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Full Length Research Paper

Human health risk characterization of lead pollution in contaminated farmlands of Abare village, Zamfara State, Nigeria

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This study was initiated to assess the level of lead (Pb) contamination in farmlands, crop plants and water sources and the health risk in one of the Pb-contaminated villages of Zamfara State. Soil samples were collected from two depths at intervals of 10, 50, 150, 300, 500 and 1000 m from the last house along each of the four cardinal directions (North, South, East and West). Crop plant samples were also collected at each sampling distance while profile pits were dug at 150 m in each direction. Water samples were collected from all available sources in the villages. Contents of total Pb was determined in all samples following *aqua regia* digestion for soil and plant samples, water samples were digested with HNO_3. Health risk assessment was based on lifetime exposure through ingestion and inhalation of soil and dust based on the USEPA risk exposure models. The average concentrations of Pb in farmlands (515 mg kg^{-1}) and profile pits (365 mg kg^{-1}) were lower than its extent in plant materials (1220 mg kg^{-1}). The average chronic daily intake (CDI) for carcinogenic risk in mg kg^{-1} day^{-1} was 1.3 x 10^5 for Pb. Non carcinogenic CDI in mg kg^{-1} day^{-1} averaged 1.7 x 10^8 in adults. For children, it averaged 9.7 x 10^7 mg kg^{-1} day^{-1}. However, the concentrations in all the samples are far beyond acceptable levels with high repercussion for environment and human health hazard. Suitable intervention measures are required to reduce these high concentrations in order to minimize risks associated with contamination.

Key words: Heavy metals, lead, Zamfara, health risk, soil contamination.

INTRODUCTION

Anthropogenic heavy metal contamination is becoming widespread with ubiquitous nature of heavy metals in the environment. Anthropogenic sources of heavy metal pollution include but not limited to mining, iron smelting, fossil burning and municipal and industrial waste disposal. Illegal mining activities in Zamfara, northern Nigeria was reported to have killed hundreds of people mostly children in 2010 (NNP 2011). This was related to lead (Pb) poisoning or high lead concentration in the blood resulting from widespread contamination in the villages and compounds where gold ore are processed. The gold ore contain Pb as an impurity and hence lead was deposited in the villages during processing. Children were mostly affected due to their smaller bodies and beha-viours. Children ingest dust when they put their hands in the ground and eat food. Efforts were made by both governmental and non-governmental organizations within and outside the country to curb the situation. Medicins Sans Frontiers (MSF) in collaboration with the Zamfara State Ministry of Health (ZMoH) administered drugs that can be used to detoxify afflicted patients. Similarly, the Zamfara State Ministry of Environment and Solid Minerals

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(ZMoE) requested technical assistance from the Blacksmith Institute (BI) of New York and another US firm, TerraGraphics Environmental Engineering (TG) to secure clean environments in the contaminated villages for children returning from treatments. Contaminated soils were excavated and replaced by clean soil to bring down the lead level. This approach effectively reduced lead toxicity in residential compounds and exterior areas where it was applied (BI, 2011).

Farming activities within the surrounding farmlands in the affected villages is still ongoing which can results to plant accumulation of Pb and other associated heavy metals like cadmium and zinc. Abdu et al. (2011a, b) reported Cd and Zn contamination of vegetables and associated health risk as a result of wastewater irrigation in Kano, northern Nigeria. Sorghum, a widely cultivated crop in the region can accumulate heavy metal in high concentration without showing any symptom of toxicity (Prasad and Freitas, 2003). Extreme of concentrations as reported in this study could lead to heavy metal accumulation by crops and eventual translocation from the shoot to the grain without the crop showing any physiological deficiency. This has a tendency of contaminating and posing a health risk to the ecosystem. Moreover, in the rural northern Nigeria, leaves and stalk of sorghum plant are highly consumed by livestock. The accumulated heavy metal will then be transferred to the animal and eventually contaminating the food chain.

