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Non-Carcinogenic Lead Inadvertent Occupational Health Risk Assessment in Select Instructional Laboratories in Moi University and University of Eldoret, Kenya

D. N. Salee[1*], G. M. Simiyu[1] and C. A. Otieno[2]
[1]*Department of Biology and Health, School of Environmental Studies, University of Eldoret, P.O. Box 1125-30100 Eldoret, Kenya; dnsalee@gmail.com*
[1]*Department of Biology and Health, School of Environmental Studies, University of Eldoret, P.O. Box 1125-30100 Eldoret, Kenya*
[2]*Department of Environmental Health, School of Public Health, Moi University, P.O. Box 3900-30100 Eldoret, Kenya*

Abstract

Settled surface indoor dust is of environmental importance since it can act as a medium of human exposure to heavy metals. Universities' laboratories are involved in varied activities some of which may expose Pb to workers. The study aimed at assessing occupational non-carcinogenic risks arising from Lead (Pb) exposure in indoor settled dust. Dust samples were collected according to standard procedure and Pb levels determined by using Atomic Absorption Spectrophotometer (AAS). Mean Pb levels ranged from 344.89±12.267-754.438±76 mg/kg, which were mostly above WHO/FAO: EU: U.S. EPA (100 mg/kg: 300 mg/kg: 400 mg/kg) recommended standards. Non-carcinogenic risk for Pb HQ results in the entire study area were found to be significantly (95 % (CI); $p < 0.05$) above unit for women and 70% for men. However, overall it was observed that there was no variation in lead non-carcinogenic risk between men and women ($p = 0.8515$) in the entire study area. The results indicate that there were potential occupational Pb non-cancer risks. Recommendation is made for periodical non-cancer medical checks to ensure workers' safety.

Keywords: Inadvertent Exposure, Lead, Indoor Dust, Instructional Laboratories

INTRODUCTION

Lead (Pb) heavy metal has been known since ancient times. It occurs naturally in the environment accounting for 0.0013% of the earth's crust and ranks number two on the ATSDR's "Top 20 List" (ATSDR, 2019). Lead has been classified as a human mutagen and probable carcinogen. Its inorganic form salts accounts for most of the lead emitted into the atmosphere.

Exposure to its inorganic form occurs primarily through ingestion and drinking of lead contaminated food and water. However, exposure via paint chips, air, soil and dust significantly contributes to the overall exposure. Direct inhalation of lead in settled dust has been found to account for a small percentage of the aggregate human exposure as compared to other exposure pathways. When it is airborne, lead along with dust settle onto clothing, water, food and other indoor and outdoor surfaces, and may subsequently be transferred to the perioral area (Janneke *et al*., 2007). Lead is ubiquitous and therefore humans are exposed to the heavy metals via many pathways (Kathryn & Farah, 2016; Lanphear *et al*., 2018).

Common sources of lead exposure in recent years include residual pollution, occupational settings or environmental contamination. Metallic lead has been widely used in the manufacture of cables, storage batteries, ammunition, steel and solder products, electronic equipment and computers circuit boards, radiation and x-rays shielding appliances and superconductor and optical technology. Inorganic lead salts have been extensively used in plastics, pigments, ceramics, enamels, glass, insecticides, paints and rubber products (Tchounwou *et al*., 2012).

Dust though mostly ignored in exposure studies as a significant environmental medium, can however provide important information on the distribution and fate of chemical substances present on the surface environment as well as their concentrations (Leung *et al.*, 2008). The composition of settled dust has been shown to be similar to atmospheric suspended particulates implying it can therefore be used as an indicator of pollutants such as heavy metal pollution in the atmosphere (Leung *et al*., 2008; Akhtar *et al*., 2014). In the indoor environment, evaluation of the settled dust may give the level of heavy metal concentrations and extrapolations done for human exposure assessment. The U.S. EPA (2011), handbook has recommended 50 mg/day maximum exposure value for indoor workers besides representing a central tendency estimate of adult soil/dust ingestion.

