Heavy metal contaminations in soil and cassava harvested near a cement processing facility in the Volta Region, Ghana: Implications of health risk for the population living in the vicinity

[1]M. A. Addo, [2]E.O. Darko, [3]C. Gordon, [1]B. J. B. Nyarko

[1]National Nuclear Research Institute, Ghana Atomic Energy Commission, P. O. Box LG 80, Legon-Accra
[2]Radiation Protection Institute, Ghana Atomic Energy Commission, P. O. Box LG 80, Legon-Accra
[3]Institute of Environmental Science Studies, University of Ghana, P. O. Box LG 209, Legon-Accra
Email: abedanka1@hotmail.com

Abstract

Heavy metals concentration of Arsenic, Chromium, Nickel and Lead were determined in fresh cassava crops and the corresponding soils, from which they were harvested, collected in the vicinity of the Diamond Cement Factory (DIACEM) in the Volta Region, Ghana. In addition, similar samples (control) were collected 8km South of DIACEM in an area without charge from industrial influence. The average concentrations of the metals in the cassava were: 0.017µg/g for As, 3.04 µg/g for Cr; 6.76 µg/g for Ni; and 0.86 µg/g for Pb. For the corresponding soils the average concentrations for As, Cr, Ni and Pb were, 0.23, 53.22, 78.35 and 1.37 µg/g respectively. With the exception of Ni, all the metal levels in cassava were higher in the subject samples than in the controls. A similar situation occurred in the case of corresponding soils with Cr replacing Ni as the exception. This observation places much responsibility on the cement plant as the culprit of the higher metals in the samples. All the metal levels in the cassava samples with the exception of As were above permissible levels prescribed by the FAO/WHO for vegetables. The results of the estimated daily intake (EDI) for the metals also observe similar situation when compared to the Provisional Tolerable Daily Intake (PTDI) proposed by FAO/WHO. Values of Target Hazard Quotient (THQ) of heavy metals were calculated to estimate the risk to human health. All the metals values exceeded the safe limit of unity indicating a high human health risk for the population who consume cassava from the area.

Key words: Heavy metal, Cement factory, human health, Daily intake, Vegetables, Chromium

INTRODUCTION

Cement manufacture can be a significant source of heavy metal contamination in the environment (Kalafatoglu *et al,* 2001; El-Albasswy et al, 2011; Bilen, 2010, Schumacher *et al*, 2002). Among the metals especially known to have toxic effect in environmental studies are arsenic, cadmium, lead, mercury and thallium (Chang, 1996; Domingo, 1994). Aluminum, beryllium, chromium, copper, manganese, nickel, lead and zinc, among others, have been identified in the emission from cement plants (Schuhmanher *et al*, 2002). The environmental concern in cement manufacture is primarily related to the emission of dust and gases (Bilen, 2010). Hindy *et al* (1990) reported that in Egypt, 1 kg of cement manufacture generate about 0.07 kg of dust in the atmosphere. Cement dust can spread over large areas through wind and rain and

are accumulated in and on soils, plants and have the potential to affect animal and human health adversely (Bayhan and Özbay, 1992; Demir et al, 2005).
The problem of air pollution in the form of particulates has become a threat to the survival of plants and the reduction of the integrity of soils in the industrial areas (Gupta and Mishra, 1994; Bilen, 2010). Excessive accumulation of heavy metals in agricultural soils, resulting in elevated heavy metal uptake by food crops, is of great concern because of potential health risk to the local inhabitants (Adriano, 2001).

