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ABSTRACT

In March 2010, Medecins Sans Frontieres (Doctors Without Borders) reported an outbreak of lead poisoning in some parts of Zamfara State, Nigeria. This was alleged to have been caused by massive environmental contamination due to local ore processing. Most of the studies conducted on the problem so far have been limited to the clinical component. Analysis of the spatial dimension of the problem is inadequately known. The present study investigates the spatial dimension of lead concentration in the soil of the study area. In addition, the concentration of copper and cadmium which occur in association with lead was also determined in order to ascertain their level of toxicity, and hence their contribution to the degradation of the soil. Soil samples were collected and analyzed for the concentration of lead, copper, and cadmium. Inverse Distance Weighting (IDW) spatial interpolation technique was employed to determine the spatial distribution of lead, copper and cadmium concentration, while comparative analysis was employed to determine their toxicity. Descriptive and t-Test (inferential) statistical analyses were utilized to establish a relationship between local gold ore processing and the concentration of lead in the study area. The results show high concentration of lead in areas where local ore processing is taking place and low concentration in non-ore processing areas, while concentration of copper and cadmium were seen to be within thresholds of internationally accepted standards. Student t-Test statistics applied to lead concentration values in mining and non-mining villages showed that T (tabulated) at 95% confidence level 0.05 > T (calculated) 0.000005. This implies there is a significant difference between the concentration of lead in mining and non-mining areas.

Keywords: geospatial, heavy metals, ore processing, environmental contamination.

1.0 INTRODUCTION

1.1 Motivation

Lead is the commonest of the heavy metals, accounting for 13 mg/kg of Earth's crust and is used in the production of lead acid batteries, solder, alloys, cable sheathing, pigments, rust inhibitors, ammunition, glazes, and plastic stabilizers (World Health Organization, 2011a).

In March 2010, Medecins Sans Frontieres (Doctors Without Borders) was alerted to a high number of child fatalities in some locations in Zamfara State, Nigeria, where an estimated four hundred children were reported to have died (MSF, 2012). Laboratory testing later confirmed high levels of lead in the blood of the surviving children. These deaths were alleged to have been caused by acute lead poisoning as a result of massive environmental contamination from small-scale artisanal mining (ASM) and ore-processing of gold in lead-rich ore (Dooyema et al., 2012). This assertion was corroborated by WHO (2011c) when it observed that a high incidence of convulsions and death in young children in some villages in Zamfara State has been noted, with a strong likelihood that this is due to lead poisoning, and that the full scale of the problem is still not fully determined.

Despite the acknowledgement that lead is an environmental and public health hazard of global proportions, yet the spatial dimensions of lead poisoning in the developing world remains poorly understood due to the persisting lack of data. This is in contrast to developed countries where studies have been carried out (e.g. Eisler, 1988; Mielke and Reagan, 1998; Fawtrell L., Kaufmann R., and Pruss-Ustun A., 2003; Fawtrell L. J., Pruss-Ustun A., Landrigan P., and Ayuso-Mateos J. L., 2004; Perham, 2009; Gould, 2010; von Geen A., Bravo C., Gil V., Sherpa S., and Jack D., 2012). The few studies carried out in Nigeria have been mostly limited to the clinical component of the problem.
spatial dimension has not been emphasized. To elucidate the spatial dimension of lead poisoning, this study sought to analyze the concentration of lead, copper, and cadmium in the soil of the study area and to determine the spatial pattern of spread and spatial variation in lead concentration. The study also sought to determine the relationship between the concentration of lead and local gold ore processing taking place in the study area.

1.2 Study Area

**Location, Extent, and Population:** Anka is one of the 14 Local Governments of Zamfara State. It is located between latitudes 11°39'N and 12°18'N, and longitudes 5°54'E and 6°19'E. With an area of 2,940km², Anka has a population of 263,400 (National Population Commission, 2006, cited in Blacksmith Institute, 2011).

**Geology:** Lead-zinc occurrence/mineralization in Nigeria is often associated with minor to significant amounts of copper and gold (Ministry of Mines and Steel Development, 2010b). The geology of Anka is characterized by the Anka schist belt that hosts the lead mineralization, and the lead-copper-silver-gold (Pb-Cu-Ag-Au) poly-metallic association (MMSD, 2010a). Lead (Pb) mineralization in Zamfara State occurs in veins and as stringers in wall rocks, in a variety of rocks like quartz-schists, and quartzitic-phylitic schists within the N-S trending Anka schist belt.

