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*Review*

## **Poisonings with heavy metals and neoplasms - possible correlations**

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**As a side effect of industrialization, some diseases have developed only recently, becoming a challenge for the medical specialists both in research and medical treatment fields. Among these, the poisoning with heavy metals occupies a certain category that must retain attention, due to since the effects of this kind of poisoning are very serious effects if these injuries poisonings are not properly recognized and treated. Most common heavy metals that are involved in poisonings are Mercury, Cadmium, Lead and Arsenic. They are capable of inducing a wide range of pathologies, including neoplasms with cerebral localization. In order to illustrate the link between the poisonings with heavy metals and neoplasms, we present a case of a 19 years old patient, who was diagnosed both with germinoma, which is a malignant tumor of the median brain structures, and mercury poisoning. Since germinoma and mercury poisoning are rare conditions, it is very hard to obtain enough data for a statistically significant study. However, the case study which encompasses the poisoning with heavy metals and germinoma supports the idea of performing proper screenings in the event of individuals being diagnosed with mercury poisoning, especially when they can turn out to be potentially treatable.**

**Key words:** Poisoning, mercury poisoning, germinoma, cerebral tumor, cerebral neoplasm.

### **INTRODUCTION**

Along with the widespread of industrialization and urbanization, the contamination with heavy metals has become a major environmental issue, which affects the metabolism of organisms in ecosystems, because of its toxic character, as well as its high prevalence and persistence (Järup, 2003; He et al., 2013). Generally, the metals whose density is  $> 5 \text{ g / cm}^3$  are considered heavy

metals. Among them, Pb, Cd, Hg, Cr and As usually exist in the environment but are considered to be the primary toxic heavy metals for human health (Yuan et al., 2016).

Environmental contamination and exposure to heavy metals is a serious issue all over the world. Its impact dramatically increased in the last 50 years as a result of the exponential increase in the use of heavy metals in

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industrial processes and products. Some metals are found naturally in our bodies and are essential to human health, being necessary for a normal metabolism (eg. Cu, Zn, Mn, Co) however, they become toxic in high concentrations. Other elements, such as Hg, Cd, As, Ni and Pb are extremely toxic and can have devastating effects even in very low concentrations. They have the tendency to accumulate both in the food chain and in the human body, namely in the soft tissues (kidneys, liver, brain) as well as in the hard tissues (bones), being actually systemic toxins with specific neurotoxic, nephrotoxic and teratogenic effects (Alloway, 1995; Huang et al., 2008; Kabata-Pendias and Mukherjee, 2007). Moreover, heavy metals can alter a long line of metabolic processes, including the endocrine system. In the last decade, studies on heavy metals that potentially interact with the endocrine system have increased significantly, emphasizing that they are disruptive for the endocrine system (Rodríguez et al., 2007). Among their various mechanisms of action, these metals are capable of exerting an estrogenic activity upon humans and animals. Choe and Coll. (2003) have found a high estrogenicity in Cd, followed by Co, Pb, Cr and Cu; these metals being considered as a new class of environmental non-steroidal estrogen. Martin and Coll. discovered reported that Co, Cu, Ni, Pb, Hg or Cr, reduced the concentration of receptor estrogen protein and an induced expression of the estrogen genes, which regulate the progesterone receptor, was noticed (Martin et al., 2003).

Some studies have shown that exposure to heavy metals is damaging to the nervous, hematological and cardiovascular systems, increases the risk of various types of cancer, such as kidney, lungs, liver, skin and gastric cancers (Järup, 2003; He et al., 2013; Welling et al., 2015). Some metals, such as Cr, Pb, As, Cd and Hg, have been classified as specific or probable cancer agents by the International Agency of Cancer Research (Järup, 2003; Welling et al., 2015). In the same vein, many researchers declared that the exposure to heavy metals has increased the incidence and mortality in the case of gastric cancer. The Cr concentration of soil is correlated with mortality of women who have upper gastro-intestinal cancer (GI). Long term exposure to low levels of As and Cr in the plant soil may be a potential risk factor in the appearance of cancer (Núñez et al., 2016). Between 2005 and 2010, the levels of As in the soil were significantly correlated with the rate of mortality by gastric, colon, kidney nose-pharynx and lungs cancer. Similarly, long term exposure to Cd and Pb has increased the mortality risk of many types of cancer, including pulmonary, esophagus and gastric cancers (Yuan et al., 2016).