Cultivation of crops for human or livestock consumption on contaminated soil can potentially lead to the uptake and accumulation of trace metals in the edible plant parts around industrial areas with a resulting risk to human and animal health (McBride, 2007; Monika and Katarzyna, 2004). It is therefore important to express concerns and question on the state of the soil and quality of food crops, fruits and vegetables cultivated and grown in areas where cement manufacture is carried out. Heavy metal contamination of agricultural soils and crops in the vicinity of a cement production facility should be of a major environmental concern.
A little over the past decade, a cement factory has been in operation in a rural suburb of Aflao, Volta Region of Ghana, where cassava production has been the mainstay agricultural crop in the vicinity of the cement plant. The cassava crop is grown and widely consumed by the inhabitants surrounding the cement facility. In terms of quantity produced, cassava is the most important root crop in the study area and ranks second to none in terms of area planted. Cassava is not only used as human food or help feed families and animals, but also serves as a vehicle to income to escape poverty in the area. Generally, cassava is a perennial shrub of the family *Euphorbiaceae*, an important starchy staple crop in Ghana with a per capita consumption of 152.9 kg/yr (Adjei-Nsiah and Sakyi-Dawson, 2012).

Common products from edible portion of the cassava tubers especially garri, fufu and akpele meals are widely consumed by the local population and constitute one of the major ingredients in the local staple. Many other processing techniques are used in Africa to produce a variety of either wet or dried products for human consumption (IFAD, 2004). It is well established that high exposure to trace metals like, As, Cr, Ni and Pb in cassava could result in an array of diseases to both human and animals. Apart from cassava, other vegetables can take up and accumulate heavy metals in quantities high enough to cause clinical problems to humans (Alam *et al*, 2003). For instance, Pb toxicity in humans could result in nervous system, liver, pancreas, blood diseases and bone health effect. On the part of As, especially in soluble organic form, can have immediate toxic effect. Ingestion of large amounts can lead to gastrointestinal symptoms such as severe vomiting, disturbances of the blood in circulation, damage to the nervous system; and eventually death (FACT SHEET, 2012).

It is known that serious systemic health problems can develop as a result of excessive dietary accumulation of heavy metals. Dietary intake is the main route of exposure for most people, although inhalation can play an important role in very contaminated sites (Tripathi *et al.*, 1997). Thus, information about heavy metal concentrations in food products and their dietary intake is very important for assessing their risk to human health (Zhuang *et al*, 2009). Recent developments in toxicities and other disorder resulting from ingestion of toxic metals have compelled food regulators around the world to revise the safe limits of these toxicants to ensure consumer health.

Meanwhile, it is important to note that the Ghana cement industry holds the key to the development of the nation as a result of its rapid pursuit for cement to enable the country meet the development of strong physical infrastructural needs in terms of construction of good roads, bridges, hospitals, schools and to overcome the country's housing deficit currently standing at more than one million with an annual delivery of only 40,000 being provided (MWRWH, 2010). In view of these developmental desires, more cement producing facilities would be needed. The current industry makes a great contribution to the socio-economic development by providing significant employment opportunities at non-skilled and skilled levels. Beyond that, the industry provides construction materials required for the other sectors of the economy to flourish. However, data regarding their environmental challenges are scarce. To date, information pertaining to accumulation of trace heavy metals in food crops especially cassava crop in the vicinity of the Diamond Cement Plant is not available.

Food safety is an important aspect of a nation's economic stability and due to previous reports on the degree of pollution of some other food items (Oniawa *et al*, 1999; Adekunle and Akinyemi, 2004), this study was aimed at assessing some heavy metal (As, Cr, Ni and Pb) levels in cassava crop and corresponding soil samples in the neighbourhood of the DIACEM. In addition, the relationship between the concentration of the heavy metals in plants and the extent of soil contamination were identified. Furthermore, values of estimate daily intake of the heavy metals in the cassava samples were calculated to estimate the risk to human health.