The significance of dust as an environmental medium of human exposure to trace metal contaminants in the indoor environment has largely been ignored. However, dust may comprise of sinking airborne particles, vehicle exhausts, house dust, soil dust and aerosols that maybe airborne or carried by water hence making a significant contribution to the pollution in the environment. Most studies of heavy metals pollution via dust have focused largely on dust deposited on roads (Mishira *et al*., 2018; Soltani *et al*., 2015; Faiz *et al*., 2012; Liu *et al*., 2014). Besides, many studies on occupational exposure to heavy metals have basically measured industrial indoor air quality and blood levels, indoor dust only being a concern in residential buildings and children’s playing grounds (Ondayo *et al*., 2016; Lu *et al*., 2014; Latif *et al*., 2014; Mercier *et al*., 2011).

In occupational settings, surface indoor dust samples have often provided vital information in two occasions; first, hands of the employees can inadvertently come into contact with settled dust on a surface and then be subsequently orally taken up when transferred from hand-mouth; and secondly, when the contaminant on the surface can be dermally absorbed if the skin comes into contact frequently with the contaminated surface dust (Han, 2017).

Earlier investigations into work related exposures to hazardous substances in dust have put more emphasis on inhalation route exposure (IPCS, 1998). However, research in recent years has taken into consideration the importance of other routes of exposure such as inadvertent ingestion and dermal exposure Gorman *et al*., 2017). This has led to the birth of occupational hygiene programmes which were designed to minimize and prevent contaminants from spreading. However, this did not take into consideration the complexity and mechanisms by which inadvertent ingestion exposures occur and its significance to the overall exposure (Cherrie *et al.*, 2006, Gorman *et al*., 2014).

Depending on the duration and level of Pb exposure, the health effects may vary. According to Caravanos (2016), mental retardation, birth defects, allergies, colic, autism, lack of concentration, dyslexia, psychosis, weight loss, arthritis, hyperactivity, mood swings, seizures, numbness paralysis (beginning in the forearms), shaky hands and muscular weakness have all been associated with chronic exposure to lead.

MATERIALS AND METHODS

Study Area

The study targeted instructional laboratories in the two public universities within Uasin Gishu County, Kenya. The study area thus comprised of Moi University (MU) and University of Eldoret (UoE) located approximately 36 km South East and 10 km to the North of Eldoret town, in Uasin Gishu County, respectively. The study area is located in latitudes 0º 30' N and 0º 35' N and longitudes 35º 30' E and 35º 37' E (Figure 1).

Ten instructional labs were sampled for this study. Practical lessons carried out in the select instructional laboratories that may expose Pb to the staff working in these facilities may include but not limited to pure Pb handling and stock/spiking spillages, repair of electronic devices, use of textile dyes (pigments), wood glue and lead adhesive tapes, sealants, wood stains, sanding, primers, paints, greasing, welding metal dust and fumes, fabrication and soldering.

Sampling, Sample Preparation and Analysis

A total of 222 composite indoor settled dust samples were collected using new pre-cleaned polyethylene brush and dustpan from the floors, corners and wiping of visible dust on equipment tops and raised areas such as windowsills and sash areas with dry ash less filter paper (Whatman No. 42) according to U.S. EPA, (2008) and as applied by Ardashiri and Hashemi (2017).

