

## Lead exposure from soil in Peruvian mining towns: a national assessment supported by two contrasting examples

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**Objective** To estimate the population of Peru living in the vicinity of active or former mining operations that could be exposed to lead from contaminated soil.

**Methods** Geographic coordinates were compiled for 113 active mines, 138 ore processing plants and 3 smelters, as well as 7743 former mining sites. The population living within 5 km of these sites was calculated from census data for 2000. In addition, the lead content of soil in the historic mining town of Cerro de Pasco and around a recent mine and ore processing plant near the city of Huaral was mapped in 2009 using a hand-held X-ray fluorescence analyser.

**Findings** Spatial analysis indicated that 1.6 million people in Peru could be living within 5 km of an active or former mining operation. Two thirds of the population potentially exposed was accounted for by 29 clusters of mining operations, each with a population of over 10 000 each. These clusters included 112 active and 3438 former mining operations. Soil lead levels exceeded 1200 mg/kg, a reference standard for residential soil, in 35 of 74 sites tested in Cerro de Pasco but in only 4 of 47 sites tested around the newer operations near Huaral.

**Conclusion** Soil contamination with lead is likely to be extensive in Peruvian mining towns but the level of contamination is spatially far from uniform. Childhood exposure by soil ingestion could be substantially reduced by mapping soil lead levels, making this information public and encouraging local communities to isolate contaminated areas from children.

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### Introduction

Children and adults are still routinely exposed to very high levels of lead in developing countries, particularly in regions with a long mining history, such as the Andes.<sup>1-4</sup> This study focuses on Peru, which ranks among the world's top five producers of silver, zinc, lead and copper<sup>5</sup> and has a long and conflict-ridden mining history.<sup>6</sup> Exposure to lead in this country may have been prolonged, despite some widely publicized and severe cases,<sup>7</sup> by the importance of the revenue generated by the mining industry, weak regulation, a lack of information about contamination and a perception that the cost of interventions might be prohibitive. The premise of this study is that many, perhaps most, egregious cases of mining-related childhood lead exposure in Peru, and similarly affected countries in South America and Africa, could be avoided at a relatively modest cost by systematically mapping hot spots for lead in soil in mining towns where ore is currently processed or has been processed in the past. Interventions carried out around mines, ore processing plants and smelters in other parts of the world have already been shown to reduce dramatically childhood exposure to lead.<sup>8-11</sup>

The exploitation of metal-rich deposits in the Andes dates from pre-colonial times.<sup>12</sup> Then, the focus was on silver, as it was during the Spanish colonial era. The extensive use of mercury to extract silver through the process of amalgamation undoubtedly had a substantial, albeit localized, impact on the health of workers.<sup>13,14</sup> Potentially just as important, however, especially when their cumulative effect is considered, could be the health impact of the mine tailings left over once the most concentrated ore has been separated. These tailings are enriched

in lead and were generated over centuries of mining silver, copper, zinc and lead deposits throughout the region. Today when a new mine enters into operation, the mining company attempts to minimize the risk of exposure by purchasing surrounding tracts of land. In the past, however, population centres typically became established near a mine and dwellings were built on top of mine tailings.<sup>15</sup> In such places, even today it is still common for children to ingest large quantities of lead by playing in contaminated soil or ingesting lead-laden dust at home.<sup>10,16-19</sup> Currently, Peru has no standard for the lead content of soil.

The assumption underlying this study is that lead contamination of soil is heterogeneously distributed and, consequently, the level of contamination within a few kilometres of one mining-related operation can differ greatly from that close to another. If suitable maps were made available locally, young children, who are especially at risk of ingesting soil when playing, could be induced to avoid the most contaminated areas.<sup>20</sup> Our aim was to evaluate the potential benefits of such an intervention on a national scale by carrying out a spatial analysis of mining operations in Peru in relation to population density. To the best of our knowledge, no similar study has previously been carried out. In addition, we performed surveys of the local distribution of lead in soil at two locations to illustrate low- and high-risk scenarios. The study focused on lead contamination linked to the exploitation of deposits of polymetallic ore, including gold-containing ore, and therefore excluded contamination associated with cement production and other extractive activities, which could also have a substantial effect on health.

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(Submitted: 18 April 2012 – Revised version received: 28 August 2012 – Accepted: 30 August 2012 – Published online: 10 October 2012)

## Methods

We obtained the geographical coordinates of 7997 sites involved in four types of activity associated with mining: (i) 113 industrial-scale mines in operation in 2009; (ii) 138 ore processing plants; (iii) 3 smelters; and (iv) 7743 “legacies” of past mining activities. Since none of the existing data compilations was exhaustive, the information was drawn from several sources (Appendix A, available at: <http://www.ldeo.columbia.edu/~avangeen/mining>). The analysis does not include undocumented artisanal mines or informal and unreported mining-related activities, which can also be major sources of lead exposure.<sup>11</sup>