MATERIALS AND METHODS

Study Area

The study area is located in the south eastern part of Ghana in the Ketu South District of the Volta region. The area is geographically enclosed between Latitudes 06.13400 N and 06.16650 N and Longitudes 01.16100 E and 01.19911 E which is part of Ketu-South Municipal Assembly. The area is bounded on the: North by the eastern boarder of the Republic of Togo; East by the Aflao township; West by Akplorkploe; and South by a lagoon which floods a wide area. The DIACEM factory is located 3 km north of the Aflao Township (Figure 1). The cement factory plays a significant role in the local building industry and in the economy of Ghana. The Indian-owned factory was established in 2002 and was a major employer in the area. The area lies within the dry equatorial climate of the region. It has two rainy seasons with the major rains in April to June, and the minor rains between September and November. Minimum temperatures in the investigated area are 13.5°C and occur between the months of August and September, and average maximum of 40°C is experienced between February and March.

The factory's surrounding area is essentially rural with minor agricultural activities. Settlements are scattered houses at varying distances with the nearest settlement at about 300m from the factory. The surrounding vegetation is made up of several shrubs and grasses and lies within the Coastal Savanna agro-ecological zone. The geological formations of the investigated area are rocks of the Dahomeyan series of the Precambrian age. These rocks consist of dense aggregate of essential stable minerals which are bounded and have medium to coarse-grained granite texture.