Yusuf et al. (2011) reported contamination of farmlands and various water sources with Pb in the affected villages beyond permissible limits. Contamination could occur due to deposit from dust and underground water movement even from landfills that are not well protected. Even at low level, Pb has no biological or physiological essentiality as a nutrient. It affects the developing brain and causes behavioral problems and intelligence quotient (IQ) deficit. Currently, there is no information on the risk assessment of Pb pollution in the lead-contaminated villages. The objectives of the study were to assess lead status of farmlands and various water sources in one of the lead-contaminated villages of Zamfara State and quantify the potential health risk and hazard from Pb contamination in the affected village.

MATERIALS AND METHODS

A systematic sampling method was used to collect soil, water and plant samples in Abare village in Anka Local Government Areas of Zamfara State. Sampling was done in the direction of each of the four cardinal points (North, West, East and South). In each direction, soil and plant samples were collected at 10, 50, 150, 300, 500 and 1000 m from the last house of the village in that direction. The soil samples were taken at 0 - 15 cm and 15 - 30 cm depth with an auger while the plant samples were collected from both cultivated and non-cultivated plants. In the case of crop plants, samples were taken from the part of high nutrient concentration e.g. flag leaf and ear leaf for sorghum and maize, respectively. All the samples were collected in three replicates. In addition to the surface soil samples, soil profile pits were dug to approximately two meters depth at 150 m in each of the four directions. At least four horizons were delineated in each pit and triplicate soil samples were taken from each horizon. Before analysis, the soil samples were air-dried, ground and passed through 2 mm screen while the plant samples were oven-dried at 65°C to constant weight, ground and sieved through 0.5 mm mesh. Water samples were taken from wells, streams and rivers encountered within and outside the village. One milliliter (1 ml) of concentrated HCl was added to each water sample to suppress microbial activities.

Soil pH was determined in $CaCl_2$ solution at a soil: solution ratio of 1:2.5 using a pH meter, cation exchange capacity was determined by leaching with 1 N ammonium acetate solution (Anderson and Ingram, 1993). Organic carbon was determined by dichromate wet oxidation as described by Nelson and Sommers (1986). Particle size analysis was measured using the hydrometer method (Gee and Bauder, 1986).

Total lead concentrations in the soil, plant and water samples were determined in atomic absorption spectrophotometer (AAS) after hot acid digestion (Lim and Jackson, 1986). Data collected were subjected to suitable statistical analysis such as descriptive statistics and analysis of variance (ANOVA) using Statistical Package for Social Scientists (SPSS, version 17.0).

Risk assessment

Carcinogenic and non-carcinogenic risk for ingestion and inhalation of heavy metals were calculated using the following formulas (USEPA, 2005):

Carcinogenic CDI (mg kg^{-1} day^{-1}) = CS x IF x EF/AT

where IF = (IR x ED/BW) Adult + (IR x ED/BW) Child

Non-carcinogenic CDI (mg kg^{-1} day^{-1}) = CS x IN x EF x ED/BW x AT

CDI (Dust inhalation) for carcinogenic and non-carcinogenic risk were calculated using the relation:

$$\text{CDI (mg m}^{-3}) = \frac{\text{CS x IF x EF (1/PEF + 1/VF)(ET}_{Outdoor} + (\text{ET}_{Indoor}\text{DF}_{Outdoor})}{\text{AT}}$$

Definition of the terms and values for individual parameters are indicated in Table 1.

RESULTS AND DISCUSSION

Assessment of lead concentrations in farmlands in Abare

The average concentrations of Cd, Pb and Zn were 17.5, 1266 and 985 mg kg^{-1}, respectively, in soil. The concentrations of the heavy metals were far beyond minimum threshold values worldwide (300 mg kg^{-1} in EU and UK, 150 mg kg^{-1} in USA and 70 mg kg^{-1} in Canada) (Abdu et al., 2011a). Very high concentrations were observed at the surface soil depth indicating superficial enrichment through anthropogenic mining processing. Sampling depth did not have significant effect on lead (Pb) concentration in all the sampling directions. Similarly, a non-significant effect was found on the interaction between sampling distance and depth in all the directions (Table 2). The concen-tration of lead between the soil horizons within the profile

Table 1. Risk assessment terms, their definition and values used in the study.