**Climate, Soil, and Vegetation:** The climate of Anka is warm tropical with temperatures rising up to 38°C between March and May. Rainy season starts in late May to September while the dry season known as harmattan lasts from December to February. Two major soil types, ferruginous tropical soils and lithosols, dominate the local government (Udiba U. U., Ogabiele E. E., Hammuel C., Mgomya A. M., Yebpella G. G., Ade-Ajayi A. F., Odey M. O., and Gauje B., 2012). The vegetation of the area consists of northern Guinea Savannah, characterized by short and stringy shrubs.

1.3 Objectives

The aim of this study was to employ geospatial approach to analyze the spatial pattern of lead concentration in the soil of the study area. Specifically, the study sought to:

Figure 1: Study Area

![Study Area Image]
i. Analyze the concentrations of lead, copper, and cadmium in the soil of the study area;
ii. Determine the spatial pattern of spread and spatial variation in lead concentration in the study area; and
iii. Determine the relationship between the concentration of lead and local gold ore processing in the study area.

1.4 Literature Review

Properties of Lead: Lead is a heavy metal that occurs naturally in the Earth, accounting for 13mg/kg of the Earth’s crust, and is dispersed in small amounts into the environment by natural processes (UNEP/UNICEF, 1997; O’Dwyer, 1998). When ingested and inhaled, it circulates in the bloodstream, is reabsorbed in the kidneys and the brain, and is deposited in bones and teeth. Available evidence indicates that lead is neither essential nor beneficial to living organisms, and that all measured effects are adverse — including those on survival, growth, reproduction, behavior, learning, and metabolism (WHO, 2010 and 2011b; Gould, 2010).

Sources of Lead Poisoning: Lead exists in the Earth’s crust, mainly as lead sulphide, and occurs naturally in the environment through a variety of mechanisms including volcanic emissions, geochemical weathering, sea spray emissions, and re-mobilization of historic sources such as lead in soil, sediment, and water from mining areas (WHO, 2010; Cheng and Hu, 2010). The majority of lead pollution, however, derives from human activity to extract and exploit the metal (Fewtrell et al., 2003). Some of these activities include mining, smelting, refining and informal recycling of lead, production of lead-acid batteries, use of leaded petrol, production of paint, jewelry making, soldering, ceramics and leaded glass manufacture in informal and cottage (home-based) industries, electronic waste, and use in water pipes and solder (Eisler, 1988; Tong et al., 2000; Pruss-Ustun A., Fewtrel L., Landrigan P. J., and Ayuso-Mateos J. L., 2004; Cheng and Hu, 2010; WHO, 2010 and 2011a).

Effects of Lead Poisoning: O’Dwyer (1998) defined lead poisoning as a medical condition caused by increased levels of the heavy metal lead in the body, with children and pregnant women being particularly vulnerable, and CDC (2005) defined children lead poisoning as a whole-blood lead concentration \(>10\mu g/dl\). Human exposure to lead is estimated to account for 143, 000 deaths every year and 0.6% of the global burden of disease (WHO, 2010). Exposure to lead affects multiple health outcomes and physiological systems, including hypertension, the gastrointestinal systems, anaemia, nephropathy, vitamin D metabolism, decreased growth, the immune system, the nervous system, behavioural/cognitive/IQ effects and as a result, multiple social effects including increased risk of violence and drug abuse, nerve conductive effects, hearing loss, effects on reproduction and development, and death from encephalopathy (O'Dwyer, 1998; Tong et al., 2000; Fewtrel et al., 2003 and 2004; Pruss-Ustun et al., 2004; CDC, 2004 and 2005; Battersby, 2008; Mitra et al., 2009; WHO, 2010, 2011a and 2011b; Dooyema et al., 2012; Lo et al, 2012; Udiba et al., 2012).

Mapping of Lead Poisoning: Many surveys examining the prevalence of elevated paediatric blood lead levels give insufficient attention to the geography of the major known risk factors (O’Dwyer, 1998). A Geographic Information System (GIS) addresses the spatial variation inherent in the distribution of these risk factors, and can identify areas, streets, and even individual dwellings with a high probability of environmental lead, and predictions can then be validated and confirmed with analysis of blood or dust/water samples (O’Dwyer, 1998). In 2004, CDC employed GIS technology to develop and improve preventive interventions, using Jefferson County, Kentucky, as the study area. The aim of the study was to identify children at risk to lead exposure, ‘at risk children’ defined as those children living in housing built before 1950 or in an area with a high proportion of older housing. The data sets used for the study included child blood lead screening data, US census data, and tax assessor (property) data. The results of this study showed that more children living in older housing had elevated blood lead levels than those living in newer housing. A major downside to this study is that ZIP codes (used for geo-coding) are unreliable for GIS mapping because they cross state, county and municipal boundaries, and their boundaries change while new ZIP codes are added periodically. Also, the approach adopted in this study may be difficult to replicate in developing countries like Nigeria because of a lack of data on blood lead levels, unreliable census data, and lack of property formalization.