### Spatial analysis

Details of the 7997 sites, including their attributes, were entered into a spreadsheet (Appendix B, available at: <http://www.ldeo.columbia.edu/~avangeen/mining>) and the data were mapped using ArcGIS software (esri, Redlands, United States of America) and the geographical coordinate system GCS WGS 1984. A circle with a radius of 5 km, termed a “buffer”, was created around each site; if there was an overlap, circles were merged. The 5-km radius is a compromise. In some cases, the population exposed to lead may have been overestimated because contamination did not extend as far as 5 km from the mining-related operation. In others, the population may have been underestimated because sites that are active at present or were active in the past were not reported. Data on individual sites and merged buffers were converted into computer files with a .kmz extension (Appendix C, available at: <http://www.ldeo.columbia.edu/~avangeen/mining>) so they could be viewed on Google Earth (Google Inc., Menlo Park, USA).

Data on the estimated size of the population of Peru in 2000 were obtained from the Global Rural–Urban Mapping Project version 1 (GRUMPv1) data product, available at a resolution of 30 arc-seconds, or ~1 km at the equator from CIESIN (Center for International Earth Science Information Network, Palisades, USA).<sup>21</sup> The data were imported into ArcGIS in a grid format. In addition, an overlay of GRUMPv1 population data for Peru was created in a .kmz file format (Appendix C) for comparison with the location of the

mining operations in Google Earth. The size of the population living within each 5-km-radius buffer was estimated using the zonal overlay method in ArcGIS: by defining the 5-km buffers as zones, the population exposed within each buffer was calculated using the raster grid population count.

### Local soil lead surveys

Two contrasting locations were selected to document the spatial variability of lead contamination of surface soil: the historic mining town of Cerro de Pasco, which is situated 4400 m above sea level in the Andes and has a population of 70 000, and the more recent mine and ore processing plant near Hualar, situated 150 m above sea level only a few kilometres from the Pacific Ocean, with a population of 160 000.

Lake sediment records indicate that heavy metals from the mining and smelting of silver-bearing ores in Cerro de Pasco were being released into the atmosphere as early as 1400 years ago.<sup>12,14</sup> In the 1800s, deposition of lead and mercury from smelting increased dramatically with the growth of the Ciudad Real de Minas, as the town was also known. Deposition peaked in the 1950s after the copper and zinc mines were purchased by the United States Cerro de Pasco Investment Co. Subsequently, the mines were nationalized and exploited by the Centromin conglomerate until, in 1999, the Peruvian Compañía Minera Volcan bought the main mines in Cerro de Pasco and the associated Paragsha ore processing plant. The town of Cerro de Pasco has been built around an open-pit mine and on top of mine tailings. In recent decades, vast quantities of waste rock and tailings have been accumulating over an area of approximately 10 km<sup>2</sup>, several kilometres to the south-west of the main pit and further away from the main population centre.<sup>22</sup>

The María Teresa polymetallic (i.e. zinc, lead and silver) mine and associated Minera Colquisiri SA ore processing plant started operating 7 km west of the town of Hualar in 1984. Human activity around the perimeter of the mine is primarily agricultural, mostly fruit trees and hog farms. However, a few hamlets were also built close to the perimeter of the site. In contrast to Cerro de Pasco, there is no large population centre close to the mine and tailings are stored in a pond located within the plant property.