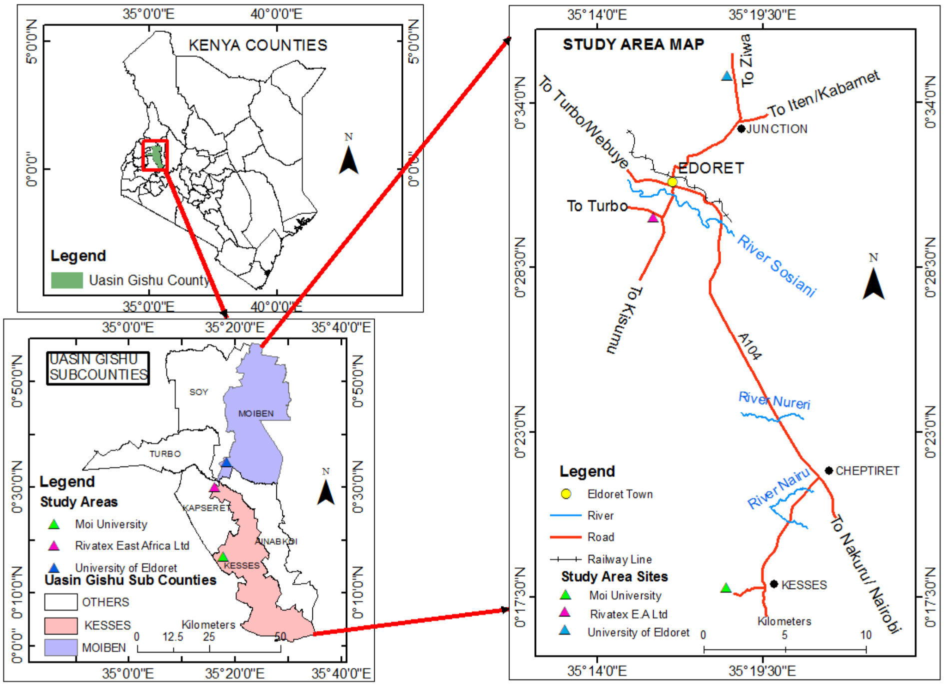

Figure 1: Location of Study Sites in Uasin Gishu County, Kenya.

Samples were oven dried in a drying furnace overnight at 70ºC and then passed through a 0.2 mm aperture sieve. For Pb analysis, 0.3 g of a well homogenized composite sweep samples was accurately weighed in duplicate into digestion (conical) flasks. An 8ml of freshly prepared aqua regia in the ratio of 1:3 (2 ml HNO_3 and 6 HCl) both analytical grade was then added and shaken for approximately 2 minutes. The conical flask was then covered and the contents heated for 2 hours on medium heat of a hot plate until all bubbling ceased. Nitric acid was added whenever necessary to avoid the samples running dry. The heating was continued until a pale brown colour resulted indicating digestion was complete.

The digests were then allowed to cool and filtered through a 0.45 µm Whatman filter paper into pre-washed 50 ml standard volumetric flasks. The residue was then washed three times with de-ionized water and the filtrate filled to the mark with de-ionized distilled water. A total of 8 blank samples were prepared following same digestion procedure as the dust samples and stored in 50 ml volumetric flasks ready for analysis. The digests were then transferred into correctly labeled acid pre-cleaned plastic bottles awaiting analysis using duly calibrated Flame atomic absorption spectrophotometer (F-AAS, Model Spectra AA/20).

Quality Control

To ascertain the accuracy of the data obtained, at each sampling station, dust samples were collected using pre-cleaned brush and dust pan and kept in a sealed plastic bag wrapped in clearly labeled brown paper bags to prevent contamination and to assure sample quality. A blank solution using de-ionized distilled water was prepared following the same processes as the field samples. Instrument calibration and recalibration was done before analysis and after every 10 samples to check for contamination and drift. All the glassware used were initially rinsed with tap water, cleaned with detergent, then washed thoroughly with tap water, rinsed again with distilled water and then soaked in 1% HNO_3 overnight to remove any anticipated contamination by heavy metals and finally rinsed thoroughly with deionized distilled water.

Occupational Non-carcinogenic Risk Assessment

Average daily intakes (ADI) in mg/kg/bw for the dermal and ingestion exposure routes were estimated using U.S. EPA (2011) models. Dermally absorbed average daily intake (ADIder) was determined as:

$$\mathbf{ADI}\text{der} = \frac{EPC_S \times SAd \times CF \times TE \times EF \times ED \times ABSder}{BW \times AT \times UCF}$$

Dermally absorbed average daily dose with subsequent inadvertent ingestion (ADIder/ing) was calculated as:

$$\mathbf{ADI}\text{der/ing} = \frac{EPC_S \times SAi \times CF \times TE \times fdo \times fgi \times EF \times ED}{BW \times AT \times UCF}$$

Non-carcinogenic ADI of dust by oral ingestion (ADIing) for occupational exposure was determined using the equation;

$$\mathbf{ADI}\text{ing} = \frac{EPC_S \times CR \times EF \times ED}{BW \times AT \times UCF}$$

The non-carcinogenic risk for each pathway was characterized using a hazard quotient (HQ), (U.S. EPA, 2011);

$$\mathbf{HQ} = \frac{\mathbf{ADI}}{\mathbf{RfD}}$$

Whereby RfD is the reference dose factor (chemical specific). Lead oral chronic reference dose for instance is 3.00E-04 mg/kg-day, whereas HQ is a dimensionless quantity that is expressed as the probability of an individual suffering an adverse effect. If HQ is bigger than 1 (HQ>1), then there is a potential risk associated with that metal. The exposure parameters used in the calculations are as presented in Table 1.

