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Original Research Article

Gold mining activities' impact on Human and Environmental Health in Macalder Migori, Kenya: Possible Interventions

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Abstract

Potentially harmful elements (PHE) are usually bio accumulated and bio transferred both by natural and anthropogenic sources. The contamination of soils and water by PHE is a major issue faced throughout the world. Attention need to be focused on the PHE because they pose a great health risk to both plants and animals and humans through the food chain. Some of these PHE are essential for proper metabolism in all living organisms yet toxic at high concentrations; while other metals currently thought of as non-essential are toxic even at relatively low concentrations. Potentially harmful elements such as Mercury (Hg), Arsenic(As), lead(Pb), Cadmium (Cd), Chromium(Cr), Copper(Cu) and Zinc(Zn) were analyzed in drinking water, soils, scalp hair and nails of female adults in the low lying areas of Migori Gold Mining Belt, who were working in the small scale mines. The control study area involved female adults in the highland regions of Eldoret Municipality which is part of the water catchment area of Lake Victoria. The samples were processed, packed and shipped for analysis in ACME Laboratories, Vancouver, Canada. The results revealed that the exposure to contaminants from gold mining activities have significantly increased the concentrations of selected metals in the bodies of the target group. Mercury, As, Pb and Cd concentrations in nails showed elevated levels reported in occupationally exposed resident. Lead, Cd, Cr, Cu, and Zn concentrations were significantly higher in the hair samples collected from the polluted area as compared to control area. The research indicated that the women in the mines are exposed to high health risks associated with PHE exposure due to exposure in the gold mining activities. The study recommends strict adherence to safety measures and remediation practices that would reduce health risks and the degradation of the environment. Education and drastic interventions need be encouraged to protect the workers from multiple health risks associated with gold mining in Migori Gold Belt in Kenya.

Keywords: Exposures, Gold mines, Humanhair, Human nails, PHE

INTRODUCTION

Human activities such as industrial production, mining, agriculture and transportation, release high amounts of PHE into surface and ground water, soils and ultimately to the biosphere (Ruqia *et al*, 2015, Jianwei *et al*., 2016). Their toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. Because of their high degree of toxicity, even in traceable levels in living organisms, As, Cd, Cr, Pb, and Hg rank among the priority metals that are of public health significance. These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure(Arruti, *et al* ., 2010).. They are also classified as human carcinogens (known or probable) according to the U.S. Environmental Protection Agency, and the International Agency for Research on Cancer. The presence of of PHE in the water may have a profound effect on the microalgae which constitute the main food source for bivalve mollusks in all their growth stages, zooplankton rotifers, copepods, and brine shrimps) and for larval stages of some crustacean and fish species. Moreover, bioconcentration and magnification could lead to high toxicity of these metals in organisms, even when the exposure level is low (Ezeronye and Ubalu , 2005, Ogoyi et. al., 2011, Sehar et. al., 2014).

Soils represents a major sink for PHE, which can then enter the food chain via water, plants or leaching into drinking water. Potentailly harmful elements' toxicity can result in brain damage or the reduction of mental processes (Gaza *et al*., 2005) and central nervous function (Bouchard *et al*., 2011), lower energy levels (Holmstrup *et al*., 2011), damage to DNA (Jonovic *et al*., 2011), and alterations on the gene expression (Salgado-Bustamante *et al*., 2010), skin and liver (Burger *et al*., 2007), muscle (Visnjic-Jeftic *et al*., 2010), blood composition (Di Gioacchino *et al*., 2008), lungs (Thomas *et al*., 2009), kidneys (Johri *et al*., 2010), heart (Otles and Cagindi, 2010) and other vital organs for humans and other living organisms.