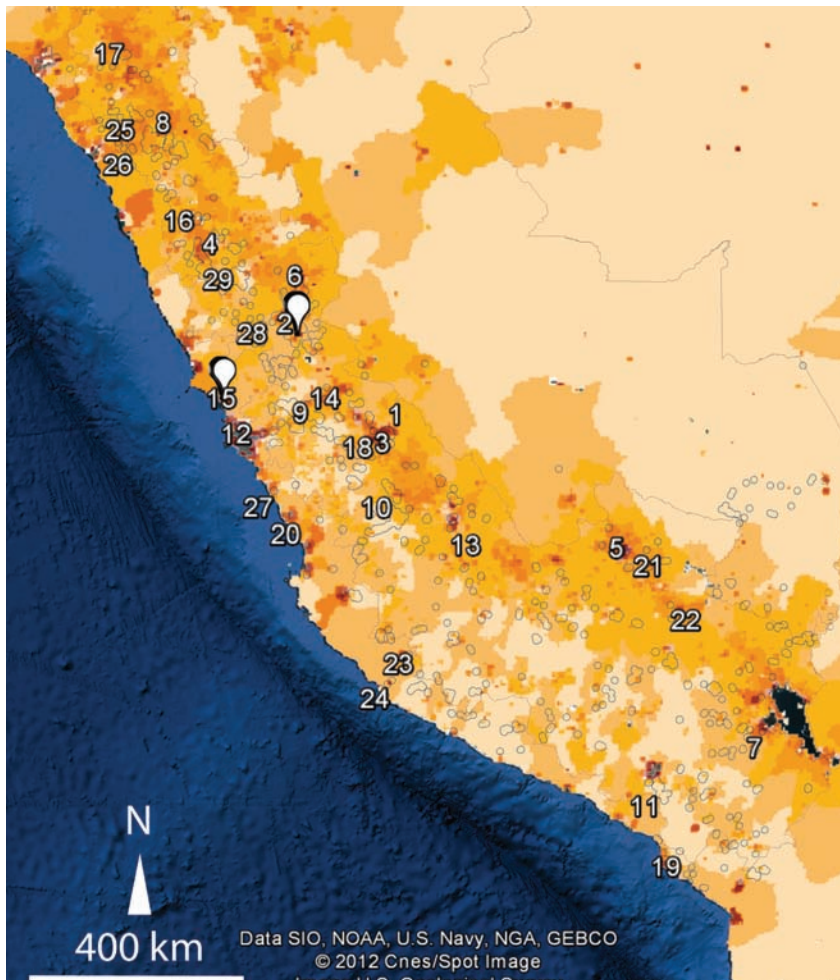
In May 2009, the distribution of lead in surface soil in the town of Cerro de Pasco and in areas outside the fence surrounding the María Teresa mine and ore processing plant near Hualar were mapped using a hand-held X-ray fluorescence analyser (Innov-X Alpha, Olympus Corporation, Tokyo, Japan), as used in other studies.<sup>11</sup> The precision of the measurements estimated by the manufacturer’s software typically ranged from 17 to 250 mg/kg for soil containing 400 to 11 000 mg/kg lead, respectively. The accuracy of the analyzer was evaluated over a period of 10 days using three soil standards from the United States National Institute of Standards and Technology: Standard Reference Material (SRM) 2710 with a mean concentration of lead in soil of 5532 mg/kg (standard deviation, SD: 80), SRM 2711 with 1162 mg/kg (SD: 31) and SRM 2709 with 18.9 mg/kg (SD: 0.5). These measurements averaged 96 % (SD: 4; 11 measurements), 97 % (SD: 7; 7 measurements) and 89 % (SD: 10; 4 measurements) of the certified values for the three soil standards, respectively. A .kmz file was created to enable the soil lead data to be viewed on Google Earth (Appendix C).

## Results

In the spatial analysis, a total of 312 nonoverlapping buffers were obtained by combining the 5-km-radius circles around the 254 active mining operations (i.e. mines, ore processing plants and smelters) with those around the 7743 mining legacies. The average size of these buffers was 170 km<sup>2</sup>, with the largest covering an area of 1800 km<sup>2</sup>. Of the 312 buffers, 227 did not contain a single active mine, ore processing plant or smelter but did include a total of 3030 legacy sites. Another 52 buffers contained a combination of legacies and active mining operations, whereas the remaining 33 buffers contained only active mines, ore processing plants or smelters.

In 2000, the population of Peru was approximately 30 million and was distributed across 195 coastal, mountain (Andean) and tropical forest (Amazonian) provinces. Around 90% of sites with active mining operations or mining legacies were located in mountain provinces, with the remaining sites divided roughly equally between coastal and tropical forest provinces (Fig. 1). The average population density of Peru was only 21

Fig. 1. The 312 sites<sup>a</sup> with active mining operations or mining legacies associated with lead in soil, Peru, 2009



The white markers indicate the locations of the Cerro de Pasco (Fig. 2) and Huaral (Fig. 3) sites.

The shading in the map represents the population density for the year 2000 based on GRUMPv1 data.<sup>21</sup>

<sup>a</sup> The outlined sites were obtained by combining the 5-km-radius circles, termed buffers, around 254 active mining operations with those around 7743 mining legacies. The 29 largest buffers that each contained an estimated population of 10 000 or more are numbered 1 to 29 according, in decreasing order, to the size of the population covered.

people per square kilometre and about two thirds of the buffers were located within areas with a population density below the national average. In total, 1.6 million people resided within 5 km of an active mine, ore processing plant or smelter or a mining legacy.

The size of the population residing in the different buffers ranged widely. It was less than 1000 in each of the 148 buffers with the smallest populations. In another 135 buffers, the population ranged from 1000 to 10 000. However, the remaining 29 buffers (Table 1) accounted for more than two thirds of the total population living within 5 km of an active mining operation or mining legacy: the population in each of these buffers ranged from 10 000 to 129 000.

The population density averaged 175 people per square kilometre in these 29 buffers and was below the national average in only 2 of the 29. Eleven of these buffers contained only mining legacies. Together, the 29 buffers encompassed a total of 3438 legacies, 52 active mines, 58 ore processing plants and 2 smelters.

