Association between Soil and Blood Lead Levels of Small Scale Battery Repair Workers in Kumasi Metropolis of Ghana

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***Abstract*-In this study, the association between measurements of soil Pb (SL) levels and previously determined blood Pb (BL) exposure responses was investigated in battery repair workers from 25 different workshops in the Kumasi Metropolis of Ghana. A curvilinear relationship was established between the SL and BL data recorded. The mathematical model of pooled BL data sets for battery repair workers in the Kumasi Metropolis is: $BL = 252.1\ e^{0.0003608SL}$ [with 95% confidence bounds for the coefficients a = 252.1 (200.2, 304), b = 0.0003608 (0.0002607, 0.0004608), R^2 = 0.6622, adjusted R^2 = 0.6475]. The correlation coefficient between the modelled BL and observed BL was 0.833457 with $p < 0.001$. The results show that the higher the SL level at the workshop, the greater the exposure and, hence, the higher the BL level of the workers. The mean SL level, 1284.48 mg/Kg and BL level, 420.96 μg/L recorded for the workshops studied were 3.21 and 1.40 times higher than ACGIH and USEPA permissible level for SL and BL, respectively.**

Keywords- Battery Repair; Permissible Level; Blood Pb; Soil Pb

I. INTRODUCTION

Heavy metal pollution of surface soils due to intense industrialization has become a serious concern in many developing countries [1-2]. Surface soils are the first locus of input of metals, where they tend to accumulate on a relatively long-term basis. These pollutants normally contaminate the upper layer of the soil at depths from 0 - 40 cm [3]. When Pb is deposited in soil from anthropogenic sources, it does not biodegrade or decay, so it remains in the soil at elevated levels. Lead is estimated to have a half-time of residence in soil of 1,000 years [4]. In soils with a pH of greater than or equal to 5 and with at least 5 percent organic matter (which immobilizes the lead), Pb is retained in the upper 2 to 5 centimetres of undisturbed soil [5].

The Suame Magazine and Asafo "Fitam" industrial slums in the region of Kumasi (Ghana) belong to the largest agglomerations of small scale cluster engineering in sub-Saharan Africa. Located in the area are numerous Pb-acid battery repair workshops. The battery repair workshops are usually 3 x 4 sq metres and employ an average of 3-4 workers. The workshops are made of dusty bare floors with poor and insufficient natural and mechanical ventilation. The group selected for this study is made up of private sector storage battery workers (males, with ages between 18-50 years and at least one year employment at the workshop) who are unfamiliar with pollutants and their effects. The job tasks include repair and charging of batteries. In most workshops, workers break batteries and take their Pb plates out to repair them, leading to spillage of battery acid onto dusty floors. Recasting of Pb to replace terminals of damaged batteries is a commonly performed job task.

Lead-acid batteries consist of grids typically containing around 90% metallic Pb (soft metal), 10% antimony (Sb) and 0.5 arsenic (As). The arsenic is added in order to harden the Pb-containing alloy. Lead oxide powder is pressed into the grid and are put into a weak solution of sulphuric acid [6]. During battery repair operations, it is expected that particles containing predominantly Pb in the metallic form, such as PbO, PbO_2 or as $PbSO_4$, contaminate the workroom atmosphere and soil.

Reports by Kumar *et al.* [7], Minozzo *et al.* [8] and Abiola [9] indicate that workers at storage battery manufacture and repair workshops are particularly at risk because industrial hygiene is poor. Several studies have found associations between soil Pb and blood Pb levels, especially in children [10-11]. Lead is a multi-organ system toxicant with effects at very low levels of exposure on cardiovascular, nervous, urinary, gastrointestinal, reproductive and hemopoetic systems [12-14]. The American Conference of Governmental Industrial Hygienist (ACGIH) has listed biological exposure index for blood Pb as 300 μg/L [15]. Neurological symptoms have been reported in workers with blood Pb levels of 400 to 600 μg/L, and slowed nerve conduction in peripheral nerves in adults occurs at blood lead levels of 300 to 400 μg/L [16].