Variable	Value	Variable	Value
CS = Concentration of heavy metal in soil		IR = Ingestion rate (Adult)	100 mg/day
IF = Intake factor	-	IR = Ingestion rate (Child)	200 mg/day
EF = Exposure frequency	350 days/year	BW = Body weight (Adult)	60 kg
AT = Averaging time	365 days/year	BW = Body weight (Child)	15 kg
ED = Exposure duration (Adult)	30 years	IN = Inhalation rate (Adult)	3.6 m^3/hour
ED = Exposure duration (Child)	6 years	IN = Inhalation rate (Child)	2.2 m^3/hour
PEF = Particulate emission factor	1.3×10^9 m^3/kg	$ET_{Outdoor}$ = Exposure time	0.68
VF = Volatilization factor	11 m^3/kg	ET_{indoor} = Exposure time	0.07
DF = Dilution factor indoor	0.4		

Volatilization and particulate emission factors are dependent on the climate of the region under study and were calculated based on the mean atmospheric humidity of 9.1 g of water per m^3 of air.

Table 2. Effect of soil depth and sampling distance on lead concentration in Abare, Zamfara, Nigeria.

Sampling	North (mg kg^{-1})	South (mg kg^{-1})	East (mg kg^{-1})	West (mg kg^{-1})
Depth (cm)				
0 – 15	748	392	401	684
15 – 30	626	387	370	508
Mean	687	390	386	596
SED	133	61	44	93
Distance (m)				
10	858^{ab}	398	327^{b}	-
50	684^{ab}	344	549^{a}	987^{a}
150	468^{b}	372	400^{b}	360^{c}
300	521^{b}	265	351^{b}	696^{b}
500	1117^{a}	550	300^{b}	342^{c}
1000	482^{b}	409	384^{b}	-
Mean	688	390	385	596
SED	243	103	69	131
Depth x Distance				
Significance	NS	NS	NS	NS

Means followed by the same letter in a column are not significantly different; NS = not significant at 5% level of significance.

pits was equally found to be at par (Figure 1). However, sampling distance was found to have significant influence on the concen-tration in all the directions except south (Table 2). In the north, soil samples taken at 500 m away from the village had higher concentration of Pb than soil samples taken at 150, 300 and 1000 m. There was no significant difference in Pb concentration of soil samples taken at 500 m as compared to those taken at 10 and 50 m. In the east and west of the village, soil samples taken at 50 m away from the last household had higher concen-tration of Pb than soil samples taken at other distances. In the west, significantly higher concentration was observed at 300 m than 150 and 500 m which were not significantly different from each other. In general, no uniform trend was observed in Pb concentration in all the directions because though hig-her concentrations were found around 50 m distance in the east and west of the village, similar values were observed at much further dis-tance such as 500 m in the north than closer distance like 150 m. This shows lack of uniformity in the distribution of the elements in the soil which could be attributed to soil heterogeneity. Luo et al. (2007) reported that concentra-tions of heavy metals vary remarkably over space due to the heterogeneity of soil itself.

This observed concentration was irrespective of sam-pling depths, distance or direction (Figure 1). The values obtained across the profile pits also fall above these acceptable limits. Although Pb contamination in this village was attributed to lead deposited from gold ore processed, high concentration down the profile pits suggests addi-

