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RESEARCH ARTICLE

Soil contamination in Colombian playgrounds: effects of vehicles, construction, and traffic

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Abstract
The presence of potentially hazardous elements (PHEs) in playground soils is generally associated with anthropogenic sources such as vehicle traffic, industries, construction sites, and biomass burning. Studies indicate that PHEs are harmful to human health and may even be carcinogenic. Therefore, the aim of this study was to evaluate the physicochemical, morphological, and mineralogical properties of soil samples from three public playgrounds located in the cities of Bogota, Medellin, and Barranquilla. Besides, the possible impacts caused by the aerodynamics of particles in Colombian cities were verified. The morphology, composition, and structure of the nanoparticles (NPs) (< 100 nm) present in these soils were evaluated by field emission scanning electron microscopy (FE-SEM) equipped with high-precision field emission (FE) and high-resolution transmission electron microscopy (HR-TEM). Soil samples were predominantly feldspar, quartz, and, to a lesser extent, clay minerals, carbonates, and hematites. The average content of PHEs was anthropogenically enriched in relation to the upper continental crust. As and Sn showed a large spatial variation, indicating the influence of local sources, such as vehicle traffic and industries. There is an inverse relationship between the total concentrations of some elements and their leachable fractions. The accumulation of traffic-derived PHEs has a negative impact on human health and the environment, which is alarming, especially for elements such as Pb, Sb, or As. Therefore, the presence of PHEs should receive greater attention from public health professionals, and limits should be set and exposures controlled. This study includes the construction of a baseline that provides basic information on pollution, its sources, and exposure routes for humans in the vicinity of Colombia's major cities, characterized by their increasing urbanization and industrialization.

Keywords Caribbean contamination · Recreation parks · Ultra-fine particles · Exposure to human health

Introduction

Urban growth directly affects air quality in urban and semi-urban areas. In this sense, the maintenance of the ecosystem, public health, and the regional and global climate is nowadays an environmental challenge (Ghosh et al. 2018; Inácio et al. 2014). Urbanization has also been accompanied by the development and modernization of urban green areas that include playgrounds, gardens, zoos, and sports facilities that are considered suitable for the recreation of children, youth, and adults. These spaces have been recognized by several international studies as beneficial for improving self-confidence, independence, and motor skills development, and reducing symptoms of attention-deficit hyperactivity disorder in children (Wang et al. 2018; Lester and Maudsley 2007; Murray and O'Brien 2005). However, urban air pollution in playgrounds causes imbalance due to the presence of PHEs, which, by natural or anthropogenic deposition, can accumulate in the upper soil layer, posing a risk to the health of humanity (Adachi and Tainosho 2005).

Children are more seriously impacted than adults by the air and soil pollution (Hoek et al. 2012), due to their higher inhalation rate and involuntary ingestion of significant amounts in soil, especially with the hand in the mouth (Valido et al.

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2018). According to US EPA (2011), the amount of dust from soil and sand that is ingested by children (1 to 6 years) is from 39 and 271 mg per day. Therefore, the concern with PHEs in soils and air in playgrounds is of major importance, since these elements negatively affect the children's neurological development (Guxens and Sunyer 2012).

Colombia's rapid development, especially in cities such as Bogota, Medellin, and Barranquilla, which are considered cities with a high rate of anthropogenic activities (industries, vehicle traffic, buildings, etc.), facilitates the emission of large amounts of pollutants into the environment (Ramírez et al. 2018) because they are the direct sources of PHEs (Botsou et al. 2016). Part of these contaminants is deposited on playgrounds, exposing site workers and visitors to inhalation, ingestion, and/or skin contact (Roy and McDonald 2015). Most risks in urban soils are associated with large amounts of As, Hg, Cd, Cr, Cu, Hg, Ni, Pb, and Zn due to the underlying human factors that are similar in most urban areas but differ in toxic element concentrations, soil residence times, and geological conditions (Horváth et al. 2018). In addition, PHEs-contaminated soils can affect city surroundings through bioaccumulation and biomagnification by plants or contaminate water bodies when leached or washed by rain (Yan et al. 2018). Therefore, it is of great importance to study the presence of likely sources of PHEs in urban playground soils.

Thus, the objective of this work was to evaluate the physicochemical, morphological, and mineralogical properties of soil samples from three public urban playgrounds located in the cities of Bogota, Medellin, and Barranquilla, in order to establish a baseline to conduct other direct studies on the risk that PHEs may pose to public health.

Materials and methods

Study area

The atmospheric dynamics of Bogota, Medellin, and Barranquilla and their geographical zone (Fig. 1) have the possibility of producing high concentrations of air pollutants due to the high industrialization rate present in these metropolitan areas, with the percentages 41.3, 19.4, and 40.0%, respectively. Among these sectors, textiles (10.2%), food production (8.2%), and plastic products manufacturing (7.2%) (DANE 2016) comprise the largest industrial establishments. Together, in these three cities, there are approximately 3500 chimneys, in the industrial sector, that emit tons of particulate matter (PM) per year as a result of combustion processes in the chemical, metallurgical, and petrochemical industries, among others (Ramírez et al. 2018). In addition, the high traffic of vehicles in urban areas compromises the air quality of cities. In Bogota, the urban automotive park is comprised of 2,182,578 private vehicles, 46,4634 motorcycles, 49,779 taxis, 4734 public transportation vehicles (busses, vans, and minibusses), and a large number of heavy vehicles (OAB 2017), while in Medellin, the vehicle fleet consists of 205,683 private vehicles, 27,281 motorcycles, 19,628 taxis, 6727 public transport vehicles, and 17,010 heavy vehicles (SDM 2018; SDTSV 2018). Furthermore, other activities that contribute to the deterioration of air quality are the resuspension of dust on roads and construction sites, which has increased in recent years due to the rapid expansion of urban areas.