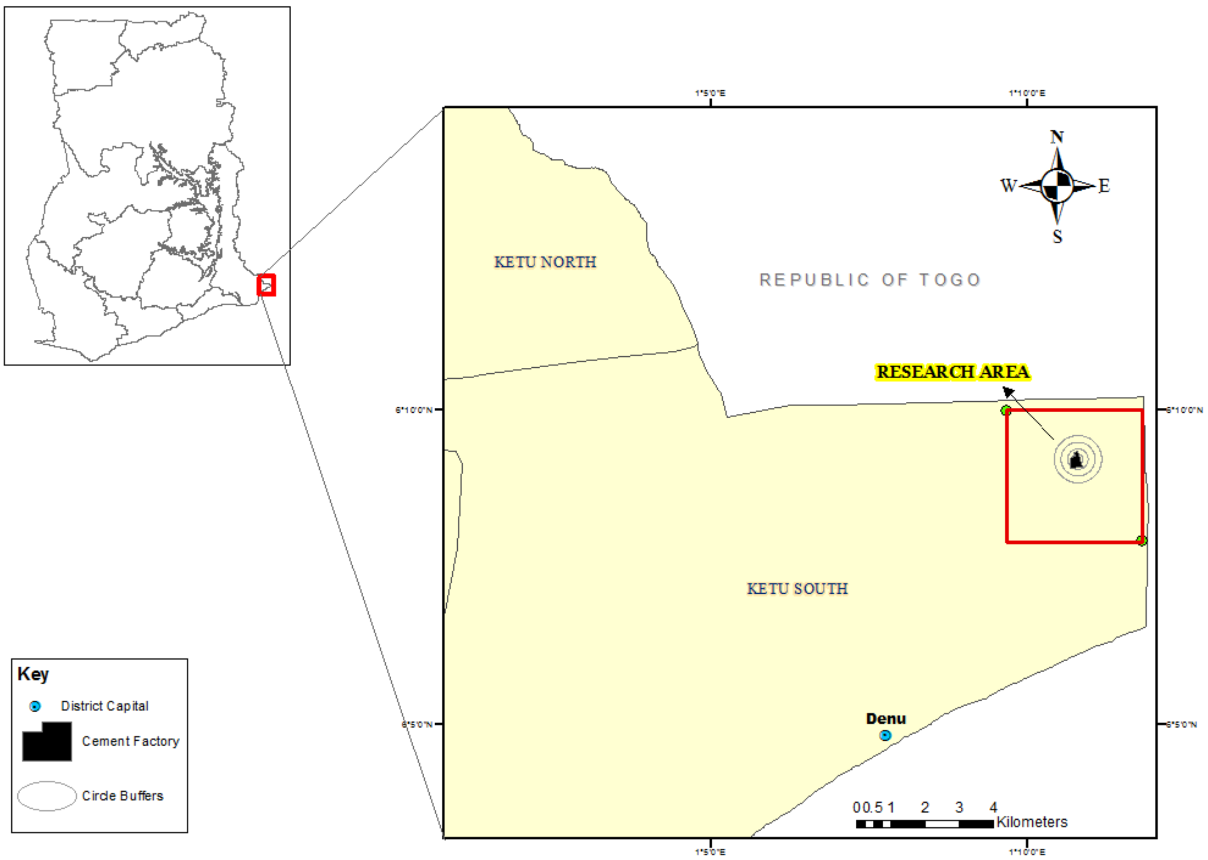

Fig. 1: Map of the study area showing the location of the cement factory

The Dahomeyan series are seismically stable and therefore there is no history of earthquake in the area. The soil types are mainly lateritic sandy soils, tropical black clays, tropical grey earths, and Sodium vleisols. These soil types are suitable for the cultivation of different types of crops (NDPC, 2010).

Sample Collection and Analysis

The cassava and corresponding samples were collected in three directions, northern, north-east and eastern, of the cement factory where the prevailing winds of the area are active. In addition those directions are represented with numerous cassava farmlands with varying sizes in area. In each direction, at least two farms were visited and sampled. The samples representing each direction of the factory were converted into composite samples before the analysis.

At each sampling site, about 1 kg cassava (fresh weight) samples were collected and initially thoroughly washed with tap water to remove surface sand. From each site soil samples of approximate 0.5 kg (wet weight) were collected into separate plastic contains.

In the laboratory, the cuticle of the cassava were removed with a stainless steel knife and the edible parts were cut into pieces of about 10 cm^3 and put together in polyethylene materials for refrigeration. The samples were freeze-dried for three days and were pulverized by means of a cleaned industrial blender and kept separately in their respective containers. About half of the samples coming from farms in the same direction from the factory were put together and gave exhaustive mixing with a spatula from which subsample of 10g each were put into fresh cleaned plastic containers and re-labelled. The soil samples after oven drying at a temperature of 80°C for three days were pulverized in a pulverizer and the subsamples prepared similarly as the cassava samples. The samples were further screened in 110µm mesh sieve to obtain smaller grain-sized sand particles before they were subjected to X-ray Fluorescence (XRF) analysis. The procedure for the cassava and soil preparation and XRF analysis were the same.

Before the XRF analysis, 4g of the milled samples were made into pellets after which 0.9g of Hoechst wax was added and grinded in a sample cup and fitted into a manual press to obtain a homogeneous mixture. Consequently, the concentration of As, Cr, Ni and Pb in both sets of samples were directly measured by XRF. Meanwhile, a series of soil and sediment Standard Reference Materials (SRM) were used to calibrate the XRF system. The standards used were: Soil 7 SRM and Soil 3 SRM, all of the International Atomic Energy Commission (IAEA). To validate the instrumentation, the mean concentration of the elements obtained from the standard used was compared with the certified values by calculating the ratio of experimental values to certified reference values. The results gave ratios between 0.94 and 1.05 indicating that the results of the XRF work were in good agreement with the certified values. To check the analytical precision of the instrumentation, ten subsamples form each soil and plant materials were analyzed. The analytical precision, measured as relative standard deviation, was between 2.5 and 7.5% for the soil samples and between 1.5 and 7.5% for the soil samples. Thus, the quality control gave good precision for all the samples.

RESULTS AND DISCUSSION

Heavy metal concentration in cassava tubers and corresponding soil samples

The mean concentration of heavy metals in the edible portion of cassava and the soils from which the cassava were harvested is summarized in Table 1. Clearly, from the results, it is evident that the trend in metal concentration for both subject locations and reference areas is of the increasing order of As<Pb<Ni<Cr. The analysis of the results indicated significant differences ($p<0.05$) in As and Pb among the sampling sites whilst Cr and Ni indicates no significant difference among the locations. The critical levels of these metals in soils have been widely studied. For example, Bergmann (1992) indicated that the toxic level of Cr in soil is around 2-50 µg/g and this in comparison with Cr measurement in the current situation (51.69-55.98 µg/g) is on the high side. The critical level of Ni in soil has been estimated in the range of 20-70 µg/g by Kabata-Pendias and Piotrowska (1984).