The buffer centred around Cerro de Pasco ranked second in our national assessment: it covered the second largest area, at 1659 km<sup>2</sup>, and had the second largest population, at 119 178 inhabitants (Table 1). The largest buffer had a slightly larger population, contained 52 legacies and no active mining operations and included Huancayo, Peru's fifth largest city. The Cerro de Pasco buffer contained 12 active mines, 9 ore

processing plants and 349 legacies. Our soil survey centred on the main open-pit mine, which continues to be exploited on a massive scale and covers 5 km<sup>2</sup> of the buffer. Only 35 of the 74 soil samples (47%) had a lead concentration below the maximum of 1200 mg/kg recommended by the United States Environmental Protection Agency for soil in residential areas where children do not play.<sup>23</sup> Soil lead concentrations above 1200 mg/kg were measured all around the open pit but no further than 1 km from its edge (Fig. 2). The five highest concentrations, which ranged between 5000 and 12 000 mg/kg, were all observed in samples taken from within 500 m of the western margin of the pit. Only 11 of the 74 soil samples (15%) had lead concentrations below the threshold of 400 mg/kg recommended by the Environmental Protection Agency for soil in residential areas where children play. Soil lead concentrations below 400 mg/kg were found primarily in the outer northern and eastern sections of the town.

The second location selected for our soil lead survey was in a buffer that ranked fifteenth by population in our assessment and contained only one mine, one ore processing plant and four legacies (Fig. 3). However, the buffer was 90 km<sup>2</sup> in area and extended to the outskirts of the town of Huaral. Consequently, it encompassed a sizeable population of 21 705 (Table 1). The soil measurements obtained from this site contrasted markedly with those from Cerro de Pasco. Only 4 of the 47 samples (8.5%) had a lead concentration above 1200 mg/kg and the maximum was 2300 mg/kg. The high lead concentrations were all observed along a road and in cultivated fields within 200 m of the perimeter of the plant. The lead concentration in soil at most other locations within that distance was less than 400 mg/kg.

## Discussion

A study conducted in 2007 by the United States Centers for Disease Control and Prevention in collaboration with the Peruvian authorities showed that the lead content of blood drawn from 52% of 163 children living in Cerro de Pasco exceeded the intervention threshold of 10 µg/dL.<sup>24</sup> In the Ayapoto area, west of the mine pit where soil was highly contaminated (Fig. 2), the blood lead content exceeded 10 µg/dL in 88% of

Table 1. Mining-related buffers<sup>a</sup> with a population greater than 10 000, Peru, 2009

Rank	Mining company <sup>b</sup> and site type	Province	No. of legacies <sup>c</sup>	No. of active mines	No. of smelters	No. of ore processing plants	Total no. of sites	Population in each buffer	Area (km <sup>2</sup> )
1	Legacies only	Tayacaja, Huancayo	52	0	0	0	52	129306	280
2	Volcan, Cerro de Pasco	Pasco, Daniel Alcides Carrión, Ambo	349	12	0	9	370	119178	1659
3	Legacies only	Tayacaja, Huancayo	33	0	0	0	33	102052	343
4	Barrick Misquichilca, Huinac	Recuay, Huaraz, Carhuaz, Aija	293	1	0	4	298	88471	1059
5	Legacies only	Cusco	2	0	0	0	2	67499	81
6	Legacies only	Huánuco, Ambo	177	0	0	0	177	59886	760
7	Legacies only	Puno	1	0	0	0	1	40862	81
8	Santa Rosa, Pan American Silver, San Simón, Barrick Misquichilca	Otuzco, Sánchez Carrión, Santiago de Chuco	337	6	0	4	347	39972	1290
9	Huachirí, Millotingo, Fortuna, Volcan, Perubar, Casapalca, Corona, Centraminas, Natividad, Austria Duvaz, Huampar	Yauli, Huachirí	341	11	0	14	366	34887	1800
10	Ramiro López	Huancavelica	159	1	0	1	161	33547	495
11	Boulder Resources	Arequipa, General Sánchez Cerro	152	0	0	1	153	29947	634
12	Refinería de Zinc de Cajamarquilla	Lima	1	0	1	1	3	29116	83
13	Legacies only	Huamanga	1	0	0	0	1	26393	79
14	Doe Run Perú	Yauli	0	0	1	1	2	21709	81
15	Colquisiri	Huairal	4	1	0	1	6	21705	90
16	Nueva California	Yungay, Huaraz	13	1	0	1	15	20685	320
17	Corona, Colquirrumi, San Nicolás	Hualgayoc	969	2	0	3	974	19772	284
18	Legacies only	Huancayo	2	0	0	0	2	19243	81
19	Legacies only	Ilo	3	0	0	0	3	18755	102
20	Negociación Minera	Cañete	0	0	0	1	1	17861	79
21	Legacies only	Quispicanchi	1	0	0	0	1	17178	80
22	Legacies only	Canchis, Canas	21	0	0	0	21	17042	463
23	Pantac Robles José, Larrea Galarza Julio Ernesto, Complejo Minero Industrial	Nazca	17	0	0	3	20	14047	373
24	Mina Justa, Marcona, Justa	Nazca	0	3	0	0	3	12320	153
25	Trinidad, Sayapullo	Gran Chimú, Otuzco, Cajamarca	60	0	0	2	62	12086	350
26	Legacies only	Julcán	3	0	0	0	3	11105	134
27	Condestable	Cañete	0	2	0	2	4	10236	93
28	Los Quenuales, Las Cumbres, Halcón de Gorgor, Buenaventura, Atacocha	Cajatambo, Oyón, Daniel Alcides Carrión, Pasco	112	5	0	5	122	10061	1073
29	Sacraancha, Pachapaqui, CCY S Corporation, Santa Luisa, Huallanca	Bolognesi, Recuay	335	7	0	5	347	10007	1037

<sup>a</sup> A circle with a radius of 5 km, termed a "buffer", was drawn around each site with an active mining operation or a mining legacy associated with lead in soil. If there was an overlap between two or more sites, the circles were merged into a single buffer.