Among all heavy metals, Cd, Hg, Pb and As are some of the most toxic elements because of their persistence in The environment. They produce oxidative, nitrosative

stress and the deterioration macromolecules in the cells, which, in turn, lead to the death of cells by apoptosis or necrosis. Although the toxicity of heavy metals upon the organisms has serious ecological consequences, the metals rarely appear in isolation, more in mixtures. As such, metallic mixtures substantially complicate the process of risk assessment for these elements and very few researchers studied the impact of heavy metal mixtures upon the environment. Little information is available on the potential side effects upon health, related to the administration of contaminants containing a mixture of the most frequently met heavy metals. Therefore, it is a must to study heavy metals not only individually, but also in mixtures. Metallic metabolism has significant effects upon the toxicity of metals. The protection processes at molecular and cellular levels cannot have an impact upon cellular homeostasis even after the exposure to the metal. One example that has been studied and it is known to alter sensitivity to metals is glutathione (GSH). GSH can interfere with toxic metals by modifying the absorption rate and elimination of metals and can protect against oxidative stress resulted from the redox reactions catalyzed by the metal (Egiebor et al., 2013).

Heavy metals, such as methylmercury (MeHg), are environmental pollutants that easily affect humans by bio-accumulation through the food chain. Several reports uphold the idea that the Central Nervous System represents a major target of mercury and the endocrine organs can accumulate large concentrations of it. Studies carried out on humans have proved that individuals exposed to various forms of mercury show a significant concentration of mercury in their hypophysis gland (Pinheiro et al., 2007; Crespo-Lopez et al., 2007; Oliveira et al., 2006; Falnoga et al., 2000).

The pituitary gland is a critical neural-endocrine organ, with posterior attachment to the hypothalamus. The front lobe (or adenohypophysis) of the hypophysis is anatomically different from the hypothalamus and contains a collection of endocrine cells. The secretory cells of the adenohypophysis include somatotrophs (almost 50%), which produce somatotropin (a growth hormone, GH); Corticotropic hormones (15 to 20%), which release the adrenocorticotrophic hormone; Gonadotrophs (10 to 15%), which synthesize the luteinizing hormone and the hormone of follicular stimulation; Thyrotrophs (3 to 5%), which release the hormone of thyroid stimulation; and, finally lactotrophs (10 to 25%), which release prolactin (PRL). The issues in hypophysis physiology result in the hypo- or hyper secretion of these hormones. Although the pituitary gland has already been pointed out as a potential target of mercury accumulation, the impact of this metal upon the regulation of hormone release is unclear. Previous studies have shown (both positive and negative) associations between serum exposure to PRL and exposure to

mercury. This dual effect can be explained by different interactions between the types of mercury (inorganic and organic) and the secretion of PRL by the pituitary gland, which is controlled by neural-transmitters, such as dopamine. Thus, it has been suggested that serum PRL can be a possible biomarker of exposure to heavy metals (Maues et al., 2015).

Germinomas are a distinctive category of heterogenic tumors that are prone to be developed in the structures of cerebral medial line, most frequent localization being in the pineal gland or the neuro-hypophyseal region (Shankar et al., 2016). It is a very rare type of neoplasm, which account for less than 1% of the total intracranial cancers. However, it is more frequent in children, representing between 3 and 8% of the pediatric and adolescent neoplasms. The highest incidence of diagnosis is in the age interval between 10 and 21 years. The incidence is higher in Asia than in Western Europe and United States of America. It appears more often in males than in females. The 5-year survival rate is between 70 and 90% of the patients (Pluschke, 2013). From a histologic perspective, germinomas are tumors similar to dysgerminomas and seminomas, which are germinal tumors; the provenience of these tumors being in germinal cells that do not migrate properly during the intrauterine life. Certain causes that lead to the development of germinomas and/or the transformation of the cells of the germinoma from a premalignant to a malignant stage have not yet been identified. But the causes suspected to be involved in this process, include the poisoning with heavy metals (Vasiljevic et al., 2015).