According to the present study, the mean level for Ni (78.35 µg/g) is alarming suggesting that pollution is critical in the investigated area. The soils being investigated here are from the bottom (non-surface) category and is been contaminated from various human sources from seepage situations. In the case of the control samples some fertilizer application to the soil had taken place, whilst the reference soil derived its elevated metal content through seepage from surface cement dust contamination. Both fertilizer and cement powder are noted for their high heavy metal contents (Schuhmacher *et al*, 2004; Addo *et al*, 2012).

Table 1: Heavy metals mean concentration (µg/g) in cassava samples and associated soil at locations from cement factory

Farm Location from Factory	Sample type	n	Concentration of heavy metals (µg/g)			
			As	**Cr**	**Ni**	**Pb**
East	Cassava	5	0.024	1.82	9.04	0.71
	Soil	5	0.09	51.69	80.40	1.97
North	Cassava	5	0.012	2.61	5.61	0.81
	Soil	5	0.21	55.98	70.32	0.88
North-east	Cassava	5	0.015	4.70	5.62	1.06
	Soil	5	0.38	51.99	84.34	1.25
Average	Cassava	5	0.017	3.04	6.76	0.86
	Soil	5	0.23	53.22	78.35	1.37
Control	Cassava	5	0.010	1.43	10.20	0.58
	Soil	5	0.14	57.99	70.12	1.37
Permissible limit of metal in foodstuffs			0.10	2.30	1.5	0.20
References			WHO/FAO (1999)	WHO/FAO Kihampa *et al* (2011)	Awashthi (2000)	WHO/FAO (1999)

The accumulation of heavy metals in cassava tuber has been summarized in Table 1. The results indicated that with the exception of Ni all the metals in the cassava uprooted from farmlands in the subject area were relatively higher compared to those of reference farmlands. This reflects a contamination of these cassava crops by heavy metals in the impacted area. Another interesting part of the result is that all the metal contents in the edible part of the cassava were less than those of the corresponding soil. The results are clear indication that the cement facility may be a potential influence in the elevated heavy metals in both soil and cassava samples in the impacted area.

According to Table 1, all the accumulated metals in the cassava tubers were above the permissible levels stipulated by WHO/FAO (1999) and Indian standard (Awashthi, 2000). The relatively high levels of chromium and nickel in the soil compared to that of the tubers can lead to increased plant uptake which may be injurious to human and animal health. Nickel and Cr are known as essential elements but could be toxic to human health if found in elevated concentrations (Nadal *et al*, 2004).

Average arsenic levels ranged between 0.12µg/g and 0.24µg/g dry weight with an average of 0.71 µg/g. This is almost twice the prescribed limit of WHO/FAO guideline for vegetables. Similarly, Pb level ranged from 0.71 µg/g to 1.06 µg/g which averaged to 0.86 µg/g dry weight. This averaged value is three times more than the legally estimated value of 0.20 µg/g specified by WHO/FAO. Average Pb levels for this study are higher than the average value of 0.50 µg/g which was obtained in a similar study along the highways of Benue State in Nigeria (Adebayo and Rapheal, 2011) and less than 1.73 µg/g in cassava tubers recorded by Nkwocha *et al* (2011) in an oil field in Bayelsa State, Nigeria.

Arsenic exceeding permissible limit (0.1 µg/g) in food stuff could cause in the short term (nausea, vomiting, diarrhea, cough and headache) and long term (cardiovascular diseases, diabetes and vascular diseases) human health effects (Col *et* *al*, 1999). On the part of Pb toxicity in humans, nervous system, liver, pancreas, blood diseases and bone health effect could result (CDCP, 2012).