<sup>b</sup> Only a partial list of mining companies is given.

<sup>c</sup> Legacies of past mining operations.

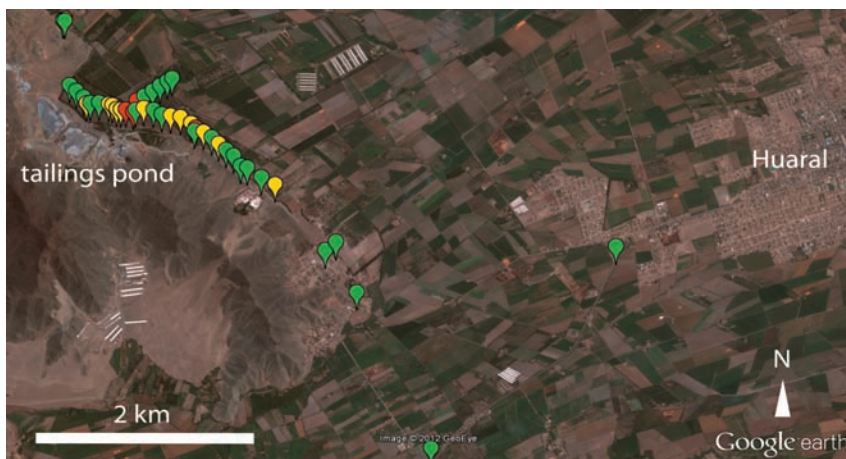
Fig. 2. Aerial image of the main open-pit mine and surrounding town of Cerro de Pasco, Peru, showing locations where the lead concentration in soil<sup>a</sup> was measured, 2009



The Ayapoto area mentioned in the main text is located immediately to the west of the open pit.

<sup>a</sup> The coloured markers indicate the concentration of lead in soil: green,  $\leq 400$  mg/kg; yellow,  $> 400$ –1200 mg/kg; red,  $> 1200$ –5000 mg/kg; blue,  $> 5000$ –10 000 mg/kg; black,  $> 10 000$  mg/kg.

Fig. 3. Aerial image of the mine and ore processing plant near Huaral, Peru, showing locations where the lead concentration in soil<sup>a</sup> was measured, 2009



<sup>a</sup> The coloured markers indicate the concentration of lead in soil: green,  $\leq 400$  mg/kg; yellow,  $> 400$ –1200 mg/kg; red,  $> 1200$ –5000 mg/kg.

local children and concentrations as high as  $62 \mu\text{g}/\text{dL}$  were measured. In contrast, blood lead levels exceeded  $10 \mu\text{g}/\text{dL}$  in only 9.4% of 194 women of child-bearing age from the same areas of the town.

The 2007 study also reported 32 soil lead measurements for Cerro de Pasco in the 150 to 20 000 mg/kg range, with the highest values again being consistently observed in Ayapoto.<sup>24</sup> The geographical association between the high blood lead content in children and the high soil lead content, and the absence of a similar association in women of child-bearing age, suggests that the primary pathway of lead exposure in children in Cerro de Pasco

is the ingestion of soil and soil dust. The association between childhood exposure and soil contamination observed in Cerro de Pasco is consistent with that seen in studies of the effect of lead mining, ore processing, and smelting carried out elsewhere, including other parts of Latin America.<sup>10,17,19,25–26</sup>

We are not aware of any studies of the blood lead level in the population living near the Colquisiri mine in our second selected location. However, given the relatively low soil lead levels we observed (Fig. 3), it seems reasonable to assume that the population residing in Huaral was much less exposed than that in Cerro de Pasco.

