International Journal of Hygiene and Environmental Health 217 (2014) 62–69

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

Environmental and toenail metals concentrations in copper mining and non mining communities in Zambia

Wesu Ndilila[a], Anna Carita Callan[a], Laura A. McGregor[b], Robert M. Kalin[b], Andrea L. Hinwood[a,*]

[a] Centre for Ecosystem Management, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027, Australia
[b] David Livingstone Centre for Sustainability, Department of Civil and Environmental Engineering, University of Strathclyde, Graham Hills Building, 50 Richmond Street, Glasgow, UK

ARTICLE INFO

Article history:
Received 14 November 2012
Received in revised form 19 March 2013
Accepted 21 March 2013

Keywords:
Metals
Personal exposure
Environment
Mining
Toenails

ABSTRACT

Copper mining contributes to increased concentrations of metals in the environment, thereby increasing the risk of metals exposure to populations living in and around mining areas. This study investigated environmental and toenail metals concentrations of non-occupational human exposure to metals in 39 copper-mining town residents and 47 non-mining town residents in Zambia. Elevated environmental concentrations were found in samples collected from the mining town residents. Toenail concentrations of cobalt (GM 1.39 mg/kg), copper (GM 132 mg/kg), lead (21.41 mg/kg) selenium (GM 0.38 mg/kg) and zinc (GM 113 mg/kg) were significantly higher in the mining area and these metals have previously been associated with copper mining. Residence in the mining area, drinking water, dust and soil metals concentrations were the most important contributors to toenail metals concentrations. Further work is required to establish the specific pathways of exposure and the health risks of elevated metals concentrations in the copper mining area.

Introduction

Mining and processing activities are known to emit a variety of metals, metalloids and heavy metals to the environment (Mining Minerals and Sustainable Development, 2001; Stüben et al., 2001; Von der Heyden and New, 2004). These often result in elevated concentrations of persistent chemicals such as arsenic, cadmium, cobalt, copper and lead in the surrounding environment (Bidone et al., 2001; Coelho et al., 2007; Panday et al., 2007). The term metals is used as a general term to cover metalloids and heavy metals.

In the Copperbelt region of Zambia, mining related discharges into air and water systems contribute significantly to increased environmental metal concentrations (Environmental Council of Zambia (ECZ), 2001; Ntengwe, 2006). Environmental studies report significant impacts of copper mining on the water quality of the Kafue River, which supplies 40% of Zambia's population with drinking water (Ntengwe, 2006; Von der Heyden and New, 2004). Concentrations of arsenic, cadmium, cobalt, copper and lead reported in water, sediments and fish have been found to be elevated in areas closest to mining (Mwase et al., 1998; ECZ, 2001).

Human exposure to metals occurs via direct contact with environmental contaminants in air, soil and water and via intake of contaminated food (Bergland et al., 2001; Bidone et al., 2001; Bhopal, 2002). Non-occupational studies have shown that people living in close proximity to areas of current and past mining or industrial activities are at risk of increased exposure to metals and hence adverse health effects (Murgueytio et al., 1998; Banza et al., 2009; Liu et al., 2010).

Despite previous studies providing evidence of elevated environmental metal concentrations in the Copperbelt region (Norrgren et al., 2000; Ntengwe, 2006; Von der Heyden and New, 2004), knowledge on actual human exposure, and the subsequent impact of metals produced from mining on the community in the region is limited (Banza et al., 2009).

This study set out to investigate non-occupational long term metal exposure within a community in the Copperbelt mining region of Zambia, as well as a non-mining community and to identify any factors that may influence exposure using toenail metal concentrations as a marker of exposure. Toenail metal concentrations have been used as suitable measures of long term metals exposure (Slotnick and Nriagu, 2006). When external contamination can be removed, toenail metal concentrations are generally considered reflective of internal body stores (Lauwerys and Hoet, 2001). They can also be useful indicators of environmental contamination (Garland et al., 1993; Slotnick and Nriagu, 2006). Toenail samples and environmental sampling, in combination with questionnaire information, were used to investigate the long-term

* Corresponding author at: Centre for Ecosystem Management, School of Natural Sciences, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027, Australia. Tel.: +61 8 6304 5372; fax: +61 8 6304 5509.
E-mail address: a.hinwood@ecu.edu.au (A.L. Hinwood).

1438-4639/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijheh.2013.03.011

exposure of communities to the metals arsenic, cadmium, cobalt, copper, lead, nickel, selenium and zinc.

Materials and methods

Study design

This was a cross-sectional study of non-occupational human exposure to metals conducted in two locations in Zambia. Ethics approval was obtained for this study from the Edith Cowan University Human Research Ethics Committee (approval #06-32) and the University of Zambia Research Ethics Committee (Assurance No FWA00000338-IRB00001131 of IORG0000774).