First signs that raise the suspicion of a germinoma and lead the patient to present to a medical unity are nonspecific and usual for almost any type of intracranial growth. Headaches, dizziness and vomiting without any other cause are among those symptoms. Other sign of a germinoma may be the development of hydrocephaly. The possibility of a germinoma diagnostic is indicated by the imagistic investigations, which reveal a tumoral mass in a specific localization. Other related diseases are hypopituitarism, visual field deficits (especially when looking upwards) and diabetes insipidus. Some of these morbidities may persist regardless of administered treatment (Shankar et al., 2016; Vasiljevic et al., 2015).

The diagnosis is based on imagistic, morphologic and biochemical criteria. From the imagistic perspective, the most useful investigation is the MRI, which provides useful information regarding the localization of the tumor, the dimensions, shape and any other vicinity structures that might be affected (Reddy et al., 2015). The diagnostic dilemma in the case of a germinoma is whether to perform a biopsy or not. The certain diagnostic is evidently based on a biopsy with the histopathological examination of the biopsy sample. The evolution of germinomas is usually favorable with a treatment consisting of an association between chemotherapy and

radiotherapy, with a full recovery expectance in the majority of cases. On the other hand, due to the deep localization of this type of tumor in the brain, a biopsy can trigger a series of complications which make some experts and medical practitioners to consider it highly risky (Awa et al., 2014). Adding the fact that the patients are typically children and teenagers at whom is expected a full recovery after a proper treatment, the risk of impairment due to cerebral biopsy exceeds the benefits of having a histopathological confirmed diagnosis of germinomas, especially in the suspected cases that fit the profile of a young male. In this case, often the therapeutic decision is to start the treatment without a morphologic confirmation of the diagnosis (Awa et al., 2014).

Germinomas localized in the pineal region produce elevated level of beta-human chorionic gonadotropic (HCG), alfa fetal protein (AFP) and carcinoembryonic antigen (CAE). The determination of high levels of these substances in the blood stream and cerebrospinal fluid is an argument in the diagnosis process and can serve as a further argument for not performing a cerebral biopsy (Ogino et al., 2005)

Treatment of germinomas consists of an association between chemotherapy, radiotherapy and/or surgery. Surgery is useful when possible, despite the fact that it does not remove entirely the tumor, but it helps in reducing its dimensions, and by this, the risk of local mechanic complication, such as hydrocephaly, is diminished. However there are certain complications, particularly in the cases in which the tumor is located very deep. By operating deep on the brain, certain damage can be produced, that sometimes, exceeds the benefits of the surgery. On the other hand, there is a continuous concern for developing new and less invasive neurosurgical techniques for tumors located in less accessible parts. Hydrocephaly itself can beneficiate from surgical approach, such as the ventricular drain placement. Chemotherapy is very useful in the treatment of germinomas because the cells are sensible to it. Radiotherapy in association with chemotherapy is indicated whenever there are no contraindications regarding this kind of therapy (Packer et al., 2000).

## CASE REPORT

To illustrate the hypothesis that heavy metal poisoning, in particular, mercury poisoning, might be involved in the development and aggravated evolution of a germinoma, we present the case of a 19-years old Romanian patient, from a rural region. This patient did not have significant previous pathologies, neither did the medical history of her family revealed anything of importance for the current developed pathology.

This patient was admitted in a neurosurgery hospital

from an academic city with symptoms including headaches and impaired vision. An MRI was performed and the results showed an irregular growth in the pineal region and imagistic signs of hydrocephaly. After this, she left voluntarily the hospital, only to return a few days later, presenting the same symptoms. The preferred therapeutic treatment was towards a neurosurgical procedure of placement of a ventricular drain in order to cure the symptoms of hydrocephaly, although it was secondary to a tumoral mass of unknown etiology in the pineal region.