Soil is considered a likely route of Pb exposure. It is therefore of interest to calculate the contribution of soil Pb to blood Pb concentration of the battery repair workers. Well-established deleterious effects of Pb have generated critical concern for Pb exposure and inspired the pursuit of a better model to predict blood–Pb concentrations, especially in children [17-18]. Several predictive models for assessing human exposure to Pb have been developed [19].

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The purpose of this study was to ascertain the level of soil Pb concentrations from selected battery repair workshops at Suame Magazine and Asafo "Fitam" in Kumasi Metropolis and to predict the blood Pb levels of workers at the battery repair workshops.

II. MATERIALS AND METHODS

A. Study Location

The study sites are located in the city of Kumasi (Ghana). The subjects were recruited from the Suame Magazine and Asafo "Fitam" area, as showed in Fig. 1.

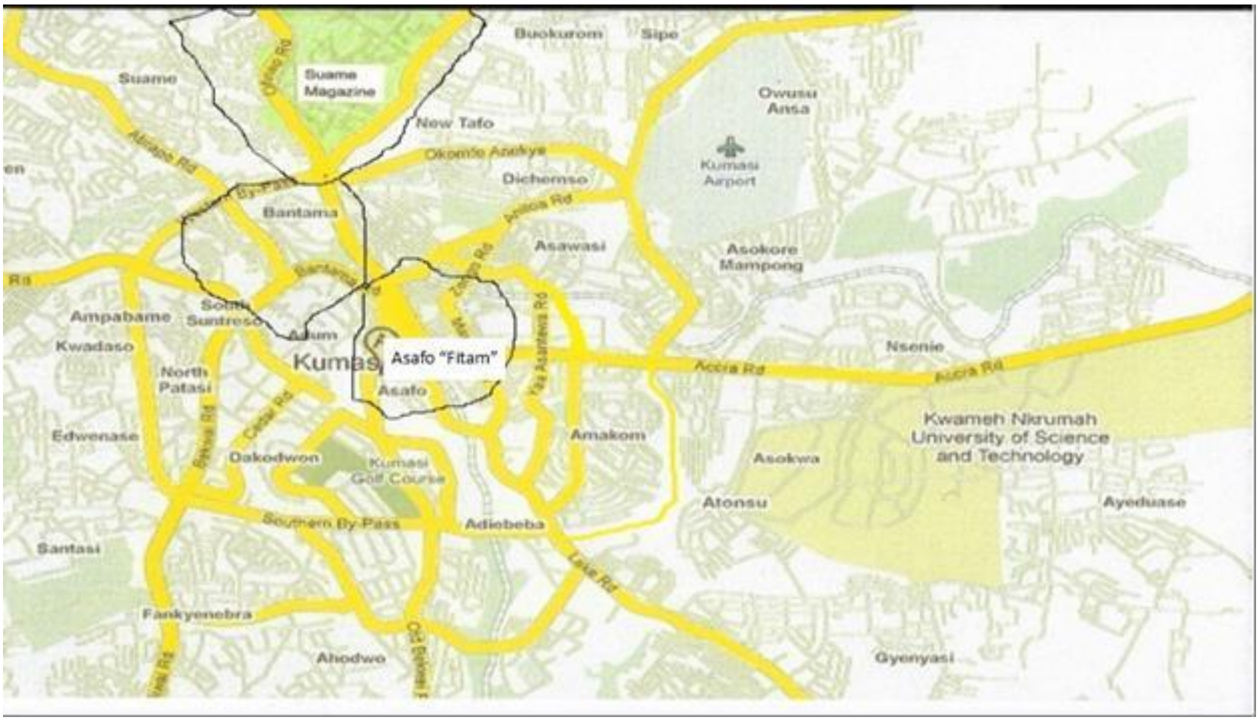

Fig. 1 Map of Kumasi showing the sampling sites

B. Sample collection procedure

Twenty five (25) car battery repair workshops in the Suame Magazine and Asafo "Fitam" area where workers' blood samples had previously been taken and analysed for Pb were selected for the study.