Perham (2009) also conducted a study to determine the highest risk areas for lead poisoning in Hartford. Data such as age of housing, location of children with elevated blood lead levels, census data, building type, and buildings with soil samples with lead levels >400ppm were collected and used. The weighted overlay analysis method was used by assigning weight to each data source, assigning risk values, running layers through weighted overlay tool, and mapping the results. 28% of residential buildings were shown to have a very high risk for lead poisoning and the highest risk areas were determined to be Barry Square, Frog Hollow, and Northeast. The same
deficiencies noted in the CDC (2004) study also applied in this study, the approach being difficult to replicate in developing countries.

Mapping was also utilized by van Geen et al. (2012) to estimate the population of Peru living in the vicinity of active or former mining operations who could be exposed to lead from contaminated soil. In this study, geographic coordinates were compiled for 113 active mines, 138 ore processing plants, and 3 smelters, as well as 7,743 former mining sites. The population living within 5km of these sites was calculated from census data, and the lead content of soil in the mining towns, and mines and ore processing plants was mapped. The study concluded that soil contamination with lead is likely to be extensive in Peruvian mining towns. Although this study did not take into consideration the implications of other heavy metals that usually occur in association with lead in ores (copper, cadmium) which are also toxic at elevated levels, the approach may be replicated in Nigeria and other areas with a history of mining.

2.0 MATERIALS AND METHODS

2.1 Materials

A soil augur was used to collect soil samples in the study area at depths between 0 – 10cm. A hand-held Global Positioning System (GPS) receiver unit was used to fix the locations of sampling points in Universal Transverse Mercator coordinates (WGS – 84 datum). Labeled polythene bags were utilized as sample collection bags.

2.2 Methods

Soil samples were collected using soil augur at depths of 0-10cm. Stratified random sampling technique was used in selecting the sampling location. The population was stratified or separated into mining and non-mining, using the chain-referral method. The chain-referral method involves an iterative, cyclical process to identify villages of interest through interviews with State and local officials, traditional rulers, and other stakeholders (Lo et al., 2012). Five mining and five non-mining villages were selected out of the several villages identified based on their locations to ensure uniform spread. Soil samples were collected from the identified villages at ore processing points, three (3) samples collected from each of the five villages identified as being at most risk from lead poisoning as a result of ore processing activities and three samples each from the five non-mining villages. A total of thirty (30) surface soil samples were collected for laboratory analysis. Locations of sampling points were fixed using a Global Positioning System (GPS) receiver unit. The soil samples were analyzed for the concentrations of lead, copper, and cadmium employing the Atomic Absorption Spectrophotometry method. This is a technique used to identify substances, especially metals, and their concentrations. Copper and cadmium were analyzed also because they occur in association with lead-zinc-gold mineralization and are also known to be toxic (Udiba et al., 2012).

2.3 Analyses

For depicting the spatial distribution of lead, copper, and cadmium concentrations in the study area, the Inverse Distance Weighting (IDW) interpolation method was employed because it creates surfaces based on the measured points or sample points. Descriptive statistics were used to determine the range (minimum and maximum values) of the data, the mean, the standard deviation, and the coefficient of variation of the data. The t-Test: Paired Two Sample for Means statistics (inferential statistics) was employed to show the relationship between local gold ore processing and the concentration of lead in the study area.

3.0 RESULTS AND DISCUSSION

3.1. Results

Concentration of Lead, Copper, and Cadmium: The descriptive statistics for the concentrations of lead, copper, and cadmium is summarized in table 1. The mean value for the concentration of lead in mining villages was 36,450.67mg/kg and in non-mining villages was 467.33 mg/kg. The mean value for the concentration of copper in mining villages was 24.87mg/kg and in non-mining villages was 17.65mg/kg. The mean for cadmium was 0.18mg/kg for mining villages and 0.14mg/kg for non-mining villages. The permissible limits for lead, copper, and cadmium in soils are 400mg/kg, 50mg/kg, and 3 – 10mg/kg respectively.
### Table 1: Descriptive Statistics