Table 1: Exposure Parameters Used for Health Risk Assessment

Parameter	**Unit**	**Worker**	**References**
EPCs-Exposure point concentration	mg/kg		Present study
BW - Body weight	kg	M-70; W- 60	U.S. EPA, 2011
EF – Exposure frequency	days/yr	250	U.S. EPA, 2011
ED – Exposure duration	yrs	30	U.S. EPA, 2011
CF – Contact frequency events/day	none	8	Michaud *et al.*, 1994; Paull, 1997
CR = Contact rate (occupational dust ingestion)	mg/day	50	U.S. EPA, 2011
SAd – Skin surface area (dermal)	cm^2	3300	U.S.EPA, 2004
SAi – Skin surface area, ingestion	cm^2	790	U.S.EPA, 2011
ABSder - Dermal absorption fraction	none	0.1	U.S.EPA, 2011
fdo – dermal-oral fraction transfer	none	0.04	Michaud *et al.*, 1994; U.S. EPA, 2011
fgi – fraction GI absorption	none	1	U.S. EPA, 2011
AF – Adherence factor	mg/cm^2	0.2	U.S. EPA, 2004
AT – Averaging time for non-cancer	days	365×ED	U.S. EPA, 2011
UCF - Unit conversion factor	kg/mg	10^{-6}	U.S. EPA, 2011

RESULTS AND DISCUSSION

Concentration of Lead in Settled Indoor Dust

Lead ranged from 165.53 mg/kg to 921.40 mg/kg (Figure 2), with mean concentrations ranging from 344.89±12.27 mg/kg to 754.44±76 mg/kg at REW and RMD sampling stations respectively. In most cases the samples were characterized by soil, hence the concentrations were compared with maximum allowable Pb soil limits.

The mean lead levels in most of the samples were significantly ($p < 0.05$) above the recommended standards. Specifically, all mean lead levels significantly surpassed WHO/FAO ($p = 0.000$) and EU ($p < 0.05$) recommended standards (Table 2) except samples from RMR which was significantly lower ($p = 0.38$) than U.S. EPA standards. One-way ANOVA analysis showed significant variations (P = 0.0001) in mean Pb concentrations between the sampling stations. Tukey's post hoc analysis showed that mean lead concentrations in samples from EWW, EC, ECA, MMW, MSM, ETD, REW and RMR were homogenous indicating insignificant variation. Variation was observed between RMD and all other sampling stations ($p = 0.0001$), and between sampling stations MC and REW ($p = 0.048$). The mean Pb concentrations were considered to be elevated and thus were further used to calculate average chronic daily intakes for Pb non-carcinogenic risk assessment.

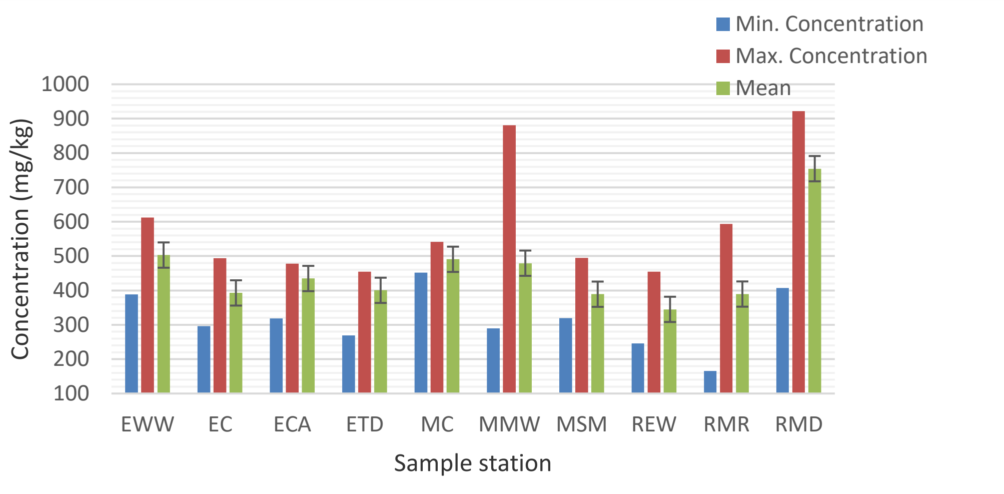

FIGURE 2: Pb Concentrations in the Sampling Stations.

