Research Letter

A Section 508–conformant HTML version of this article
is available at https://doi.org/10.1289/EHP11932.

Levels of Arsenic, Cadmium, and Mercury in Urine of Indigenous People Living Close to Oil Extraction Areas in the Peruvian Amazon

Cristina O'Callaghan-Gordo,[1,2,3,4] Jaime Rosales,[5] Pilar Lizárraga,[5] Frederica Barclay,[6] Tami Okamoto,[7] Diana M. Papoulias,[8] Ana Espinosa,[2,3,4,9] Martí Orta-Martinez,[10] Manolis Kogevinas,[2,3,4,9] and John Astete[5]

[1]Faculty of Health Sciences, Universitat Oberta de Catalunya, Barcelona, Spain
[2]ISGlobal, Barcelona, Spain
[3]Universitat Pompeu Fabra, Barcelona, Spain
[4]CIBER Epidemiología y Salud Pública, Spain
[5]Centro Nacional de Salud Ocupacional y Protección del Ambiente para la Salud, Instituto Nacional de Salud, Lima, Peru
[6]Centro de Políticas Públicas y Derechos Humanos–Perú Equidad, Lima, Peru
[7]Department of Geography, University of Cambridge, Cambridge, UK
[8]E-Tech International, El Sobrante, California, USA
[9]Hospital del Mar Medical Research Institute, Barcelona, Spain
[10]Department of Evolutionary Biology, Ecology and Environmental Sciences, Faculty of Biology, University of Barcelona, Barcelona, Spain

https://doi.org/10.1289/EHP11932

Introduction

Oil extraction can lead to long-term harm to the environment and human communities.[1] In the 1970's, oil extraction started in the northern Peruvian Amazon, in the Corrientes, Pastaza, and Tigre river basins, all major tributaries of the Marañón River, leading to high levels of environmental contamination in these four river basins. The oil concessions of this area, which are currently among of the most contaminated areas of the country [see reports on oil Blocks 8 and 192 (formerly 1AB)], overlap with the territories of the Achuar, Quechua, Kichwa, and Kukama Peoples. These Indigenous groups belong to the Jivaro, Quechua, and Tupi linguistic families, respectively. They live in the northern Amazon, on the border between Peru and Ecuador. According to the 2017 Peruvian National Census (indigenous communities module), it is estimated that ~7,944 Achuar, 11,347 Quechua, 4,742 Kichwa, and 9,532 Kukama Peoples live in these four river basins.[2] These groups were mostly nomadic-hunter gatherers until the 1960s when they settled in small communities. Nowadays, they continue to rely on subsistence agriculture and on hunting and fishing for their daily protein intake. Since the arrival of the oil companies to the area, the inhabitants of the area have shown concerns about the potential health effects of the environmental contamination caused in the area. High blood lead levels (>5 μg/dL in 49% of children and in 60% of adults) were reported among the population of these river basins,[3] but there is no information on other metals. The primary aim of this study was to estimate concentrations of metals in urine of Indigenous People residing in four major river basins in oil concessions areas in Peru. Associations were then explored between previously reported urinary metal concentrations and sociodemographic, environmental, occupational, and lifestyle factors.

Methods

We conducted a cross-sectional study and assessed urinary concentrations of total arsenic (U-As), cadmium (U-Cd) and total mercury (U-Hg) in the populations of the Corrientes, Pastaza, Tigre, and Marañón River basins (Figure 1) in collaboration with indigenous federations from the northern Peruvian Amazon (ACODECOSPAT, FECONACOR, OPIKAFPE, FEDIQUEP, PUINAMUDT) in May–June 2016. The study design was described in detail elsewhere.[3] Briefly, we followed a two-stage stratified random strategy to select study participants. Thirty-nine communities were selected and between 14% and 15% of families were randomly selected in each community. Participation was offered to all members of the selected families, excluding infants under 6 months of age. The study protocol was reviewed and accepted by the Ethics and Research Committee of the National Institute of Health (NIH), Peru. Written informed consent was given from traditional leaders to conduct the study in each of the communities. Participants ≥18 years of age provided written informed consent, and participants between ≥7 and <18 years of age provided personal verbal consent and their parents provided informed written consent. For participants <7 years of age parents provided informed written consent.