Bio-accumulation Factor (BAF)

The ability of vegetable to accumulate a particular metal with respect to its concentration in the soil substrate is called the index of bio-accumulation factor (BAF) (Zhuang *et al*., 2005). The BAF is calculated as follows:

$$BAF = \frac{C_{plants}}{C_{soil}} \qquad [1]$$

Where, C_{plant} and C_{soil} represent the heavy metal concentrations in edible part of vegetables and soils respectively. Heavy metal concentrations of soils and crops were calculated on the basis of dry weight.

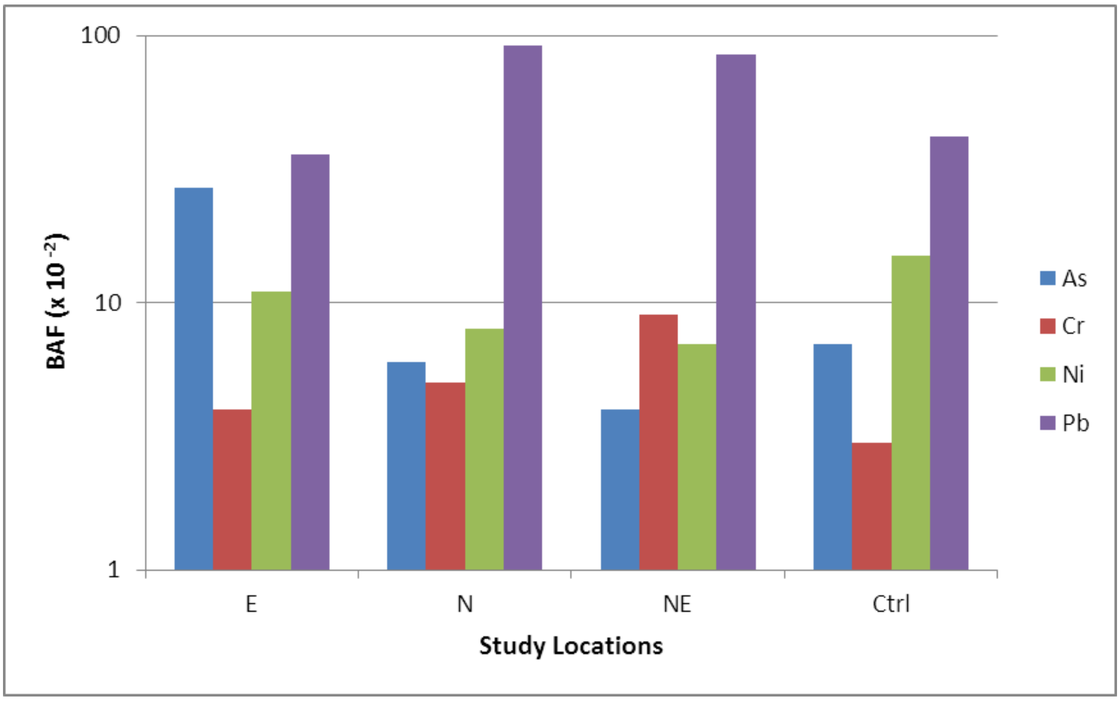

Fig. 5.2: Bio-accumulated Factors values for the study and Controlled area.

Fig.5.2 depicts the BAFs calculated for each element transfer from soil to corresponding cassava samples per sampling sites. Typically, the soil-to-plant transfer factor is one of the key components of human exposure to metals through the food chain. The calculated results indicate the mean transfer values in the BAF values was of the order Pb>As>Cr>Ni, the diversity among the sites may be due to the differences in soil properties. The least BAF values were recorded for the control sites except Ni which was significantly higher than all sites of the impacted area. The higher the value of the BAF, the more available/mobile the metal is. Therefore, Pb and As are absorbed more by the tubers than other metals and are available for more up-take by the cassava plants.

The BAF values recorded in this study is an indication of the potential of the heavy metals especially Pb and As accumulation in the soils surrounding the cement factory. This may be transferred into the food chain through the consumption of edible plants on the farmlands by either animal or man.