Although Peru phased out leaded gasoline in 2004, occasional exposure from leaded paint cannot be excluded.<sup>16</sup> In addition, exposure from the local manufacturing and recycling of batteries or the use of a lead glaze on tableware, both of which have been shown to be substantial in other developing countries, is also possible.<sup>27–29</sup>

Two long-term studies of lead in children's blood carried out in Australia and the United States, respectively, are particularly relevant to the situation in Cerro de Pasco. In the lead mining town of Broken Hill, Australia, the blood lead content of all school-aged children was greater than  $40 \mu\text{g}/\text{dL}$  in 1982.<sup>19</sup> Between 1991 and 2003, as a result of various interventions, the number of children with a concentration above  $10 \mu\text{g}/\text{dL}$  declined from 85 to 32%. Lead isotope analysis showed that soil and dust that was contaminated to a level of 1000 to 7000 mg/kg, either by natural erosion of the ore or mining, was a major source of lead in children's blood, although occasionally leaded gasoline and lead-based paint also made a substantial contribution.<sup>16</sup>

Around the lead mine and smelter at Bunker Hill, Idaho, United States, the mean blood lead level in children was  $70 \mu\text{g}/\text{dL}$  in the early 1970s. At the time the smelter was operating without any emission controls, the concentration in yard soil averaged 7000 mg/kg and the house dust lead concentration was 12 000 mg/kg.<sup>18</sup> Again as a result of a series of interventions, exposure declined dramatically: the proportion of children with a blood lead level greater than  $10 \mu\text{g}/\text{dL}$  decreased from 45% in 1988 to 3% in 2001. In addition, the observation that children were still exposed after the smelter was closed, via the ingestion of soil and house dust, prompted the removal and replacement of house yard soil with a lead concentration greater than 1000 mg/kg. The remarkable reduction in the level of lead in children's blood that was achieved in Bunker Hill sets an attainable target that can be applied to mitigation elsewhere, including areas as badly contaminated as Cerro de Pasco.

The levels of soil lead contamination around Cerro de Pasco and Huaral correspond to high- and low-risk scenarios for Peru, respectively, and therefore probably encompass the range of conditions in the other buffers. The effect of mining on the local population appears to be influenced primarily by its scale and duration. Mining started much earlier in

Cerro de Pasco than in Huaral<sup>14</sup> and led to the accumulation of a large amount of tailings on top of which the town was built. Moreover, the Cerro de Pasco buffer included 349 legacies compared with 4 in the Huaral buffer (Table 1). It is possible, then, that the number of legacies could provide a useful indication of the severity of lead contamination in locations where no soil measurements are available. Although 14 of the 29 largest buffers by population included active mining operations as well as at least one legacy, judging the severity of contamination on the basis of legacies alone could be misleading. For instance, the buffer that includes the infamous Doe Run smelter in Yauli Province, where extensive childhood lead exposure has been documented,<sup>7</sup> does not include a single legacy.

The soil lead survey in Cerro de Pasco shows that contamination is far from uniform even under a high-risk scenario. Heterogeneous distributions of lead contamination, over and above the reduction associated simply with the distance from a mine or smelter, have been reported elsewhere. Consequently, given the magnitude of the effort and resources required to mitigate contamination,<sup>5,9</sup> it is essential to identify those areas within a contaminated zone where soil replacement, or even relocation of the local population, is most needed.<sup>10</sup> Soil assessments could be used to inform local

government and families about the relative safety of various areas. These assessments, combined with information about the consequences of children ingesting lead-contaminated soil, could lead to a decrease in child exposure in the short term and enable the local community to participate in risk reduction.<sup>30</sup>

Unfortunately, currently there is no viable low-cost equipment that could reliably replace either X-ray fluorescence analysers or more laborious laboratory techniques.<sup>31</sup> Public investment in risk mapping is, therefore, urgently needed. With the exception of one recent example in Nigeria,<sup>11</sup> the use of costly large-scale soil removal or resettlement of communities to reduce mining-related lead exposure has been limited to high-income countries.<sup>18-19</sup>

In conclusion, our assessment that 1.6 million people in Peru could be exposed to lead in soil indicates that political will and resources are urgently needed to reduce the effect of exposure on the cognitive development of future generations. Our two case studies highlight the potential of local surveys of lead in soil to reduce exposure at a cost that is negligible relative to the revenues generated by mining, even in highly contaminated areas such as Cerro de Pasco. The key is to provide households and local government with appropriate information. In addition, systematic soil surveys could

help identify areas where public health education and interventions are most needed. These approaches could also be beneficial in other countries with a legacy of mining lead-rich deposits. The dramatic reduction in emissions achieved by the owners of the large smelter complex of Ilo in southern Peru in response to emissions monitoring<sup>32</sup> illustrates how interventions that rely on public data could be made more effective. ■

#### Acknowledgements

We thank government and industry representatives in Peru, Colin Cook, Sheila Xiah Kragie and Eduardo Ureta. Vladimir Gil is also a faculty member and researcher at the Graduate Environmental Development Program and the Department of Social Sciences at the Pontificia Universidad Católica del Perú, Lima, Peru, and is the general coordinator of the Consortium for the Study of the Economic Impact of Climate Change in Peru.

**Funding:** The study was funded by a grant from Cross-Cutting Initiatives, the Earth Institute at Columbia University (<http://www.earthinstitute.columbia.edu>). This is Lamont–Doherty Earth Observatory contribution number 7607.