Long-term exposure to PHE may result in slowly progressing physical, muscular and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy , multiple sclerosis (Jones and Miller, 2008), gangrene, diabetes mellitus, hypertension and ischemic heart disease (Otles and Cagindi, 2010). Allergies are commons and repeated long-term contact with some HM or their compounds may even cause cancer (Dietert and Piepenbrink, 2006). For some PHE, toxic levels can be just above the background concentrations naturally found in nature. However, PHE have been excessively released into the environment due to rapid industrialization, manufacture of fertilizers and to the high production of industrial waste (Katsou et. al., 2011) originated from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refining, paint manufacture, pesticides, pigment manufacture, printing or photographic industries (Aguilera *et al*., 2010)

This has created a major global concern because they are non-biodegradable and can be accumulated in living tissues, causing various diseases and disorders within the food chain.

During gold mining operations other elements are often present and also dissolved include Cu, Pb, Zn, Fe,Co, Hg (Boyle and Smith, 1994, Hang *et al*., 2009), with geologically enriched environments containing high concentrations. Analyses of human biomarkers have been used to demonstrate occupational or environmental exposure to toxic elements (Were *et al*., 2008). Human hair and nails reflect metal mean level in human body during a period of 2–5 and 12-18 months (Were *et al*., 2008), respectively. Simultaneous use of hair and nails for biological monitoring in relation to exposure through gold mining and drinking water consumption has not been studied sufficiently well for drawing tangible correlations with the exposure levels. The study focused on the assessment of the contribution of gold mining activies and consumption of drinking water exposure to body metal burden in women working in gold mines in the Migori Gold Belt, Kenya, through determinng the concentration of the PHE in the hair and nails simultaneously.

Experimental Design

Study area setting

The study area contains rich deposits of metals from geological origin (figure 1 and 2). Compounding the problem of metal pollution in the regio, is the continous operation of small scale artisanal gold mining over the last few decades. Water for human consumption is obtained directly from drinking water and rivers draining through the basin.

The study area of Macalder is within the Migori Gold Belt (MGB) andcovers part of the Lake Victoria Basin. This regi n is the centre of many human activities, including agriculture, fishing and gold mining. Lake ictoria (68,800 km^2) is the second largest freshwater body in the world, with a mean depth of 40 m. It lies in a catchment area of about 84,000 km^2 and is shared by three riparian states (Kenya, Tanzania and Uganda).

The major landscape units of the study area reflect the different climatic zones present. These units include: the Stable Slopes, having an altitude range of between 1500 and 2000 m, and an annual rainfall of about 1200 mm; the Ridges, with an altitude that varies from 1300 to 1600m, and an annual rainfall of between 800 and 1300 mm, the 'Sediments' which consist of alluvial fans and pediments, with slopes varying from 2% to10%, altitude ranging from 1200 to1500 m, and with annual rainfall of between 700 and 1200 mm; the Flat area (slightly undulating, with maximum slopes of 5%), with an altitude ranging from 1200 to 1600 m; and, the Lacustrine Plain, with a lithology comprised of sandy and clayey alluvial deposits, altitude of about 1200 m, and annual rainfall of between 700 and 800 mm. Alluvial sediments occur below the confluence of the Gucha and Migori rivers (North and South Kadem Locations). The texture is largely silty, but lenses of sand and gravel occur. Black cotton soils, partly alluvial in origin, occur in flat-bottomed valleys and drier parts of the area. They are characteristic of poor drainage. The Migori granite–greenstone complex consists of Precambrian rocks of about 2.8 billion years old (Ogola *et al*., 2002). These rocks are intruded by doleritic dykes along the Migori River Valley. The complex contains gold mineralisation in quartz veins that transect mafic volcanics.