Health Risk of Inhabitants Due to Cassava Consumption

To assess the health risk of the local population in the vicinity of the Diamond cement Factory due to consumption of cassava crops, estimated daily intake (EDI) and health risk (HR) indexes were used.

***Estimated Daily Intake* (EDI)**

In order to observe the health risk of any pollutant, it is very important to estimate the level of exposure. One important aspect of the estimation is by the evaluation of the daily metal intake. The estimated daily intake (EDI) of heavy metals (As, Cr, Ni and Pb) depended on both the metal concentration in food crops and the amount of consumption of the respective food crop. The EDI is widely used to describe safe levels of metallic intake through food consumed (Lanre-Iyanda and Adekunle, 2012). It also combines data on the levels of heavy metals in foodstuff with quantities of food consumed on the daily basis. The EDI of the heavy metals for adults was determined by the following equation:

$$EDI = C_{HM} \times W_{CASS} / BW \qquad [2]$$

Where C_{HM} (μg/g, on fresh weight basis) is the concentration of heavy metals in contaminated crop; W_{CASS} represents the daily average consumption of cassava by Ghanaian; and BW is the adult's body weight. The W_{CASS} for this study was taken from Adjei-Nsiah and sakyi-Dawson (2012) as 152.9 kg/y consumption of cassava which work out as (152.9/365d) 418.9g/d. An adult's average body weight of 70kg was used for the EDI evaluation. The estimated daily intake expressed as per unit body weight (μg/kg b.w. /day) were calculated for cassava in each farmland in both the affected and reference areas and presented in Table 2.

Table 2: Estimated dietary intake (μg/kg b.w./day) of arsenic, chromium, nickel and lead in cassava samples from the study areas.

Source of Cassava samples	Heavy metals			
	As	Cr	Ni	Pb
East	1.44	10.89	54.06	4.25
North	0.72	15.37	33.56	4.84
North-east	0.89	28.11	33.61	6.34
Average	**1.02**	**18.12**	**40.41**	**5.14**
Control	0.60	8.55	61.00	3.47
PTDI	2.00	3.33	5.00	3.57
References	WHO/FAO (1987)	WHO/FAO (1987)	WHO (1994)	WHO (1994)

NB: PTDI= Provincial Tolerable Daily Intake taken from WHO/FAO guideline

The degree of toxicity of heavy metal to human depends on the daily intake. The EDIs of the heavy metals with the exception of Ni through the consumption of cassava crops for the local inhabitants from farmland in the study area are higher than what was observed for the reference area. Based on the EDI results, As values for cassava in both farmlands for the subject and control areas were less that the PTDI guidelines proposed by WHO/FAO. However, the EDIs in the subject area for Cr, Ni and Pb through the consumption of cassava were found to be significantly higher than the PTDI by 5.40, 8.80 and 1.44 times respectively. Clearly, this implies that the perennial intake of cassava harvested from these farmlands is likely to induce adverse health effects largely from Cr, Ni and Pb exposure.

Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) has been recognized as a useful parameter for evaluation of risk associated with the consumption of metal contaminated food crops. In this study, the health risks associated with heavy metals ingested through cassava crop consumption were assessed using the THQ. The THQ index can be defined as the ratio of determined dose of a pollutant to the reference dose (RfD) (mg/kg b.w..day) (Liu *et al*, 2006). The mathematical expression of THQ is given as in the equation 3 below:

$$THQ = \frac{EF \times ED \times FI \times C_m}{RfD \times BW \times AT} \times 10^{-3} \quad [3]$$

Where, EF is the exposure frequency (350 d/yr); ED is the exposure duration (30 yrs per adult); AT is the average exposure time for non-carcinogenic risk (365 d/yr x number of exposure years) and 10^{-3} is the unit conversion factor. C_m is the pollutant concentration in the edible part of the cassava crop; FI is the food ingestion calculated as 418.9 g/person; RfD is the reference dose; BW is the average body weight for adult (70 years). The reference doses were based on 3E-04, 3E-02; 2E-01; and 3.57E-03 for As, Cr, Ni and Pb respectively.