1) Collection of Soil Samples

Four (4) surface soil samples, two samples taken from the inside of the workshop and another two from the outside of the workshop where the subjects worked, were collected from each of the twenty five selected workshops at a depth of (0 – 2) cm. A soft touch brush was used to gather the top soil, while a plastic spoon was used for the collection into the plastic containers. Separate plastic spoons and brushes were used for the sample collection from each of the workshops into separate well-labelled plastic containers to avoid cross contamination.

2) Collection of Blood Samples

In all, blood samples from sixty (60) battery repair workers with a minimum of two (2) from each workshop and an average age of 31.55±8.0 years was used for this study. The blood samples were collected by venipuncture using disposable syringes into a 5 mL Venoject plastic vacutainer tube with Lithium-Heparin (green stopper) by authorized health staff. The procedure was explained to all subjects, and the sampling was conducted with their informed written consent. The blood samples were frozen and stored at -20 °C at Komfo Anokye Teaching Hospital (KATH), Kumasi prior to shipment to the National Institute of Occupational Health (NIOH) in Oslo, Norway for analysis.

C. Preparation and Analysis of Samples

1) Soil Samples

The soil samples were taken to the laboratory of the Council for Scientific and Industrial Research –Soil Research Institute (CSIR-SRI), Kwadaso- Kumasi in the Ashanti region of Ghana for elemental analysis. The samples were dried in the laboratory for one week to a constant weight to avoid microbial contamination. Each sample was then homogenized and made

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lump free by gently crushing repeatedly using an acid pre- washed mortar and pestle. It was then passed through a 2 mm plastic nylon mesh sieve to remove debris prior to the analysis.

One gram of the dried fine soil sample was weighed and transferred into an acid washed 100 ml volumetric flask containing concentrated acid. A mixture of HNO_3, H_2SO_4 and $HClO_4$ in the ratio 9:4:1 was used for sample digestion. The mixture was slowly evaporated over a period of one (1) hour on a hot plate. The flask was placed on a hot plate in the fume hood and heated, starting at 80 – 90 ºC. Then, the temperature was raised to about 150 – 200 ºC until the fumes of $HClO_4$ were completely evaporated. The mixture was allowed to cool to room temperature and then filtered using whatman No. 1 filter paper into a 50 cm^3 volumetric flask and made up to the standard mark with deionized water after rinsing the reacting vessels, to recover any residual metal. Heavy metals concentrations were determined using a Varian Spectra AA220 Zeeman Atomic Absorption Spectrophotometer (ZAAS) at the Council for Scientific and Industrial Research - Soil Research Institute (CSIR-SRI), Ghana.

2) Blood Samples

Lead was determined in whole blood samples at the National Institute of Occupational Health in Oslo, Norway. The samples were prepared by adding 2 mL of 65% ultrapure HNO_3 and 100 mL of an internal standard solution containing 1mg mL^{-1} of europium (Eu) to 1 mL of whole blood in a polypropylene tube. After heating to 90 ºC for 90 minutes and cooling to room temperature, the samples were diluted to 14 mL with deionized (DI) water.

The blood Pb levels were measured using an Element2 high resolution inductively coupled plasma mass spectrometer (HR-ICP-MS) (Thermo Electron, Bremen, Germany) calibrated with whole blood matrix matched standard solutions. Seronorm™ Trace Elements human whole blood quality control materials were used for quality assurance [20].

D. Exponential Regression Model

The exponential regression model was used to establish the relationship between the soil and blood Pb levels in this study. This model was preferred over other models such as the linear regression and polynomial models because of the curvilinear nature of the relationship between the two data and also our interest in finding a standard curve that can be used to interpolate the unknown variables.