Face-to-face questionnaires were administered to the heads of households to collect information on dwelling and to all family members to collect information on individual risk factors. Urine samples were collected, preserved, and analyzed by atomic absorption spectrophotometry following protocols validated by the Peruvian NIH.[4] The limits of detection (LODs) were 2.5 μg/L for U-As and U-Hg and 0.5 μg/L for U-Cd. We replaced metal values below the LOD by the LOD divided by 2. Thirty-two percent (266), 31% (259), and 50% (408) of measurements were below the LOD for U-As, U-Hg, and U-Cd, respectively.

We used linear regression models of log-transformed variables, taking into account the multilevel study design.[3] Results were back-transformed and presented as geometric mean ratios with 95% confidence intervals [GMR (95% CI)], stratified by age using a threshold of 12 years of age. Associations were tested using the Wald test, and variables associated in individual models ($p < 0.1$) were considered in multiple regression models. If multicollinearity was observed (variable inflation factors >5), we dropped one of the correlated variables from the model. All analyses were made using Stata (version 14; StataCorp). The map in Figure 1 was elaborated using ArcGIS Pro (version 2.5.0; ESRI) and open-access spatial data on oil concessions and infrastructure, indigenous communities, and natural protected areas.

Results and Discussion

Creatinine-corrected concentrations of metals were available for 824 participants, of which 230 were children (<12 years of age) and 594 were adults (≥12 years of age). Characteristics are presented in Table 1. Average concentrations of U-Hg were 4.1 μg/g for children and 4.4 μg/g for adults. Corresponding concentrations for U-As were 27.7 μg/g and 15 μg/g, and for U-Cd 0.8 μg/g and 1.1 μg/g. Twenty-five percent ($n = 57$) of

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Address correspondence to Cristina O'Callaghan-Gordo. Email: cristina.ocallaghan@isglobal.org

The authors declare no conflicting interests.

