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Heavy metal accumulation related to population density in road dust samples taken from urban sites under different land uses

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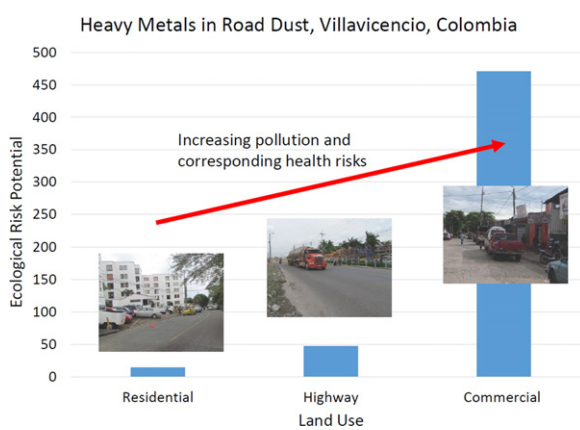
HIGHLIGHTS

- Road dust increased along with city growth and its dynamics.
- The commercial sector showed the highest concentrations of heavy metals.
- The presence of Zn, Pb and Cu in the three sectors is noteworthy.
- Road dust might cause a number of negative environmental impacts.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil pollution is a key component of the land degradation process, but little is known about the impact of soil pollution on human health in the urban environment. The heavy metals Pb, Zn, Cu, Cr, Cd and Ni were analyzed by acid digestion (method EPA 3050B) and a total of 15 dust samples were collected from streets of three sectors of the city with different land uses; commercial, residential and a highway. The purpose was to measure the concentrations of heavy metals in road sediment samples taken from urban sites under different land uses, and to assess pollution through pollution indices, namely the ecological risk index and geoaccumulation index. Heavy metals concentrations (mg/kg) followed the following sequences for each sector: commercial sector Pb (1289.4) > Cu (490.2) > Zn (387.6) > Cr (60.2) > Ni (54.3); highway Zn (133.3) > Cu (126.3) > Pb (87.5) > Cr (9.4) > Ni (5.3); residential sector Zn (108.3) > Pb (26.0) > Cu (23.7) > Cr (7.3) > Ni (7.2). The geoaccumulation index indicated that the commercial sector was *moderately to strongly polluted* while the other sectors fell into the *unpolluted* category. Similarly, using the ecological risk index the commercial sector fell into the *considerable* category while the other sectors classified as *low* risk. Road dust increased along with city growth and its dynamics, additionally, road dust might cause a number of negative environmental impacts, therefore the monitoring this dust is crucial.
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1. Introduction

Land degradation is a worldwide process affecting the Earth system due to human use and abuse of natural resources (Brevik et al., 2015; Ibáñez et al., 2015). Degradation of soils has been accelerated due to the growth of urban populations and has resulted in soil sealing, changes in albedo, in the hydrological cycle and reduced or eliminated the ecosystem services and natural resources that humankind receives from soils (Feller et al., 2015; Zornoza et al., 2015).

Road dusts accumulated in urban zones contain a diversity of materials that ranges from mineral compounds to organic and inorganic materials of anthropogenic origin that may deposit on the impermeable surfaces of cities such as roads and roofs (Shi et al., 2010). This is one part of creating the environmental problems that are triggered by the development of cities and roads, others include the increase of water and soil losses due to sealing of soils (Cerdà, 2007; Cheng et al., 2015; Seutloali and Beckedahl, 2015), and the development of increased connectivity of sediments and water (Baartman et al., 2013; Bochet, 2015; Marchamalo et al., 2015).

The heavy metal content of surface soil and street dust are good indicators of environmental accumulation of heavy metals as they act as sinks of the pollutants (Sezgin et al., 2004). Davis and Birch (2010) estimate that in urbanized basins roads may constitute 22% of the area and contribute 26% of the runoff. In our opinion even this is a conservative number, because on roads the rainfall runoff coefficient would be close to 100%. While an unsealed soil would have a rainfall runoff coefficient of about 1–30% (Okoński, 2007) when under natural forest; it can be to up to 80% when soils are heavily compacted or badland areas have developed (Cerdà, 1999). Road and road embankments can generate high to very high runoff volumes (Pereira et al., 2015).