Two weeks after the surgery, the patient returned with violent headaches. A new MRI was performed and revealed that both the tumor from the pineal region and the hydrocephaly have increased in size. A new neurosurgical procedure consisting of the replacement of the ventricular drain was performed, with improved symptomatology in the postsurgical interval. Beta-HCG and AFP biomarkers were also determined and the values were within normal ranges. Based on neuro-imagistic criteria, the patient was diagnosed with germinoma. Another important determination performed during this admittance was the determination of urinal mercury in urine, which had a value of 165 µg%, well above normal values of between 0.2 to 13 µg%.

Further investigations could not be performed, because of the rapid progression of the disease. On the last hospitalization, the patient had signs of cranial nerve damage, along with multiple cerebral periventricular masses which were interpreted as secondary determinations with the origin in the primary tumoral site from the pineal region. The evolution was unfavorable, resulting in the death of the patient.

## CONCLUSION

Based on the current stage of knowledge about the intoxications with heavy metals, which were demonstrated to be capable of inducing neoplasms, and germinomas, which have not had the mechanism of occurrence determined beyond doubt, we find the presentation of the case study above useful in providing further information for both domains of interest, namely research and medical treatment.

Due to the possible link between poisoning with heavy metals and the development of germinoma, we believe it is useful to conduct screening both on patients with poisoning with heavy metals and patients with germinoma, as well as on other patients with different types of cerebral malignant tumors. We think this is particularly useful, as both poisonings and some of the cerebral tumors, if early diagnosed, can benefit from proper, adequate treatment in order to prevent mortality, morbidity, and sometimes even achieve a complete recovery.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ABBREVIATIONS

**AFP**, alfa fetal protein; **As**, arsenic; **CAE**, carcinoembryonic antigen; **Cd**, cadmium; **Co**, cobalt; **Cu**, copper; **GH**, growth hormone; **GSH**, glutathione; **HCG**, human chorionic gonadotropic; **Hg**, mercury; **MeHg**, methyl mercury; **Mn**, manganese; **MRI**, magnetic resonance imaging; **Ni**, nickel **Pb**, plumb lead; **PRL**, prolactin; **Zn**, zinc.

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*Full Length Research Paper*

# **Post-epidemic lead exposure to animals following a decontamination exercise in gold mining village of Bagega, Zamfara State, Nigeria**

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**This study focused on the evaluation of environmental lead contamination due to artisanal gold mining at a Nigerian village of Bagega one year after a clean-up exercise was carried out. Water samples were collected from earthen dams, faucets and wells, while plant and soil samples from grazing fields, residential areas and sites within the vicinity of the gold mine. The collected samples were digested and analyzed for lead concentration using the atomic absorption spectrophotometer. The recommended safe level of lead in water is 0.01 ppm and all the sources of water analyzed showed elevated lead concentrations. Water from the earthen dam, tap and well had lead concentrations of  $31.49 \pm 7.1$ ,  $5.98 \pm 1.5$  and  $7.14 \pm 1.2$  ppm, respectively. In the grazing area, the lead concentration was  $4.6 \pm 7.5$  mg/kg, whereas in the residential area and mining vicinity, the concentrations were  $46.84 \pm 10$  and  $1153 \pm 165$  mg/kg, respectively. Two plants, *Alysicarpus vaginalis* and *Digitaria debilis* had a uniquely high bioaccumulation ratio, suggesting their potential as hyperaccumulators of lead. Given that international standards accept lead levels of 420 ppm and below, the residential area and the grazing fields may be safe, but the vicinity of the mine which had a toxic concentration could be unsafe. For animal feed, all plant ingredients analyzed accumulated low levels of lead except for *A. vaginalis*. This study suggests that soil remediation may be an effective decontaminating procedure. Additionally, grazing plants in the study area are not important sources of lead exposure to animals. However, water bodies may constitute a probable route of lead exposure to both animals and humans. Therefore, there is a need to prevent water contamination by immobilizing lead from the mining site which could be potentially leached into water bodies.**

**Key words:** Animals, Bagega, mining, environment, decontamination.

## **INTRODUCTION**

A major challenge of metalliferous mining is the mobilization of environmental contaminants, such as

mining leftovers, by agents of dispersion and weathering processes (Hinton et al., 2003). It has been estimated that humanity has mined about 1,150 million tons of heavy metals, of which only 2% corresponds to valuable metals. Consequently, the rest is discharged as wastes in the neighbourhood of mine operations (Krishna et al., 2009). Because the efficiency of mining and the extraction process is always below 100%, there is the inherent risk of pollution even when best mining practices are observed. The possibility of pollution is high in unregulated artisanal mining and this could result in widespread poisoning (Bartrem et al., 2014).