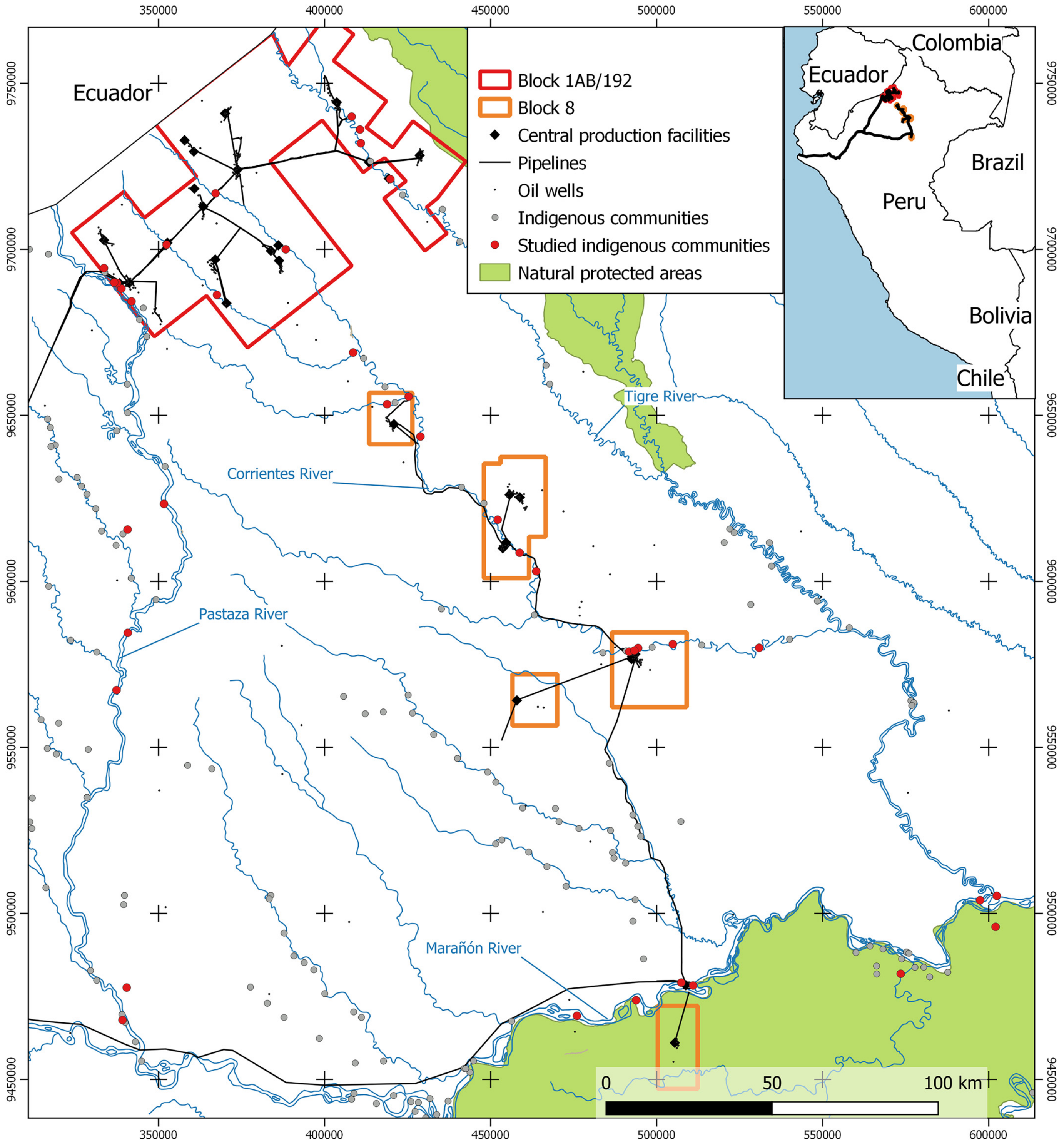

Figure 1. Map of the study area. Block 1AB/192 and Block 8 refer to the two oil concessions areas that overlap with the territories of the Achuar, Quechua, Kichwa, and Kukama Peoples in the Corrientes, Pastaza, and Tigre river basins of the northern Peruvian Amazon. Central processing facilities include production facilities where oil, gas, and produced water are collected from the oilfield and separated, as well as storage tanks, flare systems, utilities, and support buildings. The figure was elaborated using ArcGIS Pro (version 2.5.0; ESRI) and open-access spatial data on oil concessions and infrastructure, indigenous communities, and natural protected areas.

children and 28% (164) of adults had U-Hg levels above reference values (RVs) established by the Peruvian Ministry of Health (MINSA) (5 μg/g). For U-As, the corresponding percentages (RV = 20 μg/g) above the RV were 48% (110) for children and 23% (135) for adults, and for U-Cd (RV = 2 μg/g), 2% (6) and 13% (76), respectively.

U-Hg concentration (Table 1) increased with age among adults and were higher in the Kukama, mestizo (i.e., peoples that do not identify as belonging to an indigenous group themselves, often mixed-blood people) and other peoples, and among those living around the Marañón basin. Elevated U-Hg was also associated with increased fish consumption, which was higher in the

Table 1. Urine creatinine-corrected concentrations (μg/g) of total arsenic (As), cadmium (Cd), and total mercury (Hg) and associations with sociodemographic, lifestyle, environmental, and occupational exposures by age group among Indigenous People living close to oil extraction areas in the Peruvian Amazon, May–June 2016 (230 participants <12 y old; 594 participants ≥12 y old).