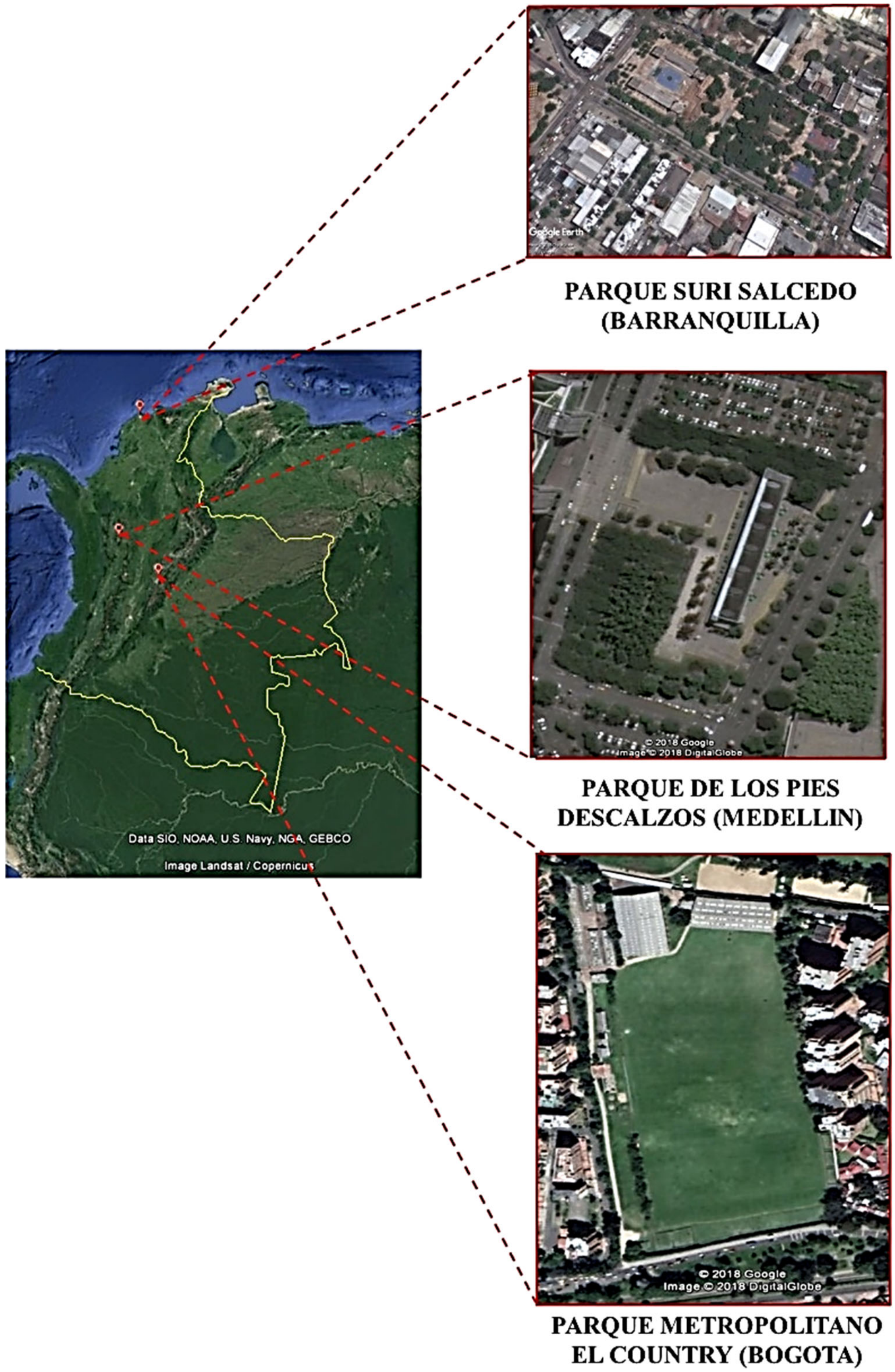
The El Country Metropolitan Playground (PG-EL), located in northwest Bogota (4° 42′ 22.31″ N, 74° 2′ 16.80″ W), has the venue for cultural, recreational, and sporting activities since 2007 (IDRD 2018). The Barefoot Playground, also called Parque de Los Pies Descalzos (PG-PD), is located in a strategic sector of Medellin near the bus and metro stations (6° 14′ 40.63″ N, 75° 34′ 37.98″ W). The playground structure provides cafes, restaurants, magazine kiosks, and sports courts. In addition, a large area allows for shows and events, and most visitors are barefoot and enjoy this area. The Suri Salcedo (PG-SS) playground, located in the center of Barranquilla (10°59′37.37″ N, 74°48′12.92″ W), was recently renovated with real estate, green areas, and irrigation, sports courts, sports equipment gymnastics, LED lighting, and sports tracks. During the sampling period, there was a large influence on construction activities due to the renovation of the Elias Chegwin and Romelio Martinez Stadium sports venues, which are used for basketball and football, respectively, for the Central American and Caribbean Games.