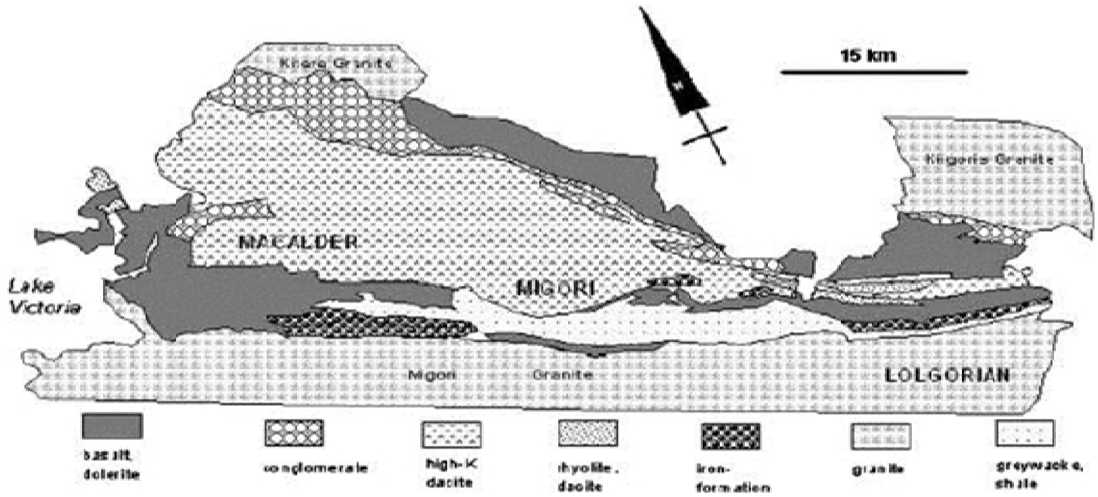

Figure 1. Geology of the study area (Source: Ogolla *et.al.*, , 2002)

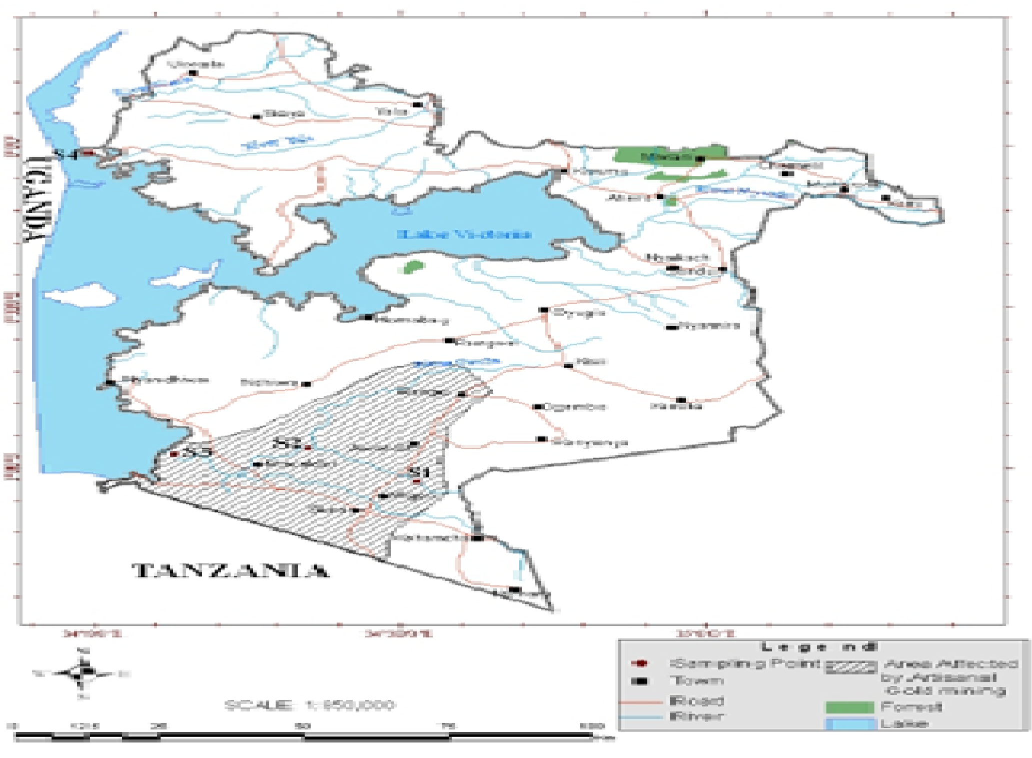

Figure 2. Sketch map of studied area showing sampling zones 1, 2, 3 in Migori, Macalder Gold Mines and 4 outside mining Region