Recently, lead poisoning epidemics have been documented in the Nigerian state of Zamfara due to artisanal gold mining from lead-rich ore (Lo et al., 2012). In the Zamfara State village of Bagega, the concentration of lead in the soil reached 23,000 ppm which resulted in the death of many children (Ajumobi et al., 2014) and animals (Tijjani et al., 2016). Albeit decontamination procedures have been instituted in affected areas, mining activities are still on-going. The possibility of recontamination of the environment or, at least, increased background exposure compared to the non-mining areas could exist (Bartrem et al., 2014). This could result in chronic toxicosis due to the gradual accumulation of toxicants over time or subclinical toxicosis in animals that may seem healthy but have derangements that may not be observed by routine physical and clinical examinations (Goyer, 1990; Bischoff et al., 2014).

In July 2013, *ex situ* decontamination procedures were carried out on the soil in the residential areas of Bagega using a technique that isolated and buried contaminated soil. This reduced the incidence of acute lead poisoning among humans but there have been cases among food animals (Kazaure, 2018). However, we presumed that this measure had not reduced the overall risk of lead exposure to animals which, when humans consumed as food, could portend health risks. Therefore, this study aimed at assessing the level of lead in water, soil and plants fed on by bucks in gold mining area of Bagega after the decontamination exercise.

## MATERIALS AND METHODS

### Study area

Bagega is a typical gold mining village in Anka Local Government Area of Zamfara State. Geographically, Bagega is located at 11° 47' N and 6° 15' E (Figure 1). Growing crops and raising livestock are the primary occupations of the local inhabitants. In recent years, however, mining has become a popular means of livelihood due to its lucrativeness.

### Study design

A cross-sectional study was carried out to determine the concentration of heavy metals in soil, water and browse plants. A survey of the environment was carried out to establish the area of mining, grazing areas, water sources and plants consumed by animals.

### Sample collection

In May 2014, samples of soil, water and commonly browsed plants were collected. Five soil samples each were collected from the residential area, mining site, gold ore and leftover tailings (Figure 1). The samples were collected in labelled polyethylene bags. Five water samples each were collected in sample bottles from an earthen dam located at the outskirts of the village, the public wells and the faucets in the community. Five samples of each of the species of plants commonly consumed by animals in the grazing fields at the outskirts of the community and adjacent topsoil samples were collected for analysis. The leaves of the plants were collected and identified by a plant taxonomist at the Department of Biological Sciences, Usmanu Danfodiyo University, Sokoto. The plant samples were then washed with deionized water to remove traces of soil and surface dust and were dried at room temperatures over a period of two weeks. The samples were then pulverized and sieved using 2 mm stainless steel sift.

### Sample analysis

Acid digests of soil and plant samples were prepared using the USEPA 3051A method as recommended by Chen and Ma (1998). Water samples were digested with concentrated nitric acid by adding 10 ml of the acid to 50 ml of water in a 250 ml conical flask. The mixture was then evaporated to half of its volume on a hot plate, which was allowed to cool and then filtered.

A Graphite Furnace Atomic Absorption Spectrometer (GFAAS) was used to measure the total concentration of lead in the digested samples. Biological accumulation coefficient (BAC) for each plant was calculated as a ratio of heavy metal in shoots/leaves to that in its adjacent soil (Cui et al., 2004).