<table>
<thead>
<tr>
<th>Metals (Mining and non-mining locations)</th>
<th>No. of Samples</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Coefficient of Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead – Mining</td>
<td>15</td>
<td>700</td>
<td>62000</td>
<td>36450.67</td>
<td>20819.46</td>
<td>0.57</td>
</tr>
<tr>
<td>Lead – Non-mining</td>
<td>15</td>
<td>320</td>
<td>670</td>
<td>467.33</td>
<td>91.53</td>
<td>0.20</td>
</tr>
<tr>
<td>Copper – Mining</td>
<td>15</td>
<td>10.15</td>
<td>49.19</td>
<td>24.87</td>
<td>12.28</td>
<td>0.49</td>
</tr>
<tr>
<td>Copper – Non-mining</td>
<td>15</td>
<td>9.10</td>
<td>25.18</td>
<td>17.65</td>
<td>4.95</td>
<td>0.28</td>
</tr>
<tr>
<td>Cadmium – Mining</td>
<td>15</td>
<td>0.01</td>
<td>0.35</td>
<td>0.18</td>
<td>0.095</td>
<td>0.53</td>
</tr>
<tr>
<td>Cad. – Non-mining</td>
<td>15</td>
<td>0.05</td>
<td>0.31</td>
<td>0.14</td>
<td>0.07</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Spatial Distribution of Lead:** Presence of lead was recorded in all the sampled locations of the study area. However, there was a significant difference in the concentration of lead in mining and non-mining villages. Spatial variation in concentration (figure 2) showed that mining villages recorded high concentration of lead while non-mining villages recorded low lead concentration.

![Spatial distribution of lead concentration in the study area](image)

**Relationship Determination:** Inferential statistics employing the t-Test Two Sample method applied to lead values in mining and non-mining villages showed that T (tabulated) at 95% confidence level (0.05) > T (calculated) 0.000005 (Table 2). This implies that there is a significant difference between the concentration of lead in mining and non-mining villages of the study area.
Table 2: t-Test Two Sample for lead concentration between mining and non-mining villages

<table>
<thead>
<tr>
<th></th>
<th>Mining</th>
<th>Non-mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>36450.6667</td>
<td>467.3333</td>
</tr>
<tr>
<td>Variance</td>
<td>43340006.7</td>
<td>8378.0952</td>
</tr>
<tr>
<td>Observations</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>-0.2632</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Df</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>t-Stat</td>
<td>6.6861</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td><strong>0.000005</strong></td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.7613</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.00001</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.1448</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Discussion

Concentration of Lead, Copper, and Cadmium: The mean value of lead concentration recorded for the mining villages was 36,450.67mg/kg from a range of 700-62,000mg/kg, with a coefficient of variation of 0.57. The coefficient of variation suggests that there is some variation in the data. This may be as a result of the data obtained at Dareta village. This village has undergone remediation, and therefore recorded low values of lead concentration. The permissible limit for lead in soils is 400mg/kg while the average for the study area is 36,450.67. Table 3 and table 4 show the US-EPA and Canadian standards for lead in soil, while table 5 shows the NESREA standard for lead in soil. The concentration of lead in the study area is abnormally high, far above the accepted limits (400mg/kg), and must be attributed to the local processing of gold ore in the study area since concentration of lead in non-ore processing locations were within acceptable limits.

Result of the analysis of the concentration of copper in the study area showed that the mean was 24.87mg/kg of a range 10.15-49.19mg/kg and 0.49 coefficient of variation for the mining villages and 17.65mg/kg of a range of 9.10-25.18mg/kg and 0.28 coefficient of variation for the non-mining villages. The coefficient of variation suggests that there is little variation in the data obtained in the study area. The maximum permissible limit for copper in soil is 50mg/kg (Udiba et al., 2012). This implies that copper is well within the acceptable standards. Although copper is toxic at elevated levels, and occurs in association with gold and lead, the result shows that copper is not implicated in the environmental contamination of the study area.

Table 5 shows the World Health Organization (WHO), Denmark, and Canadian standards for cadmium in soils. The average concentration of cadmium in the study area from result of the analysis was 0.18mg/kg in ore-processing areas and 0.14mg/kg in non-ore processing areas with coefficient of variation at 0.53 and 0.50 respectively. This shows that cadmium is well within the acceptable standards for soil cadmium concentration, and therefore, cadmium is not implicated in the environmental contamination of the study area.