A high quantity and uneven distribution of anthropogenic emission sources in combination with various weather conditions create a complex and highly modifiable pattern of geochemical fields and geochemical anomalies in the Barranquilla atmosphere. The obtained results provide the basis for the improvement of the air quality standard at local and urban levels, which take into account the deposition of PHEs-rich dust NPs.

In general, it can be said that Barranquilla, Bogota, and Medellin are affected by air pollution from mobile sources (private vehicles and public mass transit) and industries. However, in Barranquilla, the increase in works such as urban construction, sports facilities, residential and commercial buildings, roads, and other infrastructure is reflected in a proportional increase in the emission of pollutants related to these activities.

It is of great relevance to underscore that the city of Barranquilla (PG-SS) continues to grow, mainly due to hosting sporting events such as the XXIII Games of Central America and the Caribbean. However, it is important to highlight the precautions that government authorities take in to minimize and contain the impacts of pollutant emissions caused by the intensity of anthropogenic activities, as the presence of NPs loaded with PHEs represents a high risk for the health of the playground's population, as well as the people who work in the construction.

Fig. 1 Study areas



Sampling strategy and analysis

Soil samples were collected at three different locations of each playground, taking into account that the sampling areas should not have vegetation cover or be near buildings. Three samples were collected from each playground, where they were taken from the upper soil layer (0–5 cm) using a PVC shovel and stored in hermetically sealed polyethylene bags.

The samples were taken to the laboratory and kept at − 20 °C in the absence of light for further preparation and analysis.

The soil samples were dried, crushed, and sieved (diameter < 63 mm) to obtain fractions between 5 and 30 g for the different laboratory analyses. A fraction of the sample was not ground in order to verify its morphology in its natural state through microscopy and particle size distribution, thus avoiding the changing of particle sizes of anthropogenic sources. The particle size distribution was determined with a CILAS Model 1190 laser particle size analyzer (Gredilla et al. 2017; Ramos et al. 2017).

Among the soil property analyses, the pH measurement was performed from a 1:5 soil/water suspension with a Thermo Scientific-Ultrameter Myron pH meter. For total carbon (CT) analysis, 0.5 g of each sample was milled for acid digestion and then taken to an elemental analyzer (ECWL). Soil pHs were determined following the method described by Querol et al. (1995). Chemical analyses of both solid and leached material were performed by inductively coupled plasma atomic emission spectrometry (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS) for major elements and trace elements, respectively (Silva et al. 2010). In order to study the leaching of elements, the compliance leaching test EN 12457-2 (EN 2002) was applied. This is a single-batch leaching test performed at a liquid-to-solid ratio (L/S) of 10 L/kg with 24 h of agitation time and deionized water as the leaching agent. In all cases, analyses were performed in duplicate. Major, minor, and trace element concentrations in solid samples and leachates were determined by means of ICP-MS, ICP-AES, and high-performance liquid chromatography.

The study of the geochemical composition of the NPs present in the soil samples was performed by X-ray diffraction, Raman spectroscopy (after procedures by Ribeiro et al. 2010), field emission scanning electron microscopy (FE-SEM), high-resolution transmission electron microscopy (HR-TEM, 200 kV) equipped for high-precision field emission (FE). The final resolution was studied with selected area electron diffraction (SAED) and fast Fourier transform (FFT), scanning electron microscopy (STEM), microbeam diffraction (MBD), and scattered energy X-ray spectroscopy (EDS).

For data analysis, the Oxford Instruments INCA 4.09 software was used after the techniques described in previous studies (Quispe et al. 2012; Silva et al. 2010). The coefficient of variation was determined and calculated in relation to the mean of the standard deviation against the mean concentration (Ramos et al. 2017). Electron microscopy is favorable to indicate chemical speciation, and the areas with the brightest images being elements with the highest atomic number (Silva et al. 2011a, 2011b) and the dark field areas indicating elements with the lowest atomic number (Silva et al. 2011c, 2011d), facilitating the identification of NPs in PHEs present in soil samples (Bogota, Medellin, and Barranquilla).

Results and discussion

Chemical and physical properties of soils

The pH of the soil samples from PG-EC and PG-PD were 7.92 and 7.85, respectively. Similar results were found at the playground in New York City, where the approximate pH was 8.0 (Craul 1992). In PG-SS, the pH obtained was 8.97 and is related to the PM emissions resulting from the works located around the playground, which can alkalize the soil pH through the deposition of concrete waste, tiles, and clinker bricks, with approximate pH of 8.0 or slate and plaster residues with a pH of up to 11 to 12 (Greinert et al. 2013). The soils of the playgrounds studied are also characterized by the high content of clays and particles of organic carbon, with variations in organic carbon content around 0.8 to 9.5%, with an average of 5.3%.