Sampling design and procedures

Samples were collected between Jan 2014 and December 2014. All equipment used were pre-soaked with concentrated nitric acid (65%) and sulphuric acid (30%) solutions of 1:1 volume ratio. Har and nail samples were collected from 50 female working in the small scale gold mining area and 50 women from the reference site (Eldoret Municipality, 270Kms, and with no gold mining activities). Helsinki 1996 protocols were followed and permission obtained from the Institutional Research and Ethics Committee (IREC) of Moi University, Kenya.

Scalp hair and nails were collected from each individual in triplicate (IAEA, 1985). Hair and nail samples were first washed with distilled water on a stirrer for 15 min in a beaker, and then washed with acetone-water-water- water-acetone as recommended by the International Atomic Energy Agency (IAEA, 1985). The washed samples were placed in glass beakers and individually allowed to dry at 50°C overnight in a drying oven. Before washing the hair and nail samples, any visible dirt on the surface of the nails were thoroughly washed using MilliQ water.

Drinking water was collected from the same sites where the hair and nail sample donors obtained their water. In the field, the sampling bottles and caps were rinsed three times with the water to be sampled prior to sampling. Then, the samples were acidified to 1% with nitric acid and were stored in 500 mL double caped polyethylene bottles. The samples were subsequently stored at 4 °C for as short a time as possible before shipment to ACME Laboratories, Vancouver, Canada for PHE analysis to minimize changes of the physicochemical characteristics of the metals (Tuzen and Soylak, 2006). As this study is supposed to reflect the quality of the water 'as drunk', the samples were not filtered (Reiman *et al.*, 1996). All collected samples were processed and packed in Egerton and Kenyatta University Biochemistry laboratories and then shipped for analysis in ACME Laboratories, Vancouver , Canada.

Data Analysis

All analysis was performed, using SPSS for Windows Release 13.0 (SPSS Inc.). The W test (Gilbert, 1987) developed by Shapiro and Wilz was used to test thenormal/log–normal Distribution of the data for hair and nails of the studied population. Normality test of the data showed that few of data sets conformed to non parametric distribution. To meet the criterion of normality before statistical procedure, all non parametric data were log-transformed, using the equation: x'¼log (x+1) (Zar, 1996). All data among sampling sites were calculated as geometric means (GMs). Comparison of potentially harmful elements' concentration in drinking water, hair, nails and soil samples in different sampling sites was done, using One-way ANOVA. Whenever the null hypothesis was rejected, a multiple comparison test (Tukey HSD test) was used following ANOVA, to determine, which groups of individuals differed from each other. The relationships between the potentially harmful elements' concentration in the hair and nail samples for individual women were analyzed, using the linear regression model. The similarity/ dissimilarity of the potentially harmful elements' concentration in hair, nails and drinking water samples were graphically presented in a non-parametric multi-dimensional scaling ordination (NMDS), which represented matching similarities calculated in a triangular matrix of similarity coefficient computed between every pair of metal samples (Clark and Warwick, 1998). The reliability and validity of the MDS solution was determined by calculating the index of fit (R-square), which is the proportion of the variance of the optimally scaled data that can be accounted for by the MDS procedure (goodness of fit). All the levels of statistical significance were set at P >.05, unless otherwise stated.

RESULTS AND DISCUSSION

The results are presented as geometric means of the concentrations (M±) in bar graphs showing contrast in heights which correspond to the studied PHEconcentration. The results for water, soil, hair, and nails element analysis are shown in Figures 3, 4, 5, and 6.Water samples analyzed showed elevated concentrations of the studied PHE in all the samples collected in the sampled areas, which were above the WHO maximum acceptable limits (Figure 3). The control area had concentration generally below WHO maximum limits except the Cu concentration (0.27± 1.7dμg/L^{-1}). S2 showed a significant difference to the other sites in Hg concentration. Copper in water samples collected was elevated above WHO acceptable maximum limits in all the samples analyzed from both the exposed and control areas.