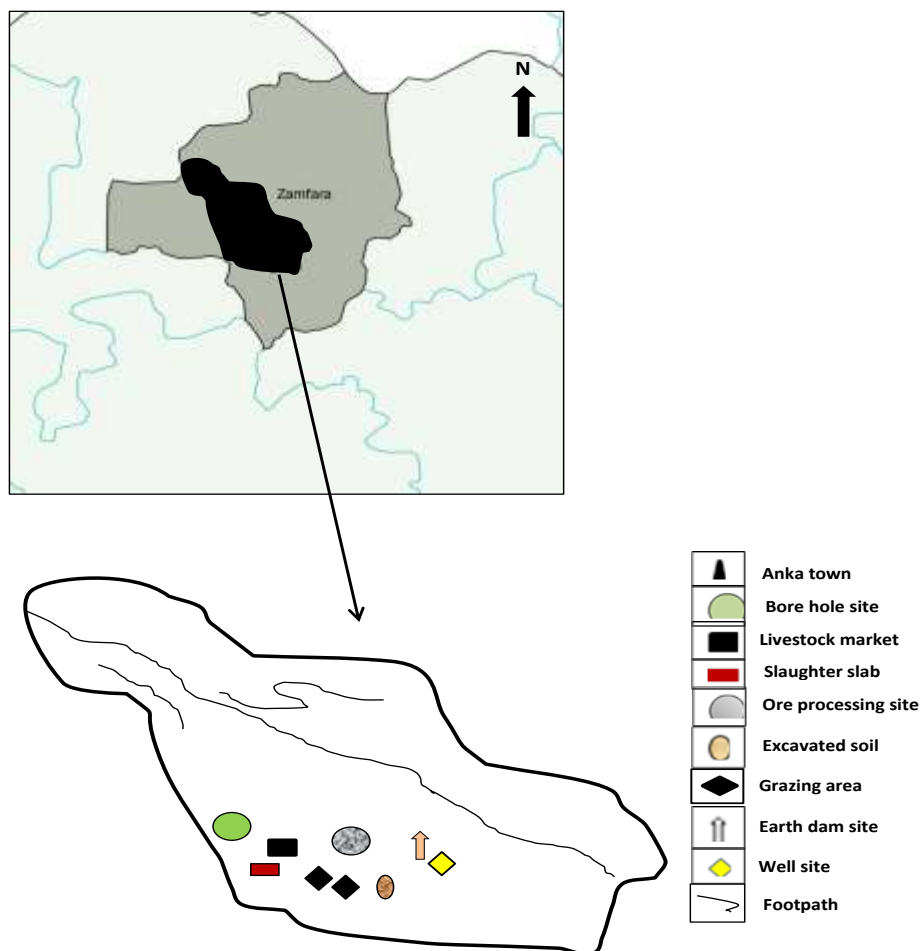
$$\text{BAC} = \frac{\text{Metal in shoot}}{\text{Metal in soil}} \quad (1)$$

### Data analyses

Data generated were presented as the mean  $\pm$  standard deviation of replicate samples, and comparisons were made with internationally acceptable standards. Analysis of variance was used to determine the level of significance within and between groups for each sample groups. The relationship between data generated from the plant and adjacent soil samples was determined by correlation analysis. GraphPad InStat statistical software with the Tukey Kramer post hoc test was used for statistical analysis and values of  $p < 0.005$  were considered significant.

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**Figure 1.** Map of Zamfara State showing the location of the study area (black) and the black arrow pointing to north. The enlargement of the study site indicates the sampling sites (Quantum GIS 2.4.0 Chugiak).

and residential soil was  $4.60 \pm 7.5$  and  $46.84 \pm 10$  ppm, respectively. The concentration for soil from the mining vicinity was  $1153 \pm 165$  ppm, while for tailings from direct mining leftovers and gold ore the concentration was  $1266 \pm 152$  and  $860 \pm 423$  ppm, respectively. The concentration of lead in residential soil and the grazing field was significantly ( $p < 0.005$ ) lower than the samples obtained from the mining zone and was below the World Health Organization (WHO) permissible levels. The concentration of lead in the mining area, leftovers and gold ore were higher than the recommended safe level (420 ppm) recommended by the WHO.