	Study population		As						Cd						Hg					
	<12 y	≥12 y	<12 y			≥12 y			<12 y			≥12 y			<12 y			≥12 y		
Category	*N* (%) or mean ± SD	*N* (%) or mean ± SD	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value
Age (y)[a]	7.3 ± 2.7	36.3 ± 16.3	—	0.93 (0.89, 0.98)	0.008	—	0.99 (0.99, 1.00)	0.008	—	0.99 (0.96, 1.03)	0.608	—	1.02 (1.01, 1.02)	<0.001	—	0.98 (0.94, 1.02)	0.304	—	1.01 (1.00, 1.01)	0.001
Sex[b]																				
Female	119 (51.7)	331 (55.7)	15.1 (12.6, 0.98)	Ref	—	10.9 (9.9, 12.0)	Ref	—	0.6 (0.5, 0.7)	Ref	—	0.9 (0.8, 1.0)	Ref	—	3.2 (2.8, 3.7)	Ref	—	3.1 (2.9, 3.4)	Ref	—
Male	111 (48.3)	263 (44.3)	20.8 (17.6, 24.7)	1.35 (1.08, 1.70)	0.013	10.0 (9.1, 11.0)	0.99 (0.88, 1.11)	0.855	0.6 (0.5, 0.7)	0.97 (0.81, 1.17)	0.769	0.8 (0.7, 0.8)	0.85 (0.75, 0.95)	0.009	2.8 (2.4, 3.2)	0.91 (0.74, 1.11)	0.350	2.9 (2.6, 3.2)	0.86 (0.76, 0.99)	0.037
Ethnic origin																				
Achuar	91 (39.6)	195 (32.8)	17.7 (14.5, 21.7)	Ref	—	9.3 (8.3, 10.3)	Ref	—	0.8 (0.7, 0.9)	Ref	—	0.8 (0.8, 0.9)	Ref	—	2.5 (2.2, 2.8)	Ref	—	2.2 (2.0, 2.4)	Ref	—
Quechua and Kichwa	79 (34.3)	231 (38.9)	20.1 (16.1, 25.2)	1.19 (0.83, 1.72)	—	9.9 (8.8, 11.1)	1.14 (0.95, 1.38)	—	0.6 (0.5, 0.6)	0.77 (0.62, 0.96)	—	0.8 (0.7, 0.9)	0.93 (0.80, 1.09)	—	3.6 (3.0, 4.4)	1.48 (1.17, 1.89)	—	3.3 (3.0, 3.7)	1.54 (1.30, 1.81)	—
Mestizo, Kukama, and other peoples	60 (26.1)	168 (28.3)	14.6 (11.8, 18.1)	0.88 (0.60, 1.30)	0.251	13.2 (11.6, 15.0)	1.48 (1.22, 1.78)	<0.001	0.5 (0.4, 0.6)	0.62 (0.50, 0.79)	0.001	0.9 (0.8, 1.0)	0.91 (0.77, 1.07)[b]	<0.001	3.1 (2.6, 3.7)	1.37 (1.07, 1.75)	0.006	3.9 (3.4, 4.5)	1.76 (1.44, 2.16)	<0.001
River basin																				
Marañón	55 (23.9)	145 (24.4)	14.3 (11.4, 17.9)	Ref	—	12.7 (11.0, 14.6)	Ref	—	0.5 (0.4, 0.6)	Ref	—	0.9 (0.8, 1.0)	Ref	—	3.2 (2.6, 4.0)	Ref	—	4.2 (3.6, 4.9)	Ref	—
Pastaza	68 (29.6)	198 (33.3)	24.2 (18.7, 31.4)	1.88 (1.24, 2.85)	—	10.2 (9.0, 11.6)	0.83 (0.68, 1.02)	—	0.5 (0.4, 0.6)	1.19 (0.95, 1.51)	—	0.6 (0.6, 0.7)	0.86 (0.74, 1.01)	—	3.5 (2.9, 4.2)	1.03 (0.76, 1.39)	—	3.0 (2.7, 3.3)	0.72 (0.58, 0.91)	—
Tigre	15 (6.5)	51 (8.6)	13.0 (8.6, 19.7)	0.87 (0.56, 1.33)	—	8.5 (6.6, 11.0)	0.68 (0.50, 0.94)	—	0.7 (0.6, 0.9)	1.55 (1.15, 2.09)	—	1.5 (1.2, 1.8)	1.91 (1.52, 2.39)	—	4.0 (2.3, 7.0)	1.18 (0.74, 1.88)	—	3.9 (3.1, 5.0)	0.99 (0.66, 1.49)	—
Corrientes	92 (40.0)	200 (33.7)	16.6 (13.8, 19.9)	1.11 (0.79, 1.56)	0.012	10.0 (9.0, 11.0)	0.78 (0.64, 0.94)	0.056	0.7 (0.6, 0.8)	1.60 (1.26, 2.03)	0.003	0.9 (0.8, 1.0)	1.22 (1.03, 1.45)[b]	<0.001	2.5 (2.1, 2.8)	0.72 (0.55, 0.95)	0.018	2.2 (2.0, 2.4)	0.54 (0.43, 0.68)	<0.001