Soil samples analyzed showed elevated concentrations of the studied PHE in all the samples collected in the sampled areas, which were above the WHO maximum acceptable limits (Figure 4). The control area had concentration generally below the four study sites but the concentrations tended to be slightly above WHO maximum limits. S2 showed a significant difference to the other sites in Hg concentration. S2 had also significantly elevated Cd concentration compared to the other sites 1, 3 and 4 although all sites recorded Cd concentrations that were above WHO recommended levels for unpolluted soils. Copper in soils sampled was significantly elevated in all sites above the WHO allowable limits with S4 recording the highest mean concentrations similar to concentrations recorded in water. Further, Pb recorded elevated concentrations in all sites including the control site.

Concentrations of hair PHE were compared with set standards in three different countries, India, Japan and England. Hair samples analyzed showed elevated concentrations of the studied PHE in all the samples collected in the sampled areas, which were above the I/J/Eng maximum acceptable limits (Figure 5). The control area had concentration generally below the four study sites but the Pb and and Cd concentrations tended to be slightly above I/J/Eng maximum allowable limits. S2 and S3 showed a significant difference to the other sites in Hg concentration. S3 had also significantly elevated Cd concentration compared to the other sites 1, 2 and 4 although all sites recorded Cd concentrations that were above I/J/Eng recommended levels for unpolluted soils. Lead in hair samples analyzed was significantly elevated

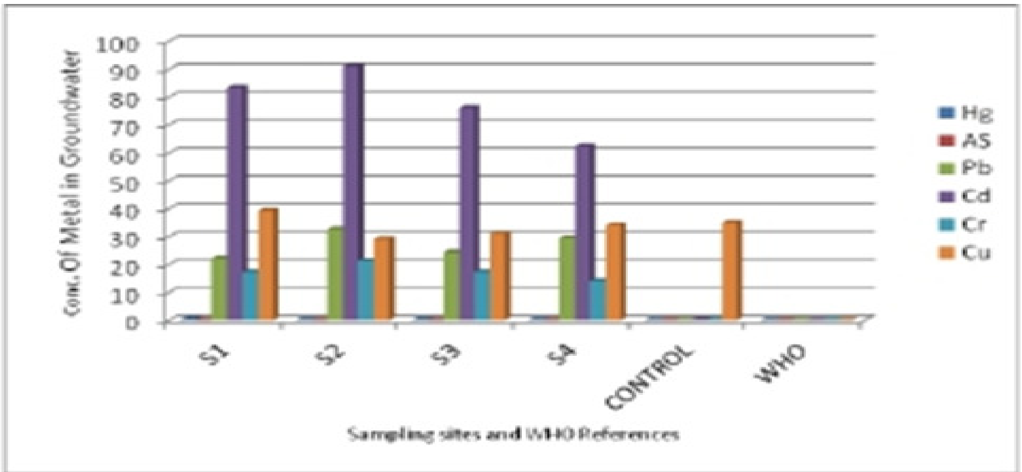

Figure 3. Concentration of PHE (μgL^{-1}) in drinking water drawn at the different sampling sites