Table 3: United States Standard for Lead in Soils

<table>
<thead>
<tr>
<th>Bare soil location</th>
<th>Standards (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Play areas (yards)</td>
<td>&gt;= 400mg/kg</td>
</tr>
<tr>
<td>All other locations</td>
<td>&gt;= 1200mg/kg</td>
</tr>
</tbody>
</table>


Table 4: Canadian Standards for Lead in Soils

<table>
<thead>
<tr>
<th>Bare soil location</th>
<th>Standards (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>600mg/kg</td>
</tr>
<tr>
<td>Agriculture</td>
<td>70mg/kg</td>
</tr>
<tr>
<td>Residential</td>
<td>140mg/kg</td>
</tr>
<tr>
<td>Commercial</td>
<td>260mg/kg</td>
</tr>
</tbody>
</table>

Source: Canadian Council of Ministers of the Environment (1999)
Table 5: Some standards for heavy metals in soils (in mg/kg)

<table>
<thead>
<tr>
<th>S/N</th>
<th>Parameters</th>
<th>Denmark standards</th>
<th>WHO standards</th>
<th>NESREA standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cadmium</td>
<td>5</td>
<td>10</td>
<td>3 – 6</td>
</tr>
<tr>
<td>2</td>
<td>Chromium</td>
<td>Not fixed</td>
<td>Not fixed</td>
<td>Not fixed</td>
</tr>
<tr>
<td>3</td>
<td>Lead</td>
<td>40</td>
<td>70</td>
<td>250 – 500</td>
</tr>
<tr>
<td>4</td>
<td>Iron</td>
<td>Not fixed</td>
<td>Not fixed</td>
<td>Not fixed</td>
</tr>
<tr>
<td>5</td>
<td>Zinc</td>
<td>500</td>
<td>200</td>
<td>300 – 600</td>
</tr>
</tbody>
</table>

Source: Ezigbo (2011)

Spatial Pattern of Spread of Concentration of Lead: High lead concentration was observed in all the mining villages except Dareta while low concentration was recorded in the non-mining locations. The technique of inverse distance weighting interpolation employed also showed the spatial spread of very high values, high values, and medium values of lead concentration in the mining villages. This is an indication that mining processes may be responsible for lead contamination of the study area. The significance of this is that an area of very high lead concentration is indicative of areas that are in most need of intervention, and vice-versa. This can be a very powerful and useful tool for policy and decision makers when planning remediation. Also, mapping of lead in soils can be useful in educating the populace, especially children to avoid contaminated areas that have been identified and mapped. This may help to reduce the incidence of lead poisoning.

Relationship: Gold Ore Processing and Lead Concentration: Descriptive statistics showed that locations in the study area that engage in ore processing showed high concentration of lead, and non-mining locations showed low concentrations of lead. Equally, inferential statistics employing the t-Test Two Sample method applied to lead concentration values in mining and non-mining villages showed that T (tabulated) at 95% confidence level which is 0.05 > T (calculated) 0.000005. This implies that there is a significant difference between the concentration of lead in mining and non-mining villages.

High concentrations of lead in soils have been shown to be the major cause of lead poisoning. Dooyema et al. (2012) conducted a study in some locations in Zamfara State and reported high levels of concentration of lead in the soil. Similar studies were conducted by Lo et al. (2012) and Udiba et al. (2012) where high levels of concentration of lead in soils of Zamfara State were reported. In all these studies, areas of high lead concentration were reported to be part of the areas affected by the Zamfara lead poisoning crisis. We can infer, therefore, that a relationship exists between artisanal (local) mining operations in the study area and lead concentration. And since inferential statistics has shown that there is a significant difference between the concentration of lead in mining and non-mining villages, we may say that lead poisoning in Anka may be attributed to artisanal mining and ore processing.

4.0 CONCLUSION

4.1 Conclusion

Presence of lead was shown and spatially depicted in all the villages studied, with only the level of concentration differing between mining and non-mining villages of the study area. Mining areas recorded very high lead concentration while non-mining areas recorded low lead concentration. Policy and decision makers may find such data useful for determining areas in urgent need of intervention. Concentrations of copper and cadmium were determined to be within the internationally acceptable threshold. We can conclude that copper and cadmium are not implicated in the environmental contamination of the study area. Descriptive and inferential statistics showed that a relationship exists between mining and gold ore processing and lead concentration in the soil of the study area. We can conclude, therefore, that mining and processing of gold ore is the cause of the massive lead contamination of the study area, leading to lead poisoning.

4.2 Recommendation

Study of food pathways (livestock, crops) should be undertaken as livestock was seen to be drinking from ponds that may be contaminated, and crops may grow on contaminated soil. Mercury is known to be used as a coagulant in the local processing of gold ore as witnessed in the study area. There is a need to study mercury pollution before it becomes a crisis as is the case with lead. As mercury is very toxic, this could easily damage the health of exposed persons especially children who tend to play on the ground where mercury may have been spilled. Further study of the whole state is clearly needful as the geographic extent and, number of people potentially affected is still not...
known. Any villages in Zamfara state not yet assessed where suspected and/or confirmed mining and ore processing activities have taken/are taking place should be assessed immediately for possible lead pollution and poisoning.

REFERENCES