The model is of the form

$$F(x) = \alpha_0 e^{-\beta_1 x}$$

where α *and* β are the calculated coefficients and $\alpha > 0$. Once the curve is fitted, values of $Y = F(x)$ may be predicted for all given values of x.

By taking the logarithm to the base e of both sides, the function transforms into the equation;

$$\ln(Y) = ln(\alpha_0) + \beta_1 x$$

Let $ln\alpha_0 = \alpha$ and set $\hat{Y} = \ln(Y)$, then the regression function of $\hat{Y}$ *on* X is approximately a linear regression and we can use the linear regression approach to make inferences about $\hat{Y}$:

$$\hat{Y}(x) \approx \alpha + \beta_1 x.$$

The coefficients α *and* β_1 will be estimated using the method of least squares as:

$$\hat{\beta}_1 = \frac{\sum(y_i - \bar{y})(x_i - \bar{x})}{\sum(x_i - \bar{x})^2}$$

And

$$\bar{\alpha} = \bar{y} - \hat{\beta}_1 \bar{x}$$

where $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ and $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$. Therefore,

$\alpha_0 = e^{(\bar{y} - \hat{\beta}_1 \bar{x})}$ and $\beta_1 = \hat{\beta}_1$.

The coefficient of determination (R-squared, R^2), of the regression equation is defined as

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$$

where $\hat{y}_i$ is the predicted value of y. R^2 is the proportion of the total variation in y explained by the regression of y on x. R^2 ranges in value between 0 and 1. When the R^2 value is 0.5 or below, the regression explains only 50% or less of the variation in the data, therefore prediction may be poor [21].

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Adjusted R^2

The use of an adjusted R^2 is an attempt to take account of the phenomenon of the R^2 automatically and spuriously increasing when extra explanatory variables are added to the model. The adjusted R^2 can be negative, and its value will always be less than or equal to that of R^2. Unlike R^2, the adjusted R^2 increases when a new explanator is included only if the new explanator improves the R^2 more than would be expected by chance. If a set of explanatory variables with a predetermined hierarchy of importance are introduced into a regression one at a time, with the adjusted R^2 computed each time, the level at which adjusted R^2 reaches a maximum and decreases afterward would be the regression with the ideal combination of having the best fit without excess/unnecessary terms. The adjusted R^2 is defined as

$$R^{*2} = R^2 - \frac{(1-R^2)p}{n-(p+1)}$$

Where p is the total number of regressors in the model (not counting the constant term), and n is the sample size.

III. RESULTS AND DISCUSSION

A. Concentration of Pb in Soils at the Battery Workshops

The concentration of Pb in soil (mg/Kg) recorded at the twenty five (25) selected workshops in Suame Magazine (S_1-S_{15}) and Asafo “Fitam” (A_{16}-A_{25}) are indicated in Fig. 2.