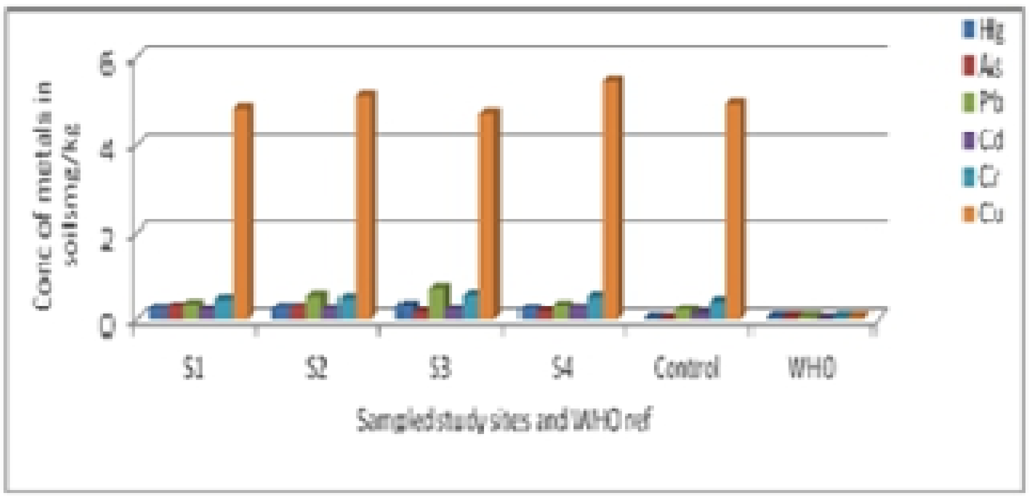

Figure 4. Concentration of PHE (mg/Kg) in soils at the different sampling sites.

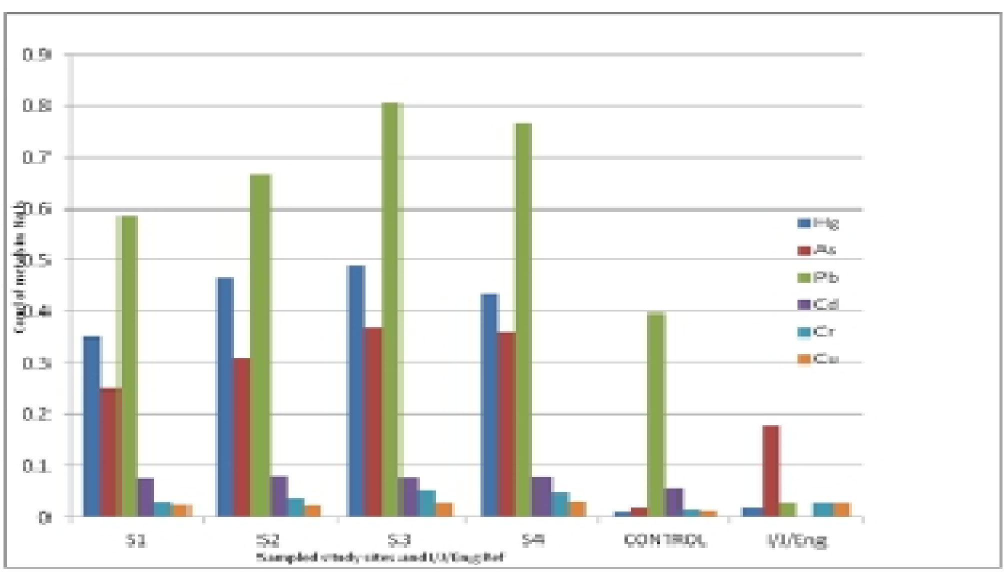

Figure 5. Concentration of heavy metals(mg/Kg) in scalp hair at the different sampling sites.