Total fish consumption (×100 g)[c]	1.3 ± 1.3	1.6 ± 1.5	—	1.00 (0.99, 1.02)	0.426	—	1.00 (0.99, 1.01)	0.954		1.00 (0.98, 1.01)	0.404	—	1.00 (1.00, 1.01)	0.594	—	0.99 (0.98, 1.00)	0.108		1.01 (1.00, 1.01)	0.038
Fish offal consumption																				
No	82 (35.7)	150 (25.3)	21.1 (17.2, 26.0)	Ref	—	11.9 (10.4, 13.6)	Ref	—	0.6 (0.6, 0.7)	Ref	—	0.8 (0.7, 0.9)	Ref	—	2.8 (2.4, 3.3)	Ref	—	3.0 (2.6, 3.4)	Ref	—
Yes	148 (64.3)	444 (74.7)	15.9 (13.7, 18.6)	0.80 (0.60, 1.08)	0.150	10.1 (9.3, 10.9)	0.85 (0.71, 1.01)	0.072	0.6 (0.5, 0.6)	0.92 (0.76, 1.11)	0.381	0.9 (0.8, 0.9)	1.03 (0.90, 1.18)	0.685	3.1 (2.7, 3.5)	1.06 (0.86, 1.32)	0.578	3.0 (2.8, 3.3)	0.94 (0.79, 1.13)	0.524
Alcohol consumption (only ≥12 y old)																				
No	—	495 (83.3)	—	—	—	10.8 (10.1, 11.7)	Ref	—	—	—	—	0.8 (0.8, 0.9)	Ref	—	—	—	—	3.0 (2.8, 3.3)	Ref	—
Yes	—	99 (16.7)	—	—	—	9.1 (7.8, 10.5)	0.86 (0.70, 1.06)	0.161	—	—	—	0.9 (0.8, 1.0)	1.17 (0.99, 1.38)	0.070	—	—	—	3.0 (2.5, 3.6)	1.07 (0.86, 1.34)	0.550
Smoking (only ≥12 y old)																				
No	—	531 (89.4)	—	—	—	10.7 (9.9, 11.5)	1.00 (1.00, 1.00)	—	—	—	—	0.8 (0.8, 0.9)	1.00 (1.00, 1.00)	—	—	—	—	3.0 (2.8, 3.2)	1.00 (1.00, 1.00)	—
Yes	—	63 (10.6)	—	—	—	9.2 (7.6, 11.1)	0.88 (0.73, 1.07)	0.219	—	—	—	1.0 (0.8, 1.2)	1.28 (0.98, 1.65)	0.073	—	—	—	3.0 (2.3, 3.9)	1.03 (0.78, 1.36)	0.840
Burning of household waste																				
No	128 (55.7)	330 (55.6)	15.9 (13.6, 18.7)	Ref	—	10.8 (9.8, 11.8)	Ref	—	0.6 (0.5, 0.7)	Ref	—	0.9 (0.8, 0.9)	Ref	—	2.9 (2.6, 3.3)	Ref	—	3.0 (2.8, 3.3)	Ref	—
Yes	102 (44.3)	264 (44.4)	20.0 (16.5, 24.2)	1.26 (0.92, 1.74)	0.162	10.2 (9.2, 11.3)	1.00 (0.85, 1.18)	0.991	0.6 (0.5, 0.7)	1.02 (0.85, 1.23)	0.826	0.8 (0.7, 0.9)	0.87 (0.76, 1.00)[b]	0.054	3.1 (2.7, 3.6)	1.07 (0.85, 1.35)	0.560	3.0 (2.7, 3.4)	0.99 (0.83, 1.18)	0.934
Main source of water for consumption																				
Public water source	116 (50.4)	265 (44.6)	15.4 (12.9, 18.4)	Ref	—	9.6 (8.7, 10.6)	Ref	—	0.6 (0.5, 0.7)	Ref	—	0.8 (0.7, 0.9)	Ref	—	3.2 (2.8, 3.7)	Ref	—	3.1 (2.8, 3.4)	Ref	—
Well or spring water	56 (24.3)	170 (28.6)	27.6 (21.8, 34.8)	1.69 (1.16, 2.46)	—	11.1 (9.9, 12.6)	1.13 (0.94, 1.37)	—	0.6 (0.5, 0.8)	1.12 (0.89, 1.42)	—	0.8 (0.7, 0.9)	1.04 (0.90, 1.20)	—	2.4 (2.0, 2.9)	0.76 (0.59, 0.99)	—	2.4 (2.1, 2.6)	0.78 (0.65, 0.94)	—
Rain	22 (9.6)	68 (11.4)	15.4 (10.7, 22.3)	0.99 (0.64, 1.53)	—	12.3 (9.8, 15.4)	1.29 (0.98, 1.70)	—	0.6 (0.4, 0.7)	1.00 (0.75, 1.33)	—	1.2 (1.0, 1.4)	1.49 (1.21, 1.82)	—	3.0 (2.1, 4.4)	0.97 (0.65, 1.45)	—	4.5 (3.6, 5.6)	1.41 (1.07, 1.86)	—