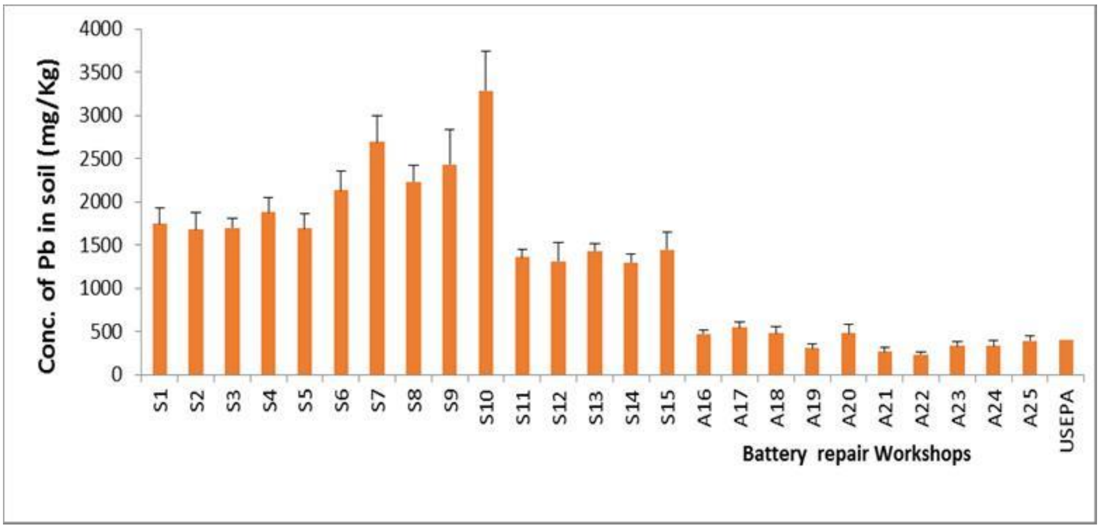

Fig. 2 Conc. of Pb in soil in mg/Kg at battery repair workshops

From Fig. 2, significantly higher mean soil Pb levels ($P < 0.05$) were obtained at Suame Magazine (1886.01 mg/Kg) compared to Asafo “Fitam” (382.20 mg/Kg). The level of economic activity in Suame Magazine, which is far greater than Asafo “Fitam”, may account for the significantly higher ($p < 0.001$) mean soil Pb level at workshops studied at Suame Magazine compared to Asafo “Fitam”. Suame Magazine is the nerve centre in terms of automobile repairs in Kumasi, Ghana and the number of lead-acid batteries repaired by artisans at Suame Magazine far outweighs that of Asafo “Fitam”. Based on oral interviews and inspection of artisans’ working premises, it is obvious that workers in Suame Magazine handle more batteries on a daily basis than their counterparts in Asafo “Fitam”.

The overall mean soil Pb level, 1284.48 mg/Kg recorded for all the workshops studied, was 3.21 times higher than the ACGIH [15] and US EPA [22] permissible level of 400 mg/Kg for soil Pb. The mean soil Pb level of 1284.48 mg/Kg obtained from the current study was lower than the mean level of 2976 mg/Kg from a former battery production factory in Albania [23]. However, the mean soil Pb level recorded in the current study was similar to the mean value of 1162 mg/Kg reported by Nwachukwu *et al.* [24] in an auto-mechanic village in South East Nigeria.

B. Relationship Between Blood Pb and Soil Pb

The general exponential model is given as: $BL = ae^{bSL}$, where *BL = blood Pb and SL= soil Pb*.

In Fig. 3, the coefficients (with 95% confidence bounds) were computed as: a = 252.1 (200.2, 304), and b = 0.0003608 (0.0002607, 0.0004608). The R^2 was 0.6622, while the adjusted R^2 was 0.66475. The mathematical model of the pooled BL data sets for the battery repair workers in the Kumasi metropolis is $BL = 252.1\ e^{0.0003608SL}$.

The correlation coefficient between the modelled and observed blood Pb is 0.833457 with P<0.001.