If THQ is less than 1, there is no obvious risk from the substance over a lifetime of exposure, while if THQ is higher than 1, the toxicant may produce an adverse effect (Han *et al*, 1998). The higher the THQ value, the higher the probability of experiencing long term carcinogenic effects.

Table 3: Target Hazard Quotient (THQ) of heavy metals in cassava samples from the study areas.

Source of Cassava samples	Heavy metals			
	As	Cr	Ni	Pb
East	4.57	2.79	2.07	0.87
North	1.83	3.99	1.29	0.99
North-east	2.30	7.19	1.29	1.30
Average	**2.90**	**4.65**	**1.55**	**1.05**
Control	1.53	2.19	2.34	1.05

The THQs of heavy metals in cassava samples for the inhabitants around the vicinity of the diamond cement factory are listed in Table 3. Among the four trace elements, the average THQ for Cr was the highest and higher by 1.16-4.43 times than that of the other elements investigated in the subject area. The extent of health risk was of the order Cr>As>Ni>Pb. All that notwithstanding, the average THQ of all the metals were higher than unity, which shows that the inhabitants around the cement producing facility are experiencing relatively high health risk.

The present results indicate that Cr was the major component contributing to the potential health risk with Pb being the least. However, the contribution of As and Pb to human health risk at any accumulated level cannot be underrated because of their high toxic potential and chronic health implication to the human system. From the current data, it is clear that As and Pb pose a potential risk to the local inhabitants through consumption of contaminated cassava.

CONCLUSION

In this study, by comparison of the environmental situations in the vicinity of the cement factory and a reference area coupled with guidelines from WH/FAO, we attempt to emphasize the quality of samples of fresh cassava tubers together with their corresponding soils from the trace metal contamination point of view. Health risk indexes were used to assess human health risk through the consumption of cassava crops by local inhabitants in the study area. The levels of trace metals in both cassava and soil samples from the impacted area are higher than those from the control samples indicating that the cement factory might be responsible for making that difference.

The study indicated that the soil is over bloated with trace heavy metals (As, Cr, Ni and Pb) which further encourage the contamination of the cassava tubers through plant metal uptake mechanisms. Of serious concern among the elements was high EDI level for Pb which exceeded the WHO/FAO acceptable limits for food crops. Similarly, As and Pb which are the most toxic element for humans exceeded the WHO/FAO threshold limits in respect of the THQ. This indicated a situation where As and Pb poisoning from cassava harvested and consumed from the vicinity of DIACEM could mean a serious health risk.

Common products from edible portion of the cassava tubers especially garri and akpele meals are widely consumed by the local population and constitute one of the major ingredients in the local staple. It is well established that high exposure to As and Cr could result in an array of diseases to both human and animals. The high health risk of the trace metals in general selected for the study may affect the vulnerable population especially in children and all adults through cassava consumption from the area.

One important deduction realized from the study was that the health risk from cassava consumption could be pervasive and cannot be limited to the area alone. This was derived from the fact that, more people especially those living in urban areas depend on agricultural products from the rural communities in Ghana for their living, hence an extension of the health risk of metal contamination to the outside public. Another important aspect of the study to note is that it is only cassava as a food crop which was assessed for health risk under the current investigation. As humans takes daily varieties of food, the health risk around the investigated area could be problematic as a result of other food intakes. For example, maize and mango are important crops grown in the area which could also encounter similar food contamination from these metals. Therefore, the present study sufficiently justify a position to recommend further studies to bring the potential health risk from foodstuffs consumed in the area to a full disclosure. Furthermore, the Food and Drugs Board (FDB) must take the responsibility of educating inhabitants of the area to reduce the level of cassava and processed products intake.

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