The mean elements present in different playgrounds and also its concentrations are shown in Table 1. From Table 1, it can be observed the average concentrations of As, Sb, Ni, Cu, and Pb and other PHEs in the playgrounds studied in this paper were relatively high (approximately double) when compared with other studies in China, Australia, Canada, Poland, and Italy, while Cr, Co, and Cd were similar to those reported by different places (Yan et al. 2018; Kicińska et al. 2017; Silva et al. 2016; Wiseman et al. 2015; Nannoni and Protano 2016). For example, in this study, the average amount of As was 26.02 mg/kg; for China, the value found was 56 times lower (0.46 mg/kg). In comparison with Poland, the Pb value was 9 times lower, and Cu was 3 times lower than that described in this work. In comparison with Australia, the Ni value was 6 times lower. In relation to Italy and Canada, the values for Sb, Cu, and Pb were approximately half. Thus, the high concentrations found may indicate a consequence of the impact of vehicle traffic or proximity to industries, as the sampling sites are close to heavy vehicle traffic lanes such as road crossings, gas stations, busses, and subways, while sampling sites in other cities were long distances from road crossings and with little influence from vehicle traffic (Yin et al. 2013).

The presence of high Cu concentrations in PG-EL and PG-SS deposited on the ground surface may be related to car corrosion or dry or wet deposition of air pollutants, while high Pb levels in the three playgrounds may be associated to the use of fuel mixed with Pb (in the old days), coal combustion, and smelting (Gmochowska et al. 2019). However, the specific source of these metallic compounds is difficult to detect. Although this is not the only source of Pb in the study areas, its accumulation in the upper soil layer can also be attributed to intense activities such as construction and industrialization. One of the characteristics of Pb is its poor mobility in the presence of alkaline pH, so it is easily accumulated despite the heavy rainfall in the cities of Bogota and Medellin. Generally, pollutants emitted by stop-and-go traffic bind to

Table 1 Mean concentration and leachable fraction of Colombian playground soils

Element	Barranquilla, Bogota, and Medellin*	
	Concentration (mg kg^{-1})	Leachable (%)
Al	83.7 ± 15	< 0.1
As	26.0 ± 8	0.5
Ba	879.0 ± 57	< 0.1
Ca	23.0 ± 6	7
Cd	2.1 ± 1	0.5
Co	5.3 ± 3	0.3
Cr	27.0 ± 9	< 0.1
Cu	39.0	0.7
Fe	28.1	< 0.1
Hg	0.1	0.001
K	10.8	< 0.1
La	84.0	< 0.1
Mg	494.5	11
Mn	967.1	0.3
Mo	2.9	9
Na	21.1 ± 9	< 0.1
Ni	10.8	< 0.1
Pb	89.0 ± 49	< 0.1
Rb	203.3 ± 53	< 0.1
S	146.0 ± 19	9
Sb	4.8 ± 2	5
Se	3.8 ± 1	0.8
Sn	27.0 ± 7	< 0.1
Sr	146.0 ± 37	9
Ti	4045.0 ± 59	< 0.1
U	18.0 ± 6	< 0.1
V	51.0 ± 18	< 0.1
W	16.0 ± 5	5
Zn	204.0 ± 46	< 0.1
Zr	396.0 ± 52	< 0.1

*These values are the means between the three playgrounds, in terms of concentration and leachable fraction

humic substances or clay minerals from the soil surface. Therefore, controlling or limiting traffic can reasonably reduce Pb and Cd concentrations in the topsoil of playgrounds.

In the case of Cd, it can be absorbed in alkaline soils and have high mobility; its presence is associated with solid waste incineration, wastewater management, or wear of automotive tires, the latter being its main source. Several studies have also documented tire wear on vehicles as a source of Zn emission (Valido et al. 2018; Yan et al. 2018; Silva et al. 2016). In addition, Zn and Cd proportions may be derived from crash barriers and street lights as these appliances are galvanized with Zn and rainfall causes the release of these compounds on the roads (Kluge and Wessolek 2012). The presence of mercury is possibly due to industrial activities (e.g., coal combustion) and land use (e.g., volcanic activity) (Yin et al. 2013).

In general, the main sources of PHEs come from vehicle traffic and construction work, data confirmed by the elemental composition, and separate particle size fractions with high concentrations of Cd, Sb, W, Bi, and Pb. Likewise, the contribution of part of the soil contamination may be caused by thermal energy emissions containing the trace elements V, Ni, Pb, Mo, Ge, Cr, Zn, W, Cu, and Sn (Kosheleva et al. 2018); incineration plants in the presence of Bi, Ag, Sn, Pb, Cd, Sb, Cu, Zn, Cr, Hg, and As; chemical and petrochemical companies, with trace elements such as W, Hg, Cd, Sb, Sn, Ag, Zn, Cu, Bi, Pb, Mo and Co; and mechanical and metallurgical engineering plants, W, Mo, Zn, Sn, Sb, Ni, Cr, Cu, Mn, Pb, Co, V, and As (Demetriades and Birke 2015).

Mineralogy and nanoparticles

XRD results show mineralogy dominated by feldspar, quartz, and, to a lesser extent, clay minerals (kaolinite, muscovite, illite, and chlorite), carbonates (calcite and siderite, Fig. 2), goethite (Fig. 3), hematite (Fig. 4), magnetite, and rutile. All of these compounds and many others were also detected by HR-TEM/SAED, FFT/EDS, and FE-SEM/EDS, highlighting the presence of large amounts of marine spray in PG-SS due to proximity to the sea (Fig. 4).

The size distribution of the playground soil studied (< 63 mm) reveals that they contain a moderate amount of fine particles, ranging from 2 to 11% particles < 2.5 mm, 14 to 21% particles 2.5 × 5 mm, and 17 to 28% particles 5 × 10 mm by mass. Small distribution of soil size can be a result of children's activity, stepping on the sand and playing in areas where they act as a mill or shredder. Fine particle deposition from anthropogenic activities can influence soil particle size distribution in playgrounds, and finer fractions can be considered a source of dust prone to be re-suspended due to children's activity or the wind effect, especially in Barranquilla, due to the more intense wind speed compared with Bogota and Medellin.

