to their stable oxidation states ($Zn^{2+}$, $Pb^{2+}$, $Cd^{2+}$, $As^{2+}$, $As^{3+}$, $Hg^{2+}$ and $Ag^{+}$) and combine with the body's biomolecules such as proteins and enzymes to form strong and stable chemical bonds (Ogwuegbu and Muhanga, 2005)

## CONCLUSION

Lead in eleven percent of soil samples exceeded the range for unpolluted soils of 0.1 to 20 ppm while 97% of samples had cadmium level exceeding the range for unpoluted environment of 0.5 ppm. Industrial effluents from the sugar factories and the paper mill and municipal effluents from the urban centres may be the source for the high concentration of cadmium and lead. Pesticides, manure and fertilizer application on farms and vehicular emissions may have also contributed to high level of these metals. Copper and zinc were within the recommended limit of 100 ppm and 250 respectively. There was positive correlation ($P<0.05$) between the wet and dry seasons, indicating insignificant seasonal variations in heavy metal concentrations. This paper has significantly advanced our understanding of the level of heavy metals in soils in western Kenya, and the possible influence of agricultural and industrial activities on the level of various heavy metals. In a larger study, considerably more resources should be devoted to understanding the concentrations of heavy


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metals in fertilizers and pesticides used on farms and industrial and municipal effluents discharged to the environment. A risk assessment needs to be carried out to establish how these elevated levels of heavy metals have affected the population feeding on produce from these soils.

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