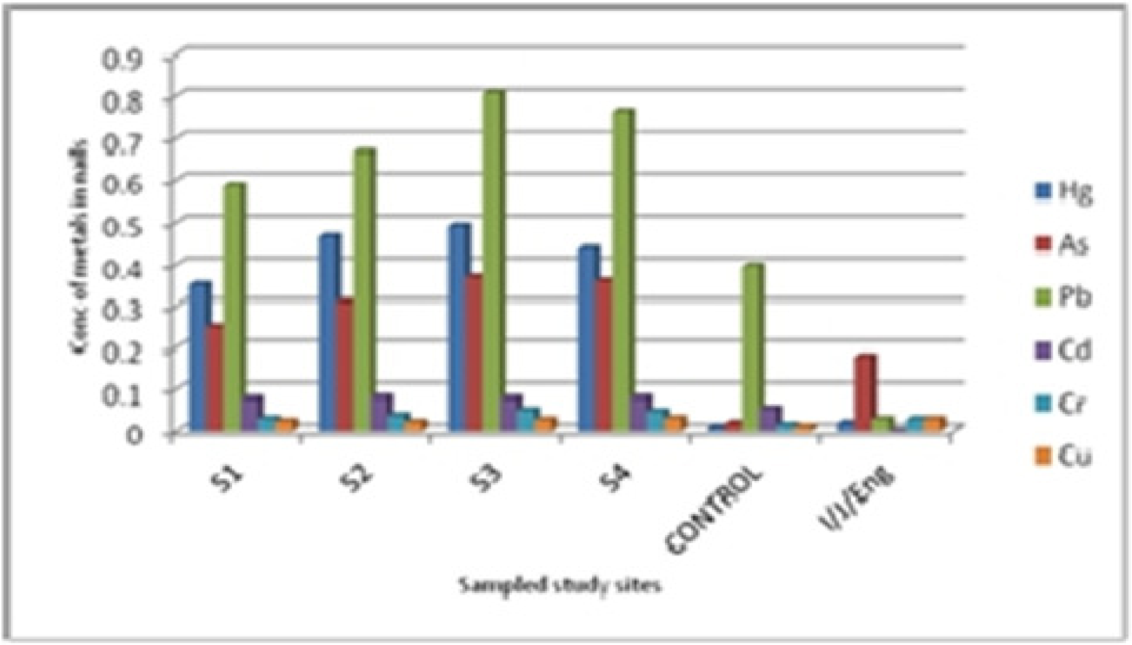

Figure 6. Concentration of heavy metals(mg/Kg) in nails at the different sampling sites.

in all sites above the I/J/Eng allowable limits with S4 recording the highest mean concentrations similar to concentrations recorded in water and soil samples. Further, Pb recorded elevated concentrations in all sites including the control site above the I/J/ENG recommended allowable levels for unpolluted hair samples.

Concentrations of nail PHE were compared with set standards in three different countries, India, Japan and England. Nail samples analyzed showed elevated concentrations of the studied PHEin all the samples collected in the sampled areas, which were above the I/J/Eng maximum acceptable limits (Figure 6). The control area had concentration generally below the four study sites but the Pb Cd concentrations tended to be slightly above I/J/Eng maximum allowable limits as observed in hair samples. S2 and S3 showed a significant difference to the other sites in Hg concentration. S3 had also significantly elevated Cd concentration compared to the other sites 1, 2 and 4 although all sites recorded Cd concentrations that were above I/J/Eng recommended levels for unpolluted soils. Further, Pb recorded elevated concentrations in all sites including the control site above the I/J/ENG recommended allowable levels for unpolluted nail samples.

Simple regression was used to determine PHE relationships in the samples,. There were positive relationships between all the PHE. In nails and hair, however, increased concentrations of Pb, Cd and Cu in nails were better estimated(>58%) by increased concentration of PHE in human hair, but not for Cr.

The regression trends in humanhair and nails results were interpreted as PHE competition for sorption in the active sites, since Pb and Cd have no known functions in the body, while Cu are required in low quantity. High significant levels of PHE recorded in the human hair and nails showing positive relationships between PHE in hair and nails could possibly be as a result of exogenous sources of PHE, which reflect environmental exposures. Many researchers cite the inability to separate endogenous and exogenous deposition of PHE, in the human hair and nails as a major problem in the use of hair and nails as biomonitors of environmental exposure, because proportions of substance from the environmental media are incorporated and strongly bound to the hair and nails structure (Kempson *et al*., 2006). It is also possible that washing of the hair and nail samples may remove all the exogenously deposited contaminants in hair and nails, and thus the observed PHE can be said to be originating from the physiological body systems and diet.