The sources of anthropogenic activities were identified through the presence of high concentrations of Hg, Sb, As, and Cu. However, these elements (Sb, Pb, Mn, and Cu) are commonly found due to wear on vehicle brake discs (Schauer et al. 2002) but can also be emitted by metallurgical industries (Amato et al. 2009).

The chemical profile of the studied soils (not including quartz and clays) was predominated by Fe minerals (e.g., Fig. 4), C, S, and Ca (siderite, hematite, magnetite, and amorphous phases), containing an abundant fraction of organic particles, probably derived from traffic and abundant burning, especially in Barranquilla.

Aluminum silicates are responsible for the majority of soil composition in playgrounds, contributing to a high variation

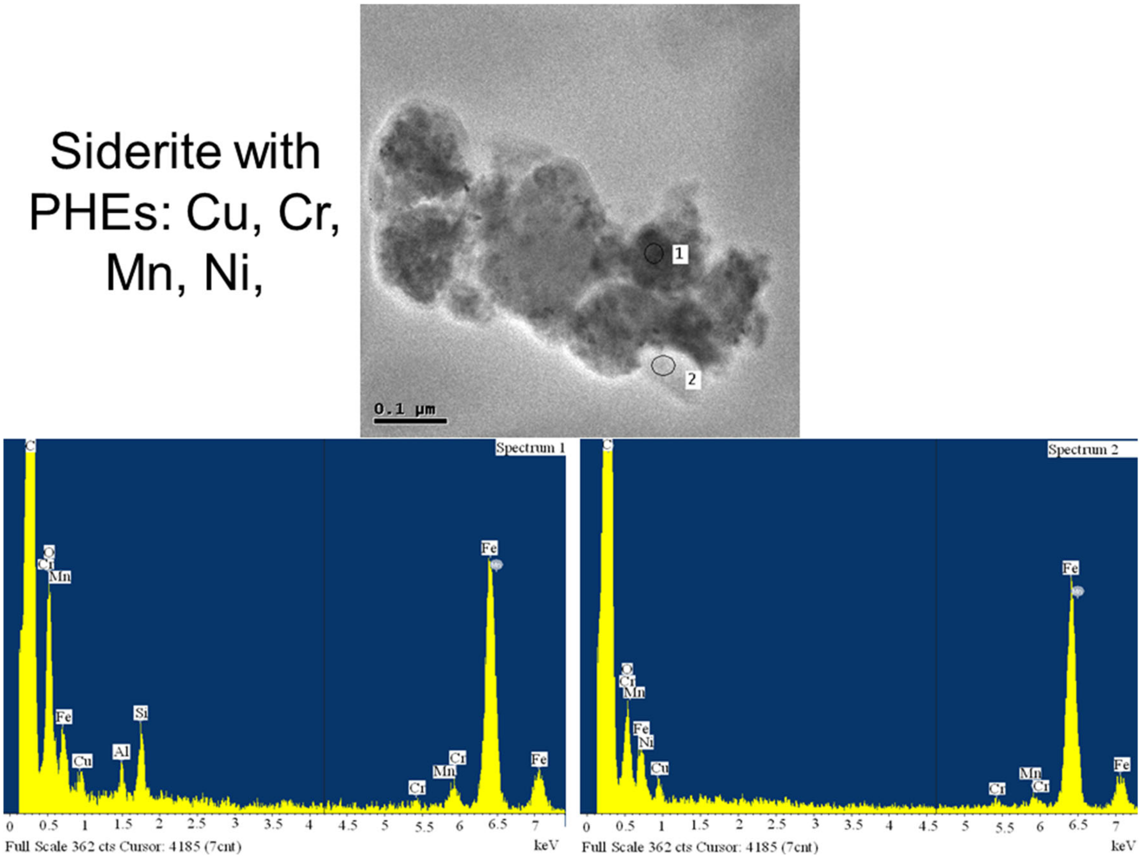


Fig. 2 Siderite containing PHEs (PG-EL)

of elements such as Al, Mg, Na, K, Fe, Rb, Ti, and Mn, which are related to carbonate minerals (Fig. 2), clays (Fig. 3), oxides (Fig. 4), and feldspars. This factor shows that elements such as Cu, Cr, Fe, Ni, Zr, Sn, and Pb have a high affinity for aluminum silicates.

The detected salts explained the variation of Na, Cl, and K, suggesting that the presence of halide salts and marine aerosol results from atmospheric deposition, especially in the city of Barranquilla.

Carbonates show a high amount of Ca, Mg, C, and Fe but also contain Sr, Ba, and Ni, according to the results of the EDS analysis, as these elements are very common in calcite, siderite, and dolomite. The presence of S and Ba may also indicate the presence of barite according to the images detected by FE-SEM and the chemical composition confirmed by EDS (Fig. 5).

The detection of the main chemical elements present in the NPs, by the applied analytical procedure, is related to the evolution of some less abundant minerals, as well as to the amorphous phases. In addition, the results of the determination of NPs show that the relationship between PHEs and C for NPs, especially those with particle sizes smaller than 10 nm, increased considerably in PHEs, indicating that they are transported to smaller carbonaceous portions and generate clumps in the PHEs. The present work validates the preservation of As, Cd, Cr, Pb, Hg, Zr, U, and other PHEs by amorphous NPs, which can be a geochemical generator of crystalline compounds. NPs may be natural or anthropogenic minerals formed due to natural forces or pollution and have been widely studied due to their presence in the atmosphere (Cyphert et al. 2016).

