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The importance of evaluating metal exposure and predicting human health risks in urban–periurban environments influenced by emerging industry

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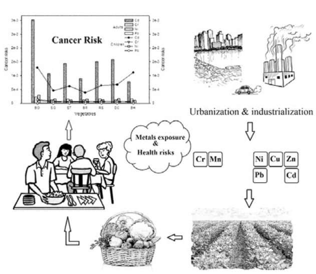
HIGHLIGHTS

- The metal exposures in the urban–periurban environments of an emerging industrial city were assessed.
- The health risks of metal contaminants via dietary exposure were estimated for local inhabitants.
- The predicted risks of developing cancer from lifetime exposures of Cd, Cr and Ni in adults exceeded the safe level.

GRAPHICAL ABSTRACT



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ABSTRACT

The human population boom, urbanization and rapid industrialization have either directly or indirectly resulted in the serious environmental toxification of the soil-food web by metal exposure from anthropogenic sources in most of the developing industrialized world. The present study was conducted to analyze concentrations of Cd, Cr, Cu, Mn, Ni, Pb, and Zn in soil and vegetables in the urban–periurban areas influenced by emerging industry. Vegetables and their corresponding soil samples were collected and analyzed for heavy metals contents from six random sites. According to the results, the potential health risks from metals to the local communities were assessed by following the methodology described by the US-EPA. In general, the total non-carcinogenic risks were shown to be less than the limits set by the US-EPA. However, the potential risk of developing carcinogenicity in humans over a lifetime of exposure could be increased through the dietary intake of Cd, Cr and Ni. In some cases, Pb was also marginally higher than the safe level. It was concluded that some effective remedial approaches should be adopted to mitigate the risks of Cd, Cr, Ni and Pb in the study area because these metal levels have exceeded the safe limits for human health. However, new studies on gastrointestinal bioaccessibility in human are required to heighten our understanding about metals exposure and health risk assessment.

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1. Introduction

The evolution of modern industry after the industrial revolution led to commercial expansion and rapid urbanization that acted as engines of economic development (Douglas et al., 2002). The creation of great cities during the urbanization process as great opportunities, particularly in developing countries, brought numerous internal migrants from the countryside to urban regions (Cohen, 2006). Although urbanization provides a high probability of economic emergence and improves the lifestyles of urban inhabitants, it may also act as a hindrance to reaching the paragon of a sustainable environment (Galea et al., 2005; Grimm et al., 2008; McDonald, 2008; Domingo and Nadal, 2009; Shahbaz et al., 2014; Zhou et al., 2015). These growing urbanized worlds and industries have been characterized by the development of unceremonious settlements that are rife with the severe environmental contamination of the air, water, soil and food (Hancock, 1996; Cohen, 2006; Peña-Fernández et al., 2014).

In recent years, soil has been highlighted worldwide in numerous environmental policies as a natural resource, and it is a key component in supporting life in terrestrial environments (EU, 2006). Soil health can be affected by various natural and anthropogenic causes such as erosion, the burning of organic matter, soil salinity and desertification from extreme climatic conditions, and environmental contamination (EU, 2006; Nadal et al., 2007; Peña-Fernández et al., 2014). Environmental pollutants of concern are usually metallic elements, biocides (insecticides and fungicides etc.), POPs and organic toxicants (petrochemicals, PAHs, halogenated hydrocarbons, dioxins and toxins), and natural and synthetic radioactive nuclides (Domingo and Nadal, 2009; Cao et al., 2010; US-EPA, 2011; Tiwari et al., 2011; Weldegebriel et al., 2012; Liu et al., 2013; Niu et al., 2015). Across the world, millions of sites have been contaminated by chemical pollutants. According to the US-Environment protection Agency (US-EPA), the European Environment Agency (EEA), and the Special Policy Group on Environmental Issues Facing New Rural Development (SPGEIFNRD), 0.5 million soils (22 million acres, or almost 22% of all developed land in the US), 0.25 million soils and 0.1 million km^2 of agricultural land in USA, the European Union and China have been identified as contaminated sites, respectively (SPGEIFNRD, 2006; EEA, 2007; US-EPA, 2015).