Table 1. (*Continued.*)

	Study population		As						Cd						Hg					
	<12 y	≥12 y	<12 y			≥12 y			<12 y			≥12 y			<12 y			≥12 y		
Category	*N* (%) or mean ± SD	*N* (%) or mean ± SD	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value
Surface water (river, ravine, lagoon)	36 (15.7)	91 (15.3)	14.6 (10.9, 19.7)	0.81 (0.53, 1.24)	0.011	11.0 (9.2, 13.1)	1.10 (0.90, 1.34)	0.313	0.7 (0.6, 0.8)	1.19 (0.91, 1.55)	0.568	0.8 (0.7, 1.0)	1.15 (0.93, 1.41)	0.006	3.2 (2.6, 4.1)	0.98 (0.71, 1.35)	0.262	3.2 (2.7, 3.9)	1.10 (0.84, 1.43)	0.001
Main bathing place																				
Well	38 (16.5)	118 (19.9)	25.9 (18.6, 36.1)	Ref	—	10.4 (9.0, 12.0)	Ref	—	0.6 (0.4, 0.7)	Ref	—	0.8 (0.7, 0.9)	Ref	—	2.8 (2.2, 3.5)	Ref	—	2.6 (2.2, 2.9)	Ref	—
Surface water (river, ravine, lagoon)	156 (67.8)	399 (67.2)	16.5 (14.2, 19.1)	0.68 (0.47, 0.98)	—	10.5 (9.7, 11.4)	1.03 (0.85, 1.24)	—	0.6 (0.5, 0.7)	1.04 (0.79, 1.35)	—	0.8 (0.8, 0.9)	1.07 (0.91, 1.26)	—	3.2 (2.9, 3.6)	1.09 (0.85, 1.41)	—	3.4 (3.1, 3.7)	1.32 (1.10, 1.58)	—
Others	36 (15.7)	77 (13.0)	15.7 (11.9, 20.6)	0.82 (0.66, 1.02)	0.071	10.6 (8.8, 12.8)	0.98 (0.77, 1.26)	0.906	0.6 (0.5, 0.8)	0.82 (0.66, 1.02)	0.745	0.8 (0.7, 0.9)	0.94 (0.77, 1.16)	0.326	2.3 (1.7, 3.1)	0.82 (0.66, 1.02)	0.175	2.1 (1.7, 2.5)	0.80 (0.60, 1.08)	0.001
Residence at <1 h walking																				
None of these places	75 (32.6)	160 (26.9)	16.8 (13.6, 20.7)	Ref	—	10.1 (8.9, 11.6)	Ref	—	0.6 (0.5, 0.7)	Ref	—	0.8 (0.7, 0.9)	Ref	—	3.1 (2.7, 3.6)	Ref	—	3.3 (2.9, 3.8)	Ref	—
Active oil infrastructures	30 (13.0)	117 (19.7)	24.2 (16.4, 35.7)	1.38 (0.84, 2.25)	—	11.7 (10.0, 13.6)	1.16 (0.91, 1.48)	—	0.5 (0.4, 0.7)	0.84 (0.63, 1.12)	—	0.8 (0.7, 0.9)	1.10 (0.91, 1.33)	—	2.3 (1.8, 2.9)	0.70 (0.51, 0.95)	—	2.8 (2.5, 3.3)	0.96 (0.75, 1.22)	—