Detected NPs (Figs. 2 and 3) might enter the body by inhalation, ingestion, or dermal routes. These systems behave as early biological barriers and are strategically designed by nature to control two vital functions (Sushma et al. 2018). The first function is to allow the passage of essential and required substances by the body, and the second function is to protect the biological system from dangerous foreign substances entering the body (Dumkova et al. 2016).

The minerals exemplified in Figs. 2, 3, and 4 belong to the family of silicate/oxide/sulfate minerals. Quartz, due to its inert nature, has been widely used in the manufacture of mechanical, abrasive, and glass products (especially in Barranquilla). In addition, it can be obtained from natural sources, as an original constituent of the soils. Exposure to microscale quartz particles is related to the development of numerous medical conditions that eventually lead to silicosis and lung cancer (Turci et al. 2016). However, several

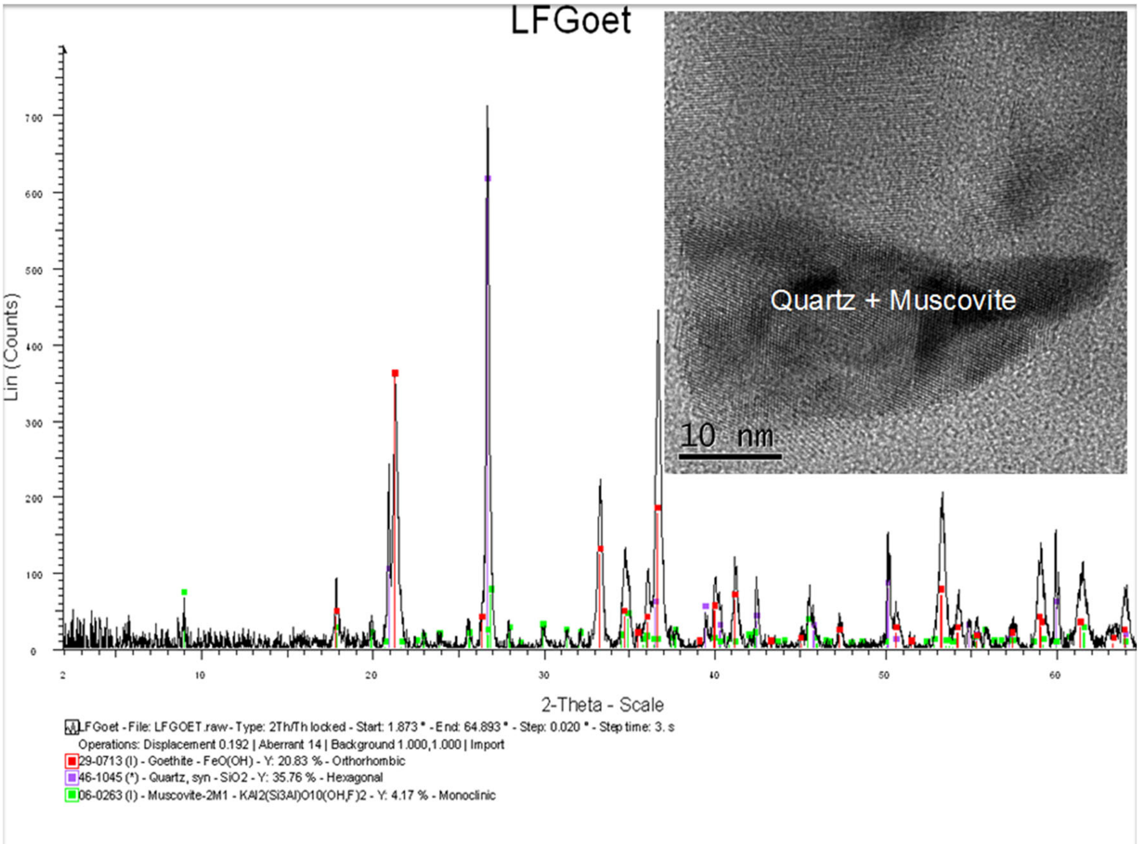


Fig. 3 XRD and HR-TEM image of major mineral compounds

cytotoxicity studies of Si present in NPs have shown the possibility of posing a high health risk by inducing oxidative stress and inflammation (Sushma et al. 2018).

Arsenic compounds showed an affinity with many NPs of Fe (oxides and silicates and carbonates). Such compounds can be accumulated in the bones, liver, and kidneys and also in keratin-rich tissues (Kicińska et al. 2017). Prolonged exposure and excess of As-containing NPs in humans results in skin and circulatory, nervous, and respiratory disorders, and is a highly carcinogenic agent (Zwozdziak et al. 2016).

Chromium, often accumulated in insoluble NPs such as hematite and magnetite as well as carbonates, is probably derived from inefficient combustion by vehicles, especially busses. It is important to mention that the presence of Cr was as the hexavalent (Cr^{6+}) form in clay and oxy/hydroxide NPs of Fe and Al. In the human body, Cr, along with As, can accumulate in the brain, spinal cord, and kidneys, as well as in children's hair and teeth (Kicińska et al. 2017). Prolonged exposure to high concentrations of NPs with Cr disrupts the circulatory and respiratory systems and results in skin disease, while chromic acid can seriously damage internal organs.