The study investigated the PHE health risks involved in working in Migori Gold Belt and consuming water in small scale gold mining area of Macalder Area. Human exposure to the PHEs studied is considered high, on the basis of the significantly high concentrations of these elements found in soils and drinking water. This is unsurprising, considering that the area receives increasing pollutants from geological terrains rich in gold deposits and associated elements. Measuring the concentrations of PHE in hair and nails as biomarker for short term and long- term exposures gavean insight into the levels of exposure for the women working in the small scale mines. The drinking water, soils nails and hair elemental concentrations in the gold mining area are generally above WHO recommended levels and mostly above levels in the control area. As such, it may be postulated that the gold mines in Migori Gold Belt have resulted in the dispersion of increased levels of the PHE studied against their background levels in the surrounding areas. Potentailly harmful elements from the gold mines activities are rain-washed into near-by surface and ground water systems causing increased metal concentrations in the soils and drinking water. WHO recommended guidelines and other countries maximum metal levels for Hg, As, Pb, Cd, Cr and Cu are well exceeded for the water and soils. Scalp hair Hg concentrations is near maximumm permissible level based on Italy/Japan/England maximum recommended limits especially in site 3.

The analyzed samples of nails showed metal concentration that were within the recommended limits of Italy/ Japan/England for All but Hg concentration in sites 2 and 3 are near maximum permissible levels. All studied metal concentrations in soils exceeded reported permissible levels. Increased levels of Hg, As, Pb, Cd, Cr and Cu in the environment has degraded the quality of the water and soils. Women working in the gold mines and consuming water from these localities are exposed to high, probably irreversible health risks. WHO recommended guidelines and other countries maximum meta levels for Hg, As, Pb, Cd, Cr and Cu are well exceeded for the water and soils but this is not duplicated in the hair and nails in the study area. Dependence on gold mining in this area has caused both human health and environmental problems. There are high health risks posed to the women who are very vulnerable to PHE poisoning through mining exposure and drinking water. The health risks are grrave since the toxicity may be passed on to unborn children through the placenta and suckling ones during lactation.

CONCLUSION

In this study, the PHE content were measured in the water soils hair and nails to determine the role of hair and nails as biomarker of short- and short-term exposure to PHE among women working in the gold mine in the coastal zone of Lake Victoria. There was evident of PHE contamination in the studied sites in the gold mining areas. Furthermore, there were close associations established between the specific metals in hair/nails and metal estimated from drinking water consumed. Metal consumption patterns from water suggested that the local residents though were not only exposed to short-term metal risks, but consumption of higher quantity of water could pose potential long term health risk from heavy metals to the women in this study area where they are involved in gold mining activities. The present study demonstrated that determination of metals in human hair and nails, and relating this with heavy metals estimate from water consumption has potential utility as a biomarker of exposure to PHE from the water consumption.

The most frequently cited factors which may jeopardize the usefulness of hair and nail analysis include difficulties in differentiating between endogenous and exogenous depositions, inconsistency of hair and nail concentration anomalies with nutritional status and the absence of well defined reference concentration ranges (Gulson, 1996). However, the simplicity with which hair and nails can be sampled, transported and handled, and generally higher element concentrations compared to other biological media, such as blood and urine (Rodushkin and Axelsson, 2000; Sukumar and Subramanian, 2007), together with finding from the present study, makes hair and nails to be suitable tool for monitoring localized exposure to metals from water consumption. Based on this finding, the study recommended measures that would reduce exposre to the workers in the mining as well remedial measures to conserve the environment. This study proposed the following:

i). Encouragement to use of protective gear at all times during gold mining and processing; retorts, simple fume chambers, etc; Active role of Government authorities on health and pollution control, e.g., protection of water sources; Trained personnel to oversee the health aspects both to the worker and the environment.

ii). Biological remediation and interventions: such as use of local plants known to have accumulation capacities to reduce the PHE in the soils and therefore in plants. The bio-accumulators would concentrate the PHE thus extracting them from the environment: must be part of the considerations before the issue of permits to carry out gold mining.

Growing plants can help contain or reduce heavy metal pollution. This has been successful in large mining areas and can be used in Migori area with possible outcomes.

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