#### The concentration of lead in water

Water from the earthen dam, faucets and wells had lead content of  $31.49 \pm 7.1$ ,  $5.98 \pm 1.5$  and  $7.14 \pm 1.2$  ppm,

respectively. These were higher than WHO safe level of 0.01 ppm. The concentration of lead in the earthen dam was significantly ( $p < 0.005$ ) higher than that from the faucet and well water and no significant difference ( $p > 0.005$ ) between tap and well water (Table 2).

#### The concentration of lead in leaves of browse plants and adjacent soil in grazing fields

The level of lead concentration in *Alysicarpus vaginalis* was 68.5 mg/kg which was significantly ( $p < 0.05$ ) higher than in other plants sampled. Additionally, *A. vaginalis* is the only plant with a concentration of above 30 mg/kg. A concentration level of 30 mg/kg is the acceptable level of lead in livestock feed according to European Union Directives 2005/87/EC. *Digitaria debilis* and *A. vaginalis* had bioaccumulation coefficients of 4.9 and 2.9,

**Table 1.** Soil lead concentration at different locations one year after cleaning up exercise.

| Location          | Heavy metal concentrations (ppm) | WHO permissible level in soil (ppm) |
|-------------------|----------------------------------|-------------------------------------|
| Residential soil  | 46.84±10 <sup>a</sup>            | 420                                 |
| Grazing field     | 4.60±7.5 <sup>b</sup>            |                                     |
| Mining site       | 1153±165 <sup>c</sup>            |                                     |
| Tailing leftovers | 1266±152 <sup>c</sup>            |                                     |
| Ore               | 860±423 <sup>c</sup>             |                                     |

Values with different superscript are statistically ( $p < 0.005$ ) different.

**Table 2.** Concentration of lead in water sources after the clean-up exercise in Bagega mining community.

| Water source | Heavy metal concentrations (ppm) | WHO safe level (ppm) |
|--------------|----------------------------------|----------------------|
| Earthen dam  | 31.49±7.1 <sup>a</sup>           | 0.01                 |
| Faucet (Tap) | 5.98±1.5 <sup>b</sup>            |                      |
| Well         | 7.14±1.2 <sup>b</sup>            |                      |

Values with different superscript are statistically ( $p < 0.005$ ) different.

**Table 3.** Concentration of lead in leaves of browse plants and adjacent soils in Bagega village.

| Botanical                    | Plant name |                        | Lead concentration (mg/kg) |      | BAC |
|------------------------------|------------|------------------------|----------------------------|------|-----|
|                              | Hausa      | Leaves                 | Adjacent soil              |      |     |
| <i>Ficus synchomorus</i>     | Baure      | 0.12±0.03              | 0.67±0.14                  | 0.17 |     |
| <i>Digitaria debilis</i>     | Harkeya    | 4.48±0.23              | 0.9 ±0.13                  | 4.92 |     |
| <i>Vitellaria paradoxa</i>   | Kade       | 0.13±0.03              | 0.62±0.18                  | 0.21 |     |
| <i>Combretum glutinosum</i>  | Taramniya  | 0.18±0.01              | 0.32±0.05                  | 0.56 |     |
| <i>Securinega virosa</i>     | Tsah       | 0.58±0.16              | 0.94±0.27                  | 0.62 |     |
| <i>Alysicarpus vaginalis</i> | Gadagi     | 68.5±30.1 <sup>a</sup> | 23.94±4.94 <sup>a</sup>    | 2.90 |     |
| <i>Albizia chevalieri</i>    | Katsari    | 6.18±0.61              | 6.73±0.06                  | 0.91 |     |
| <i>Ipomoea muricata</i>      | Yaryadi    | 2.83±0.52              | 5.71 ±0.23                 | 0.50 |     |

Value with superscript is significantly ( $p < 0.005$ ) different from other values in the same column.

respectively thereby having an excellent ability to absorb lead from soil (Table 3).