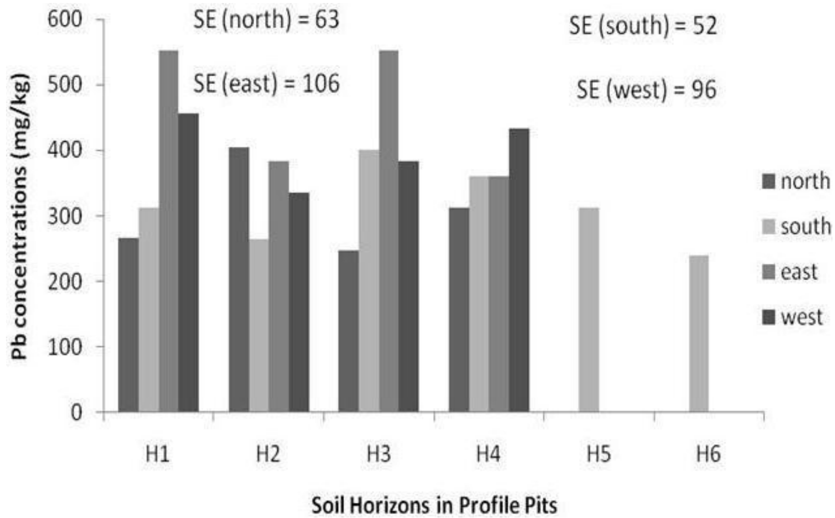

Figure 1. Lead concentration of soil horizons in provfile pits in the four cardinal directions of Abare.

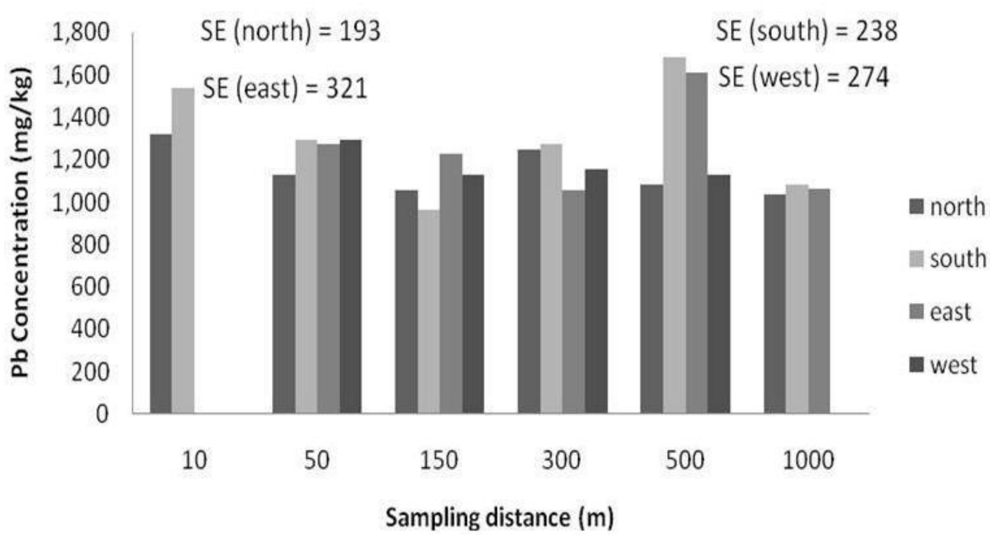

Figure 2. Effect of sampling distance and direction on Pb concentrations in plant samples in Abare.

tional below ground sources of these elements. Parent material could be an important origin of Pb and pedogenesis, a natural input of the Pb into the soils. Phosphate fertilizers are other sources of Pb that may cause pollution in agricultural soils, however, they are not readily available for farmers use in the study area.

Assessment of lead concentrations in plant samples in Abare

Lead determination in plants mainly focused on sorghum and cowpea leaves. These are the dominant crops grown in the study area. Plant samples collected at the various soil sampling points along each direction showed no significant difference in their Pb concentrations (Figure 2). However, Pb concentration in these plant materials was over 3500-fold higher than the recommended thresholds of 50 mg kg^{-1} in edible crops by FAO/WHO (2001). The extremely high levels of Pb in the plant materials could not have been due to uptake from soil solution alone, atmospheric deposition of dust from the contaminated gold ore processing plants within the village must have greatly contributed. Plant sampling was done at the period when contaminated soils were being excavated and replaced by clean soils. This process would generate a lot of dust which will eventually settle on surrounding vegetation. This suggests that the high