EWW (Wood science workshop); ECA (Chemistry Lab 1); EC (Chemistry Lab 3); ETD (Technology Education workshop); MC (Chemistry Lab); MMW (Welding shop); MSM (Sheet metal shop); REW (Electronics workshop); RMR (Motor rewinding shop); RMD (Mechanical shop).

Table 2: Mean Lead Concentrations against International Standards in Soil/Dust

S. Station	**EU (*p* values)**	**U.S. EPA (*p* values)**	**WHO/FAO (*p* values)**
EWW	2.5 E-09	2.5E-06	1.54E-12
EC	0.000169	0.002734	2.68E-09
ECA	4.72E-08	0.00439	3 E-12
ETD	4.29E-05	0.00852	1.49E-09
MC	5.13E-10	3.42E-07	8.41E-13
MMW	0.00509	0.00991	2.07E-05
MSM	9.31E-06	0.00682	5.36E-11
REW	0.01197	0.00402	4E-09
RMR	0.01164	0.3826	1.13E-06
RMD	0.00028	0.00116	2.87E-05

Occupational Lead Non-Carcinogenic Risk Characterization

The calculated HQs' using mean Pb indoor settled dust concentrations and the U.S. EPA (2007) reference doses for the considered pathways for both male and female employees' scenarios at the various sampling locations were as presented in Table 3. The mean HQ's for all the sampling stations ranged from 0.8849 - 1.9356 and 1.0322 - 2.2533 for men and women respectively. The highest HQ was recorded at RMD sampling station with the lowest recorded at REW sampling station.

Comparison of lead HQs' for dermal and ingestion pathways for men and women using one sample t-test at 95% (CI), indicate that women in all the sampling stations had significantly ($p < 0.05$) higher HQ's than unit indicating they could be potentially at risk of lead non-carcinogenic exposure. Men seemed relatively safer in 30% of the sampling stations (RMR, REW and MSM) considering the HQs' were significantly lower than unit ($p > 0.05$) implying they could be potentially safe.

One-way ANOVA analysis showed there was significant variation in lead HQ in men ($p = 0.0000$) and women ($p = 0.000472$) between the sampling stations. The RMD sampling station posed potentially elevated risk as depicted in the relatively high mean

HQ for both men and women (Table 3). This poses concern for the workers in this facility.

TABLE 3: Lead Non-Carcinogenic Risk Characterization

	Mean HQ		**P value (1-tailed) (HQ =1)**		**P value (2-tailed) between M and W**
S.S	**M**	**W**	**M**	**W**	
EWW	1.2903	1.5053	0.0000	0.0000	0.0003
EC	1.0076	1.1756	0.0432	0.0018	0.0126
ECA	1.1153	1.3013	0.0909	0.0000	0.0004
ETD	1.0271	1.1959	0.0319	0.0451	0.1531
MC	1.2589	1.4687	0.0000	0.0000	0.0000
MMW	1.2297	1.4346	0.0159	0.0236	0.3193
MSM	0.9981	1.1645	0.4776	0.0005	0.0026
REW	0.8849	1.0322	0.4420	0.0273	0.0399
RMR	0.9993	1.1657	0.4966	0.0543	0.2045
RMD	1.9356	2.2533	0.0010	0.0004	0.3006

S.S – Sampling Station M – Men W – Women

CONCLUSION

The study deduces that workers in the study area were not entirely safe from Pb non-carcinogenic risks that may arise from exposure to indoor settled dust. Variations in men and women non-carcinogenic risks for risks could be attributed to their differences in weight, with women having a lower weight. It should however be noted that not all men and women bear the assumed weights of 70 kg and 60 kg respectively and therefore risk of exposure may as well be an individual case based on this attribute.

The findings further exemplify the importance of indoor settled dust as a medium of occupational exposure.

Previous research has attributed chronic occupation low exposure of Pb to various health effects. Further, to the health effects as reported by Caravanos (2016), Mason *et al*. (2014) also indicated higher rates of hypertension leading to cardiovascular disease. Besides, Pb can be transferred through the placenta barrier to the fetus, in females it can therefore result in miscarriage and low birth weights of offspring besides affecting their IQs in future. In males, it may result in low sperm count or impotence.

In devoid of comparable studies under similar environmental scenarios, the findings may therefore be utilized as a pilot study or a baseline survey to monitor and evaluate workers health in the studied institutions. Recommendation is made for periodical non-cancer medical checks to ensure instructional laboratory workers' safety. Besides there is need for carrying out process-specific risk assessments.

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