Soil contamination caused by the presence of metallic toxicants has attracted more and more attention because of serious environmental concerns relating to how it can affect human health significantly through various exposure routes such as dietary intake, inhalation, ingestion and dermal contact (Al-Saleh et al., 2004; Komárek et al., 2008; Abel et al., 2010; Lu et al., 2011; Liu et al., 2013). Several studies have concluded that humans are more likely to be exposed to heavy metals through vegetable consumption, which plays a key role in our regular diet in the form of produce, and this exposure pathway alone can exceed the toxicological safe limits (Zheng et al., 2007; Augustsson et al., 2015). Vegetables can easily absorb and accumulate heavy metals from contaminated soils because most metallic elements are highly soluble in water. The uptake of metals by different vegetables depends on various factors such as the bioavailable concentrations of metals in soil solution, the type and nature of the vegetables and the physico-chemical characteristics of the soil (Wang et al., 2005; Tiwari et al., 2011; Liu et al., 2013; Cheng and Yap, 2015).

Chronic intake of toxic metallic elements has deleterious impacts including clinical and physiological effects on humans as well as other animals (Zheng et al., 2007; Khan et al., 2008; Farmer et al., 2011; Liu et al., 2013; Amin et al., 2013; Xu et al., 2015). For example, excessive amounts of Cr, Cu, Mn and Zn have the ability to increase non-cancer risks such as systemic toxicity (e.g., liver, kidney, or generalized toxicity) over a subchronic or chronic duration, neurotoxicity, reproductive toxicity, developmental toxicity (which has effects on the developing fetus) and immunotoxicity (which has effects on the immune system organs (spleen, thymus)) (US-EPA, 2000; Ni et al., 2011; Liu et al., 2013). Similarly, several studies have shown that lifetime exposure to low-dose carcinogenic metallic elements may be responsible for various types of cancer risks. For example, Itoh et al., 2014 explained that a high risk of breast cancer was linked to the consumption of Cd-contaminated food. Lifetime exposure to arsenic, lead and mercury could also cause severe human health hazards (Lin et al., 2013).

To protect the health of local inhabitants, particularly children, it is necessary to remediate, reclaim and restore soils disrupted by metallic contaminants. These metallic elements do not degrade easily because of their persistent nature in the environment, and they can quickly bio-accumulate, bio-concentrate and bio-amplify up the food web (French et al., 2006; Liu et al., 2013). Numerous advanced land remedial methods have been discovered to support the restoration of the environment through the remediation of metal-contaminated areas (Peña-Fernández et al., 2014). The in-situ remediation of urban–periurban areas necessitates sustainable technologies to prevent negative effects from contaminants on the ecological environment and the quality of life.

Human health risk assessment studies on dietary exposures in urban, urban–periurban and urban–industrial environments have recently been given great importance (Rovira et al., 2011). Negligible risk assessment-related studies have been conducted in Pakistan, and the existing studies have been focused only on the point of exposure or on directly targeted industrial areas. Moreover, these types of risk assessment studies are nearly irrelevant for metal exposures via dietary intakes in Gujranwala, although this city is one of the urbanized and industrialized regions of Pakistan.

In view of the importance of human health risk assessments on urban–periurban environments that are influenced by emerging industries, this study was conducted with the following aims: a) to evaluate the levels of the following metals: [cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn)] in soil and vegetable samples that were collected from the urban and periurban areas of an emerging industrial city; b) to estimate metal exposures in adults and children from the food web via vegetable consumption; and c) to predict the carcinogenic and non-carcinogenic risks to the local population and whether the risk levels require remediation.

2. Materials and methods

2.1. Description and location of study area

Gujranwala is located in the Punjab region of northeast Pakistan (Lat/Long: 32°90′N, 74°11′E; Alt: 226 m or 744 f), and it covers a total area of 3198 km^2 with a population of approximately 4,834,869 inhabitants (PBS, 2008). This area has a semi-arid climate with a mean annual temperature and precipitation of approximately 25 °C and 500–700 mm, respectively. It is the 6th largest and fastest growing industrial city of Pakistan, and it has extensive road and rail links to flourishing agricultural and manufacturing markets. As one of the top industrialized centers in Pakistan, Gujranwala is well known for its multi-industrial groups including chemicals, textile, electric appliances, auto parts, the cutlery industry and large agricultural-processing plants, and for its manufacturing of fans, ceramics, engineering tools, electrical switch gears, cutlery, crockery, iron safes, woolen sweaters, sanitary fittings and tannery production. In the vicinity of Gujranwala, the small towns and villages are very famous for producing various types of agricultural crops including grains (especially rice) and