Sartor et al. (1974) determined that the pollutant load in storm runoff from urban areas is significantly higher than in rural runoff. This, in combination with the observation that roads provide a large amount of storm runoff in urban areas, indicates that most of the pollution in urban water sources and adjacent soils may be related to road input (Vaze and Chiew, 2002). Rissler et al. (2012) found that the main pollutants associated with urbanized basins are copper (Cu), lead (Pb) and zinc (Zn); together with these nickel (Ni), cadmium (Cd) and chromium (Cr) can also be found, which come from industrial activities (García-Martínez and Poleto, 2014). Most heavy metals are poorly soluble, and therefore are transported through the catchment bonded to sediment particles (Loganathan et al., 2013; Morgan, 2013). Therefore, our level of understanding of the fate of the sediment associated pollutants in a catchment is highly dependent on the how well we understand the transport processes of sediment in these catchments (Rossi et al., 2013). Practices like use of vegetation buffers, storage dams, and establishment of riparian vegetation along small streams within catchments are elements that impact the cascade of sediment and can partition the amount sediment with its associated pollutants (Keesstra et al., 2012, 2014; Mekonnen et al., 2015a). Sediment transport in urban catchments is highly complex and difficult to measure and predict with modelling because of non-linear processes and bypassing of the natural system with drainage and sewer pipes (Fletcher et al., 2013; Franz et al., 2014).

Urban sediment accumulated on roads is a sink of pollutants from cities, such as heavy metals, where contact and ingestion of particles derived from these might represent serious issues for human health (Brevik, 2009; Zheng et al., 2010; Acosta et al., 2014; Brevik and Sauer, 2015). Pollutants affect human health in many ways; one of them is the production of quality food in the area surrounding cities as well as within cities (Roy and McDonald, 2015; Beniston et al., 2015; Brevik et al., 2016).

Based on the above, surveillance of roads that show high traffic flow and that are also in industrial areas should be a primary task for public health and risk management programs (Nazzal et al., 2014; Neff et al., 2013), as remediation of health hazards and preventing exposure to health risks are major goals of public health officials (Neff et al., 2013). Common sources of metal contaminants like Pb, Cu, Cd and Zn include the use of gasoline type fuels, tire and brake pad wear, oils, lubricants, and grease (Christoforidis and Stamatis, 2009); while Cr and Ni come from the wear of metallic parts and chrome accessories (Al-Shayep and Seaward, 2001). Road sweeping and cleaning systems have been implemented in several cities around the world to mitigate the effects of rainwater runoff on urban water systems (Brinkmann and Tobin, 2001; Tobin and Brinkmann, 2002). Road cleaning is a suitable mechanism for the management of urban pollutants. According to Calvillo et al. (2015), little research has been done on the comparison of quantitative data about the efficacy of various road sediment cleaning and sweeping methods.

There is a lack of data for this region, and in general metals data and funding to conduct such work in developing countries is not abundant. Keeping in mind that new data for regions that are data deficient provides new knowledge and carries with it a certain level of uniqueness, the main goals of this study were to 1) assess the levels of select heavy metals: Cu, Pb, Ni, Zn and Cr, in dust taken from urban sites with different land uses 2) investigate the differences between geochemical background values and metal levels, and 3) calculate pollution indices to assess the level of pollution as a tool for urban sanitation decision-making.

2. Materials and methods

2.1. Study area

The study took place in the urban area of the city of Villavicencio, located in mid-eastern Colombia (Fig. 1). Its coordinates are 4°15′48″N – 73°65′49″W, its annual average temperature is 25.6 °C, annual average rainfall is 3700 mm, and mean elevation is 467 m.a.s.l. Villavicencio is one of the cities with the highest urban growth rate over the last decade in the country, with an estimated population in 2014 of 473,718 inhabitants (DANE, 2010). The of population growth rate in the city of Villavicencio is 2.3% per annum. Geomorphologically, soils of the region are located on upper and middle terraces, which initially were tropical grasslands with native grasses. The lower terraces, including the catchment area of the river Ocoa, were covered by gallery forest. The natural vegetation is tropical rain forest but that has been mostly removed to establish agricultural fields with production characteristics different from agriculture in the foothills. Many soils were incorporated into agricultural production and then occupied by urban or peri-urban uses. Soils in the study area are dominated by Inceptisols and Oxisols as classified by the USA Soil Taxonomy system (Goosen, 1971), which often translate to Cambisols or Ferralsols in the FAO-ISRIC-ISSS system.

2.2. Sampling system

A total of 15 sediment samples were collected from the streets of three sectors of the city with different land uses (commercial, residential and highway); sampling was carried out between March and April 2014. Background metal levels were taken from Fadigas et al. (2006), as the data in this paper is considered to be representative for the background levels in this area. Fadigas et al. (2006) conducted their heavy metal analyzes using extraction with aqua regia and inductively coupled plasma analysis (ICP-AES). Samples were collected from a frame of 0.25 m^2, using 7.6 cm brushes and a plastic hand-shovel; different equipment was used to collect the samples at each site. The samples were dried at room temperature and homogenized with a 2 mm sieve previous to analysis, as described by Charlesworth et al. (2003). Each sample was composed of five subsamples.

2.3. Chemical analyses

Determination of the concentrations of total heavy metals (Cu, Pb, Ni, Zn, Cr) was carried out according to the nitric acid, hydrochloric

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