## DISCUSSION

The process of removing all the contaminated topsoil and isolating it in a controlled disposal site is called soil destruction and is carried out when other remediation methods cannot guarantee containment of toxicants (Blacksmith Institute, 2011). In Bagega, the contaminated soil was removed but not replaced with good, unaffected soil. However, remediation exercise was not carried out on water and plants. After one year of soil decontamination, lead concentration levels have

significantly declined from their initial value of 5000 ppm, as earlier reported (Blacksmith Institute 2012). This could be attributed to the adoption of new methods for safer mining activities than previously used, as well as increased education and awareness on lead poisoning.

The lead content of grazing fields and residential soil in Bagega was found to be low compared to the international standard of 420 ppm. As the distance from the mining vicinity decreased, higher levels were obtained which exceeded safety limits, as seen in the soil from the mining area, tailing and gold ore. The primary focus of the cleaning exercise was the residential area and could be the reason for the low concentration of lead found in Bagega residential soil. Since the concentration of lead was within international safety levels for all the

residential and grazing fields, this study found that soil remediation may have been successful.

In water samples, the highest concentration of lead was recorded in earthen dams, followed by faucets and wells. However, all sources of water had elevated lead content compared to acceptable international standards of 0.01 ppm (WHO, 2008). This may be worsened by the lack of potable water supply for human and animal consumption in rural villages. As such, animals often drink from surface waters which are polluted with environmental contaminants. Heavy metals accumulate in surface waters due to leaching (Sophocleous, 2002). Guidelines on acceptable lead levels in drinking water by WHO and National Agency for Food and Control (NAFDAC) in Nigeria are stringent because heavy metals are slowly excreted from human and animal bodies resulting in build-up of lead-levels (Lanphear, 1998; Standard Organization of Nigeria, 2007; WHO, 2008). The higher concentration of lead in the earthen dam when compared with other sources may be attributed to the fact that surface water is more easily subjected to environmental contamination than underground water. Because surface water remains the primary source of water in Bagega, animals are still at risk of being affected by lead poisoning.

Among plants species used for animal feed, *A. vaginalis* leaf was found to have remarkably elevated values. Plants with bioaccumulation coefficients above 1 indicate good ability for absorbing lead in their leaves (Kazaure, 2018). Therefore, *A. vaginalis* and *D. debilis* pose a hazard to grazing animals.

The ecological zone of Zamfara State falls within Northern Guinea Savannah that is characterized by abundant grasses and shrubs; hence, grazing animals thrive well because of abundant feed (Garba et al., 2015). Some plants accumulate heavy metals in their leaves from their surroundings. Among all the plants sampled, the present study discovered that leaves of *A. vaginalis* have the highest concentration of lead, with its concentration exceeding acceptable standards. A proportionately high concentration of lead in adjacent soil observed in *A. vaginalis* could be due to inherent biological differences that affect its uptake capacity. *D. debilis* had a four-fold higher concentration of lead in its leaves compared to its soil while *A. vaginalis* has 2.3 times higher. Since this study confirms that there is a positive correlation between soil and plant leaves, *D. debilis* could be more dangerous in accumulating lead in its leaves and *A. vaginalis* should be investigated for possible phytoremediation of the environment.

## Conclusion

Grazing plants as a source of exposure to lead in Bagega after the cleaning up exercise, have been remarkably

insignificant as all the plants accumulated safe levels of lead except for *A. vaginalis*. Water sources from the area have been shown to have high concentrations of lead when compared with internationally acceptable standards. Plants used in this research could also be used as indicators of environmental lead pollution because of the positive correlation with the soil concentration.

There is a need to assess the buffering capacity of soil in Bagega to further investigate the safety of the low lead concentrations observed after the clean-up exercise. Also, since many ores are polymetallic, further studies should be carried out to assess concentrations of other heavy metals in the environment. Water is the most important source of exposure and better design of mine waste storage is necessary to prevent weathering, leaching and mobilization of contaminants. Also, provision of potable water for both human and animals will greatly reduce the risk of exposure to lead poisoning.

Food animals in Bagega are managed semi-intensively and, as such, are at high risk of lead exposure by grazing on plants and drinking from surface water. For one health benefits, there is a need to assess the incremental health risk associated with lead exposure in animal populations in Bagega.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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