**Competing interests:** None declared.

#### ملخص

التعرض للرصاص من التربة في مدن التعدين البيروفية: تقييم وطني مدعوم بمثاليين متباينين  
الغرض تقدير عدد سكان بيرو الذين يعيشون بالقرب من عمليات التعدين النشطة أو السابقة الذين يمكن أن يتعرضوا للرصاص من التربة الملوثة.  
الطريقة تم تجميع الإحداثيات الجغرافية بخصوص 113 منجماً نشطاً و138 وحدة صناعية لمعالجة الخامات و3 مصاهر و7743 موقع تعدين سابق. وتم حساب عدد السكان الذين يعيشون في نطاق 5 كيلومترات من هذه المواقع من بيانات التعداد لعام 2000. بالإضافة إلى ذلك، تم رسم خريطة لمحتوى التربة من الرصاص في مدينة التعدين التاريخية سيرو دي باسكو وحول منجم حديث ووحدة صناعية لمعالجة الخامات بالقرب من مدينة هوارال في عام 2009 باستخدام جهاز التحليل بالأشعة السينية الفلورية المحمول باليد.  
النتائج أشار التحليل المكاني إلى احتمال وجود 1.6 مليون شخص في بيرو يعيشون في نطاق 5 كيلومترات من عملية تعدين نشطة أو سابقة. وتم إحصاء ثلثي السكان الذين يُحتمل تعرضهم للرصاص

بواسطة 29 مجموعة من عمليات التعدين يزيد سكان كل منها عن 10000 شخص. وتضمنت هذه المجموعات 112 عملية تعدين نشطة و3438 عملية تعدين سابقة. وتجاوزت مستويات الرصاص في التربة 1200 ميليغرام/كيلوغرام، وهو المعيار المرجعي لتربة المناطق السكنية، في 35 موقعا من 74 موقعا تم اختبارها في سيرو دي باسكو وفي 4 مواقع فقط من 47 موقعا تم اختبارها حول العمليات الأحدث بالقرب من هوارال.  
الاستنتاج من المحتمل أن يتسع نطاق تلوث التربة بالرصاص في مدن التعدين في بيرو غير أن مستوى التلوث غير منتظم من الناحية المكانية. ويمكن خفض تعرض الأطفال الناتج عن ابتلاع التربة بشكل كبير من خلال رسم خريطة لمستويات الرصاص في التربة وتعميم هذه المعلومات وتشجيع المجتمعات المحلية على عزل الأطفال عن المناطق الملوثة.

## 摘要

### 秘鲁矿业城镇的土壤铅暴露：由两个对比性实例所支持的国内评估

**目的** 估算秘鲁居住在现役或者废弃的采矿作业点周围地区并可能会暴露于来自污染土壤的铅环境中的人口。

**方法** 整理出113个现役矿场、138个选矿厂和3个冶炼厂以及7743个废弃的采矿作业点地理坐标。使用2000年的人口普查数据计算在这些地点周围5公里内生活的人口。此外，在2009年利用手持式X射线荧光分析仪绘制了历史上的采矿城镇塞罗德帕斯科以及瓦拉市附近时间较近的矿区 and 选矿厂周围的土壤铅含量分布图。

**结果** 空间分析表明，秘鲁有160万人口可能居住在现役或废弃的采矿作业点5公里范围内。潜在暴露人口中有

三分之二来自29个采矿作业密集区，每个密集区的人口都超过万人。这些密集区包括112个现役和3438个废弃的采矿作业点。在塞罗德帕斯科检测的74个地点中有35个地点的土壤铅含量超过1200 mg/kg（居民区土壤的参考标准），而在瓦拉附近较新的作业点检测的47个地点中仅有4个地点超过该数值。

**结论** 土壤铅污染在秘鲁的矿业城镇可能非常广泛，但污染程度在空间上极不均衡。通过勘测土壤中的铅含量，将此信息公开，并鼓励当地社区将污染地区与儿童隔离开，可显著减少儿童的土壤摄入铅暴露。

## Résumé

### Exposition au plomb dans le sol des villes minières du Pérou: une évaluation nationale soutenue par deux exemples contrastés

**Objectif** Estimer la population péruvienne vivant à proximité d'une exploitation minière, ancienne ou active, qui pourrait être exposée au plomb de sols contaminés.

**Méthodes** Les coordonnées géographiques de 113 mines actives, 138 usines de traitement du minerai et 3 fonderies, ainsi que de 7 743 anciens sites miniers, ont été compilées. La population vivant à moins de 5 km de ces sites a été calculée à partir de données du recensement de l'an 2000. En outre, la teneur en plomb du sol dans la ville minière historique de Cerro de Pasco et autour d'une mine et d'une usine de traitement du minerai récentes, près de la ville de Hualar, a été cartographiée en 2009 à l'aide d'un appareil portatif de spectrométrie de fluorescence X.