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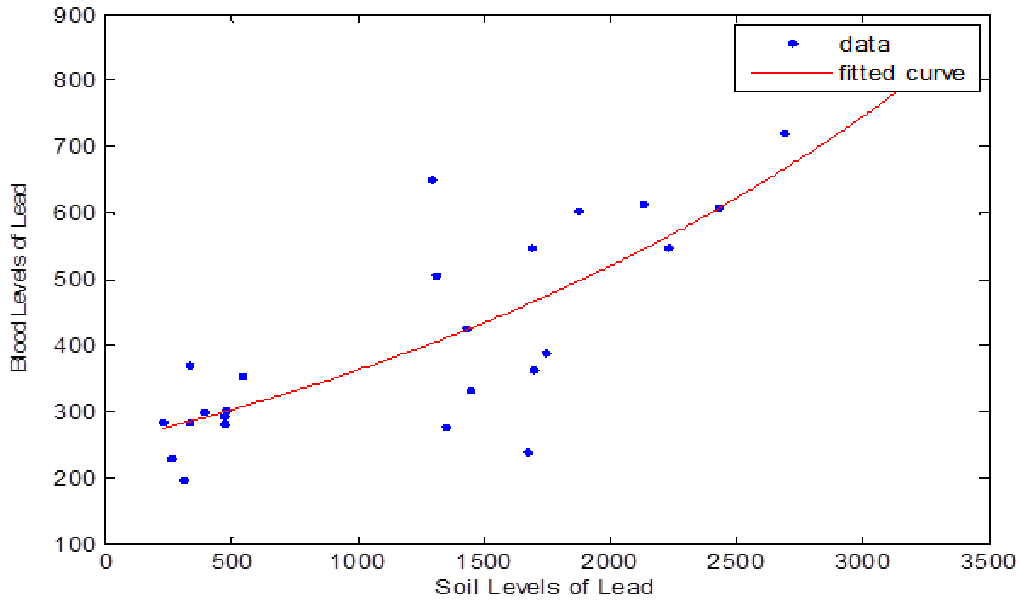

Fig. 3 Curvilinear relationship between blood Pb (µg/L) and soil Pb (mg/Kg)

Trace metal exposure has been strongly correlated with surface soil concentration, and can be linked to soil ingestion [4]. According to the model, when the level of soil Pb is not significant at the battery workshops, the expected minimum and maximum blood Pb concentrations are 200.2 and 304 µg/L, respectively. The value of the coefficient of determination, $R^2 = 0.6475$, indicates that approximately 65% of the factors that influence blood Pb at the battery workshops are from soil Pb.

From the current study, the mean and median blood Pb concentrations recorded for the battery repair workers were 420.1 and 363.1 µg/L, respectively. This shows that the high blood Pb levels recorded for the battery repair workers were influenced significantly by the soil Pb level. The results agree with reports of several studies, which have indicated a positive correlation of trace metal exposure with surface soil concentrations [25-26].

The high soil Pb levels recorded by the current study may be attributed to factors such as indiscriminate disposal of Pb-acid battery electrolytes, Pb plates and expired Pb-acid batteries into the surrounding areas. The outsides of the workshops (where most repair work is carried out) are not cemented, and as a result, there is easy penetration of battery electrolytes and other contaminants. The activities at these battery repair workshops thus have a negative effect on both workers and the surrounding environment, which calls for stricter regulation of their activities.

IV. CONCLUSIONS AND RECOMMENDATIONS

This study revealed that the higher the soil Pb level at the battery repair workshop, the greater the exposure and, hence, the higher the blood Pb level of the workers. The mean concentration of Pb in the soil at the battery repair workshops in Suame Magazine far exceeded permissible levels for industrial soil as set by the ACGIH and U.S. EPA. The model for predicting concentrations of Pb showed extremely high probabilities of blood Pb levels exceeding regulatory limits of U.S. EPA. The correlation coefficient between the modelled and observed blood Pb was 0.833457 with P<0.001, which indicates a very strong agreement between the modelled and observed blood Pb.

It is recommended that workshops or seminars be organized to educate the artisans on the dangers of eating and drinking at the workplace. Workers should segregate work and eating areas, wash their hands/spoons properly with soap before taking their meals and establish clothes changing facility in order to protect their health. Lead contaminated clothes should not be laundered at home. Artisans need to be encouraged to improve on their working methods and procedures and to use personal protective equipment in order to minimize exposure at the workplace. Furthermore, the artisans need to be impressed with the need to take regular medical screenings/examinations to maintain their health.

It is also recommended that the attention of all stakeholders including governmental and non-governmental health authorities, the artisans and the general public be drawn to the real danger posed by over-exposure to metal pollutants, particularly Pb. Practical ways to achieve this may include aggressive mass media campaigns on the radio and TV to educate the general public on metal pollution, and enactment of relevant legislations that can regulate the handling and disposal of materials containing hazardous metals.

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