Despite the different geological aspects, historical processes, and development of urban settlements, the playgrounds of the three selected cities may be characterized by similar anthropogenic processes, due to civil construction, fuel burning, and local industries located around these playgrounds.

Leachable fractions and perspectives

The contribution of anthropogenic activities related to the deposition of PHEs in the playground areas studied is exorbitant due to the ability of NPs to act as carriers, assisting in the transfer of adsorbed PHEs. However, little attention has been given to this situation and its consequences due to PHEs' transport in the studied playgrounds. The presence of PHEs in soils, vegetation, fruit and horticulture, and groundwater/drinking water are places of access that are extremely harmful to human health, even in small quantities (Inácio et al. 2014; Kosheleva et al. 2018). Therefore, the use of advanced analytical tools, as applied in this article, provided relevant data for the proper identification of PHEs in NPs.

Most NPs enriched elements detected by EDS (As, Ni, Cu, Fe, Hg, Mo, Ni, Sn, and Zn), and other species such as Ca, Mg, S, Cr, Co, and Cl are soluble in water and were clearly present in the < 10 and < 5-mm fractions. The leachable fraction generally varied in considerable fractions (5–95%), especially for the elements S, Sr, Mg, Cl, and W. It is emphasized that the procedure used for leaching is approximate and, in