Study area

The mining area of Kitwe in the Copperbelt Province (located at around 12°49′ S and 28°12′ E) was selected to represent the mining area and the town of Livingstone in the Southern Province (located at around 17°51′ S and 25°52′ E) was selected to represent a non mining area. Kitwe is one of the major copper mining towns located in the Copperbelt province thus making it an appropriate study location as elevated metals concentrations have been found in the environment (Ntengwe, 2006). Several locations within Kitwe were selected for data collection to ensure a large enough population from which to recruit the required number of participants. St Anthony compound was selected as the primary site for the exposure study as it is a residential area located adjacent to and 1 km north of the Nkana copper mine which is a source of metals (ECZ, 2001; Ntengwe, 2006). A secondary site, Nkana West was selected due to its location directly adjacent to and south-west of the Nkana copper mine. In the mining area 87% of participants were from St Anthony compound and 13% from Nkana West.

Livingstone town was selected as the control as no mining takes place in the region. In addition its location being outside the Kafue river drainage basin within which the Copperbelt province is located excludes it from influences from the mining region (Von der Heyden and New, 2004). Livingstone is largely tourism based and the community selected had similar socioeconomic characteristics to the communities selected in Kitwe (Bhopal, 2002).

The study areas differed in geology. The Copperbelt region comprises predominantly sulphidic ore deposits, while Livingstone is characterised by Bakota basalt which is high in quartz and rich in iron oxide and in some places lime (Livingstone District Planning Office October 2005). Copper deposits do extend from the extreme north west of the country, through the Copperbelt to the southern province where Livingstone was situated (NERC, 2001). While Livingstone was situated some 1000 km away, no towns closer that were free of mining could be identified with similar socio economic characteristics.

Participant recruitment

It was aimed to recruit 40 non occupationally exposed adults from the mining area and 40 from the control area. Community consultation was undertaken prior to commencement of the study. For cultural reasons, collection of biological samples was approached very carefully. Recruitment methods included door knocking, community meetings and recruitment through local community representatives. Verbal information was provided to those unable to read the information sheets. Participants were required to have resided at their current address for more than 1 year, and to be a non-smoker between the ages of 21–30 years. This age group was selected as it has been identified as a vulnerable group in terms of prevalence of HIV/AIDS (Bhopal, 2002). Participants were also required not to work in an occupation, such as mining or metal work, where exposure to a variety of metals may occur. Informed consent was provided either by signature or by thumb print in the presence of a witness, prior to data collection.

Data collection

Sampling was undertaken in June/July, the dry season, therefore representing the worst-case scenario when metal levels in water will be most concentrated. Dust particles were also expected to be more mobile in the dry season, representing a period of higher exposures (Bidone et al., 2001; Georgopoulos et al., 2001; Pettersson and Ingri, 2001).

Interview administered questionnaire: This method was used due to potential literacy issues in the communities. Information was collected on water use, occurrence and frequency of soil contact, consumption of home grown produce, previous occupational exposure and passive exposure to cigarette smoke.

Toenail samples: Toenail samples were collected by participants from all ten toes and stored at room temperature prior to sample preparation. Participants were asked to wash their feet and toenails with soap. Disposable stainless steel razors were provided in the sample packs for participants to use to ensure consistency across sample collection.

Drinking water: Samples were collected from the common sources of drinking water in each of the study sites. Water sources included the river, council supply and a borehole. Sample bottles were 250 mL polyethylene and were 1 M hydrochloric acid washed prior to sample collection. Samples from a hand pump or tap were run continuously for 1 min prior to sample collection to ensure that no stagnant water was collected (Bergland et al., 2001). Once collected, water samples were acidified with 10% nitric acid and stored at −20 °C prior to analysis.

Soil samples: Participants collected a soil sample from the land around their place of residence; either from the vegetable garden or an area of bare soil. Samples were collected from the top 10 cm layer of soil into plastic bags and stored at room temperature prior to analysis.

Dust samples: Participants were asked to provide dust samples by brushing dust off the interior walls of their home, or other dusty indoor surfaces, onto paper. The dust samples were then funnelled into the sample collection bag provided.

Sample preparation

As a condition of importation of toenail samples for research purposes into Australia, toenail and soil samples were autoclaved at 15 lbs for 45 min in polypropylene containers to destroy microorganisms. Toenail samples were washed thoroughly to remove exogenous contamination (Slotnick and Nriagu, 2006). The methods used to clean the exterior surface of the toenails were adapted from those of Mehra and Jujena (2005). Ultrasonication of the toenails in Milli-Q water was undertaken for 30 min. Milli-Q water was replaced with acetone and samples were ultrasonicated for a further 30 min to remove inorganic contaminants on the nail surface. Thereafter, the toenails were rinsed five times with Milli-Q water and oven dried at 60 °C to constant weight. All washed toenail samples were acid digested using a wet digestion method (4 mL concentrated nitric acid) and heated to 65 °C for 2 h. Hydrogen peroxide (4 mL) was then added and the digest returned to 65 °C until the reaction was complete (Kazi et al., 2000).

Soil samples were sieved using a 2 mm sieve to remove large amounts of organic matter and pebbles, then oven dried at 40 °C for 12 h. Samples were then homogenised in smooth bottomed Eppendorf tubes by addition of two ball bearings per tube and grinding for 3 min at a frequency of 30 (1/s) (Rayment and Higginson,