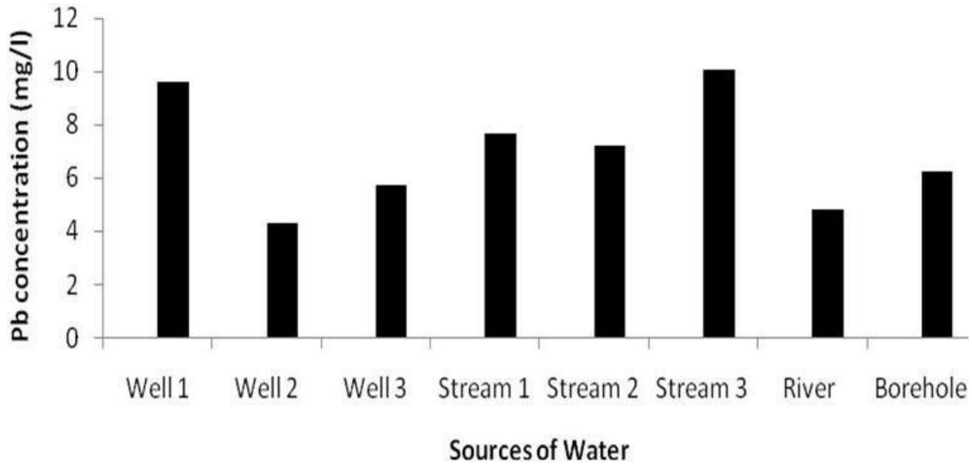

Figure 3. Lead concentration of some sources of water in Abare village.

Pb concentration in the plant materials must have come from dust deposition. High levels of Pb in the soil coupled with human input could result in phytotoxicity at high concentrations and the transfer of these elements to the human and livestock diets from plant uptake. We could not determine the concentrations in the edible part of the crop because sampling was done at the middle of the growing season. The plant parts sampled (leaves and stalk) are essential components of livestock feed especially after harvest and heavy metal accumulation in them could be indirectly used to assess exposure risks.

Assessment of lead concentrations in water samples in Abare

Lead concentration determined in eight sources of water in the village ranged from 4.32 to 10.08 mg/l (Figure 3). The highest concentration was found in the water collected from one of the streams while the lowest was obtained from well water. Generally, stream water had higher con-centration of lead than well water. River and borehole water had intermediate concentration of 4.80 and 6.24 mg/l, respectively. The results from all the water sources showed no immediate risk of Pb contamination. Its con-centration is not above the threshold limit set by the United States Environmental protection Agency (USEPA, 2004). This limit is in the range of 5 to 10 mg/l.

Risk assessment

Chronic daily intake (CDI) of metals for carcinogenic and non-carcinogenic risks indicated significant danger to the inhabitants of the study area. The average CDI for carcinogenic risk was 1.3 x 10^5 mg kg^{-1} day^{-1} for Pb. Non carcinogenic CDI were estimated for both adults and children and the average values for adults was 1.7 x 10^8 mg kg^{-1} day^{-1}. Even for children, the estimated values were very high with an average of 9.7 x 10^7. Dust inhalation was used as the exposure route of soil considering the exposure time indoor and outdoor. The CDI through this route was calculated to be 1.5 x 10^6 mg kg^{-1} day^{-1}. These values are far beyond the report of Abdu et al. (2011b) in waste-water irrigated vegetable gardens of Kano, northern Nigeria. They are equally beyond acceptable values worldwide and can thus, be related to high Pb level in blood samples and associated death among inhabitants of this village.

Conclusion

High concentrations of Pb in both soil and plant and the estimated health risk may have posed a health hazard for the environment and the ecosystem as a whole. Based on data description, the primary input of this heavy metal in the soil is the soil parent material. Both human and natural activities influenced concentrations of Pb in the plant material. Processing of contaminated gold ore in this village has been responsible for the severe Pb pollution. Remediation studies are required to tackle Pb contamination in the farmlands.

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