**Résultats** L'analyse spatiale a indiqué que 1,6 million de personnes au Pérou pourraient vivre à 5 km d'une exploitation minière active ou ancienne. Les deux tiers de la population potentiellement exposée

représentaient 29 groupes d'exploitations minières, avec plus de 10 000 habitants chacun. Ces groupes incluaient 112 exploitations minières actives et 3 438 anciennes. Les niveaux de plomb du sol dépassaient 1 200 mg/kg, une norme de référence pour les sols résidentiels, dans 35 des 74 sites testés à Cerro de Pasco, mais dans seulement 4 des 47 sites testés dans les exploitations les plus récentes, près de Hualar.

**Conclusion** La contamination des sols par le plomb est probablement importante dans les villes minières du Pérou, mais le niveau de contamination est loin d'être uniforme dans l'espace. L'exposition des enfants par ingestion de sol pourrait être sensiblement réduite en cartographiant les niveaux de plomb des sols, en rendant cette information publique et en encourageant les communautés locales à tenir les enfants à distance des zones contaminées.

## Резюме

### Подверженность воздействию свинца, содержащегося в почве, в горнопромышленных городах Перу: национальная оценка, подтверждаемая двумя сравнительными примерами

**Цель** Оценить численность населения Перу, проживающего вблизи действующих или выведенных из эксплуатации горнодобывающих предприятий, вероятно подверженного воздействию свинца, содержащегося в загрязненной почве.

**Методы** Были собраны географические координаты 113 действующих горнодобывающих предприятий, 138 рудообогатительных фабрики и 3 металлургических предприятий, а также 7743 выведенных из эксплуатации рудников. Оценка населения, проживающего в 5-км зоне от указанных участков, проводилась на основе данных переписи населения 2000 г. Кроме того, в 2009 г. с помощью портативного рентгено-флуоресцентного анализатора проводилось картографирование содержания свинца в почве в историческом горнопромышленном городе Серро-де-Паско и вокруг современной обогатительной фабрики, расположенной вблизи г. Хуарал.

**Результаты** Пространственный анализ показал, что 1,6 млн. людей в Перу предположительно проживают в 5-км зоне от действующих или выведенных из эксплуатации горнодобывающих

предприятий. Потенциальная подверженность двух третей населения воздействию свинца объясняется нахождением на территории Перу 29 кластеров горнодобывающих предприятий, в зоне каждого из которых проживает свыше 10 000 человек. Данные кластеры включают 112 действующих и 3 438 выведенных из эксплуатации горнодобывающих предприятий. Уровни содержания свинца в почве превышали 1200 мг/кг (ПДК для жилых районов) на 35 из 74 участков, исследованных в Серро-де-Паско, и только на 4 из 47 участков, исследованных вокруг новых предприятий, расположенных рядом с г. Хуарал.

**Вывод** Загрязнение почвы свинцом в горнопромышленных городах Перу, вероятно, является значительным, однако уровень загрязнения распределен территориально неравномерно. Подверженность детей воздействию свинца в результате попадания почвы внутрь организма могла быть существенно сокращена путем картографирования уровней загрязнения почвы свинцом, обнародования подобных данных и поощрения местных общин к недопущению детей в загрязненные области.

## Resumen

### La exposición al plomo en el suelo en los pueblos mineros peruanos: una evaluación nacional respaldada por la comparación entre dos ejemplos

**Objetivo** Calcular qué parte de la población peruana residente en las inmediaciones de explotaciones mineras activas o cerradas podría estar expuesta a suelos contaminados con plomo.

**Métodos** Se recopilaron las coordenadas geográficas de 113 minas activas, 138 plantas procesadoras de minerales y 3 fundiciones, así como de 7743 ubicaciones mineras cerradas. Se calculó la población residente en un radio de 5 km de dichos lugares a partir de los datos del censo del año 2000 y, además, en el año 2009 se trazó, por medio de un analizador de fluorescencia de rayos X de mano, un mapa del contenido de plomo del suelo en el histórico pueblo minero de Cerro de Pasco, así como de una mina nueva y una planta procesadora de metales cerca de la ciudad de Huaral.

**Resultados** Los análisis espaciales indicaron que 1,6 millones de personas en Perú podrían estar viviendo en un radio de 5 km de una explotación minera activa o cerrada. Dos tercios de la población

expuestos en potencia se correspondieron a 29 grupos de explotaciones mineras con una población superior a 10 000 habitantes. Dichos grupos incluyeron 112 explotaciones mineras activas y 3438 cerradas. En 35 de las 74 ubicaciones sometidas a prueba en Cerro de Pasco, los niveles de plomo en el suelo excedieron los 1200 mg/kg, el estándar de referencia para los suelos residenciales. Sin embargo, sólo 4 de las 47 ubicaciones sometidas a prueba alrededor de las explotaciones más nuevas cerca de Huaral superaron dicho estándar.

**Conclusión** Es probable que la contaminación del suelo por plomo esté muy extendida en los pueblos mineros peruanos, sin embargo, el nivel de contaminación de las ubicaciones dista de ser uniforme. Se podría reducir la exposición infantil por ingesta de tierra trazando un mapa de los niveles de plomo en el suelo, publicando esa información y animando a las comunidades locales a aislar las áreas contaminadas de los niños.

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