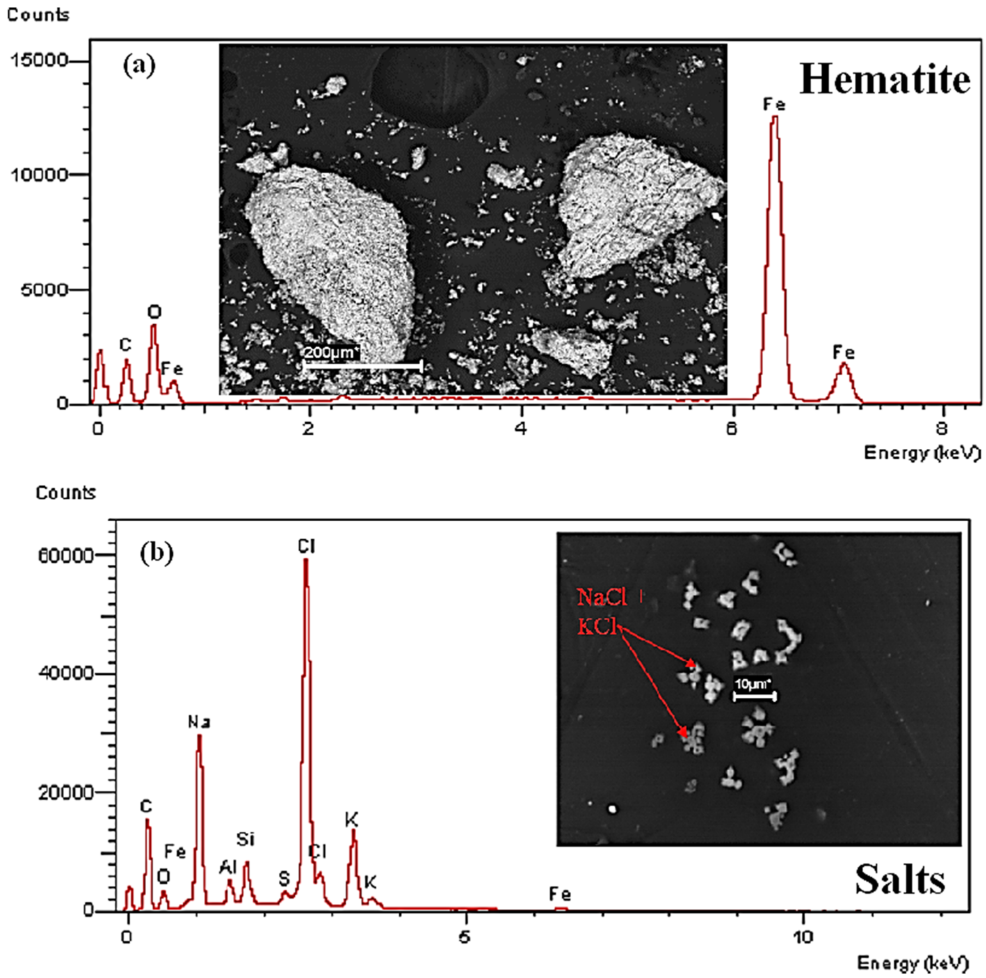


Fig. 4 Hematite detected salts from (**a**) PG-PD and (**b**) PG-SS

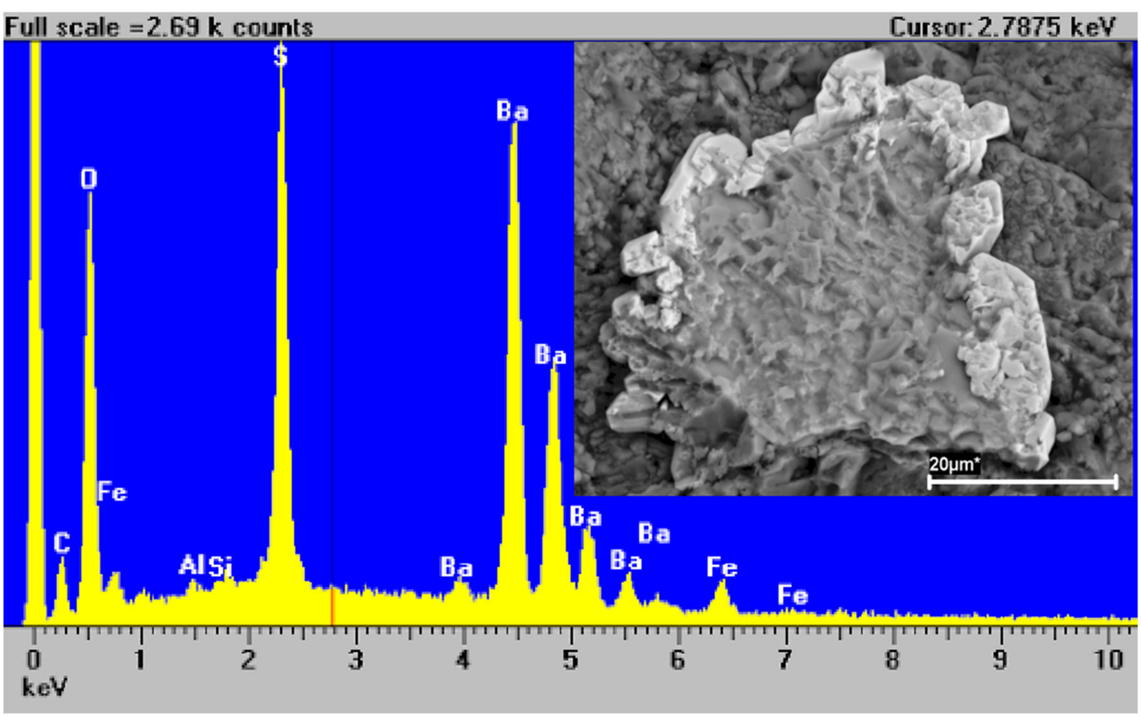


Fig. 5 EDS indicates the presence of barite

fact, the leachable fractions may be larger than those detected, so it is possible that they pose a high risk to workers' health, perhaps even higher, considering that NPs can be easily inhaled into the bloodstream.

According to the occurrence of carbonate/sulfate NPs in the playground samples, Ca, S, K, Na, Mg, Sr, and Ba presented higher solubility. On the other hand, As, Sb, Mo, Zn, and Co presented lower, but not negligible, solubility in the < 63-mm fraction and higher in the smaller fractions. Most of these elements are probably present in anionic form, soluble in the slightly alkaline pH of soils.

The average leachable fraction of each element is detailed in Table 1, where it can be observed that the most soluble elements were Ca, Mg, Mo, S, Sb, Sr, and W, although their soluble fractions did not exceed 7, 11, 9, 9, 5, 9, and 5%, respectively. Consequently, solubility is not related to specific sources since S and Mo are mainly derived from silicates and building materials, Sb by anthropogenic sources, and Ca, Mg, and Sr from carbonate sources and building materials. The results of the composition and solubility of specific elements in the studied samples indicate that their composition is influenced by the material deposited by the elimination of anthropogenic environmental pollutants, mainly atmospheric. Therefore, the re-suspension of these soils can affect the playground air quality, besides the mineral matter concentrations.

For several elements (such as Sb, Ca, Cd Zn, Cr, Zr, Ni, Sr, and Mg), it was observed that the higher the total concentration of the element, the lower the leachable fraction, thus indicating that the elements come from different sources, either through vehicle traffic or buildings.

In this study, the main sources of leachable pollution can be attributed to motor vehicles, industrial activity, biomass burning, waste disposal, and construction activity, the proportions depending on the city. Economic growth, industrialization, and urbanization led to a huge increase in the emission of different pollutants, which made the difference in the leachate load between the cities studied, with Barranquilla being the city most influenced by leachate elements in relation to Bogota and Medellin.

Conclusion

The increased frequency of anthropological activities favors environmental impact and human health. As a result, population availability and access with the NPs containing PHEs become more common, especially in public places. Soil samples from different Colombian cities were characterized in terms of their mineralogy and composition in order to improve understanding of the possible impacts that may be caused during contact with the soil. The analyzed samples show quartz- and clay-dominated mineralogy with smaller amounts of carbonate minerals (calcite and siderite) and smaller portions of hematite, magnetite, and rutile. Therefore, the presence of high concentrations of PHEs in the three playgrounds showed that they contribute to contamination with the elements As, Pb, and Zn, indicating a public health risk, especially for frequent playground visitors, such as children. With this, the study serves as a warning that there should be a legislative regulation to impose PHE limits available on recreation soils. When compared with the cities studied with those of other countries, the PHEs' levels in this study were relatively high, which may be due to the intense construction and traffic activities near the sampling sites. The samples have a considerable fraction of particles smaller than 5 mm, which can easily be re-suspended by children's activity and the strong Caribbean Sea winds in Barranquilla. The enrichment in some PHEs found may be caused by the cumulative action of rain with PM, although further studies on the problem are needed. Therefore, the study recommends the renewal of playground soil occurring systematically using clean and less crushed soil. In addition, implement strategies to reduce vehicle emissions and biomass burning and also the adherence of efficient masks to at least PM10 and PM1 for construction workers who are constantly exposed to construction-generated NPs.

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