Oil spill, environmental remediation spot	107 (46.5)	288 (48.5)	17.1 (14.3, 20.4)	0.97 (0.66, 1.44)	—	10.5 (9.5, 11.6)	1.05 (0.86, 1.30)	—	0.6 (0.5, 0.7)	1.02 (0.80, 1.29)	—	0.9 (0.8, 1.0)	1.25 (1.05, 1.49)	—	3.4 (2.9, 4.0)	1.07 (0.84, 1.38)	—	3.0 (2.7, 3.3)	0.96 (0.77, 1.19)	—
Old infrastructures (not in use)	18 (7.8)	29 (4.9)	15.4 (9.7, 24.6)	0.85 (0.50, 1.44)	0.380	8.7 (6.8, 11.2)	0.89 (0.62, 1.29)	0.481	0.7 (0.5, 0.9)	1.08 (0.77, 1.50)	0.423	0.8 (0.6, 1.0)	1.02 (0.80, 1.31)	0.093	2.0 (1.4, 2.7)	0.60 (0.43, 0.84)[b]	0.004	2.8 (2.1, 3.7)	0.88 (0.58, 1.33)	0.942
Vegetable garden at <1 h walking																				
None of these places	102 (44.3)	261 (43.9)	16.6 (13.7, 20.1)	Ref	—	10.8 (9.8, 12.0)	Ref	—	0.6 (0.5, 0.7)	Ref	—	0.8 (0.7, 0.9)	Ref	—	3.0 (2.6, 3.4)	Ref	—	3.3 (3.0, 3.7)	Ref	—
Active oil infrastructures	31 (13.5)	87 (14.6)	19.8 (13.3, 29.6)	1.05 (0.64, 1.74)	—	11.1 (9.4, 13.0)	0.99 (0.79, 1.25)	—	0.6 (0.5, 0.8)	1.04 (0.77, 1.41)	—	0.8 (0.7, 0.9)	0.96 (0.79, 1.15)	—	2.1 (1.7, 2.6)	0.69 (0.52, 0.93)	—	2.6 (2.2, 2.9)	0.79 (0.64, 0.98)	—
Oil spill, environmental remediation spot	93 (40.4)	232 (39.1)	18.2 (15.2, 21.8)	1.09 (0.76, 1.55)	—	10.2 (9.1, 11.4)	0.90 (0.75, 1.08)	—	0.6 (0.5, 0.7)	1.02 (0.83, 1.26)	—	0.9 (0.8, 1.0)	1.20 (1.03, 1.39)	—	3.5 (2.9, 4.2)	1.14 (0.89, 1.46)	—	2.9 (2.6, 3.3)	0.88 (0.72, 1.08)	—
Old infrastructures (not in use)	4 (1.7)	14 (2.4)	14.4 (3.2, 64.5)	0.98 (0.45, 2.12)	0.973	7.8 (5.8, 10.6)	0.73 (0.55, 0.96)	0.174	0.6 (0.2, 2.0)	1.08 (0.47, 2.48)	0.991	0.5 (0.4, 0.7)	0.75 (0.54, 1.04)[b]	0.031	1.9 (0.8, 4.7)	0.61 (0.41, 0.90)	0.005	2.6 (1.9, 3.6)	0.85 (0.55, 1.32)	0.246
Use of crude oil to keep insects away from the house																				
No	138 (60.0)	368 (62.0)	16.3 (13.8, 19.4)	Ref	—	9.9 (9.1, 10.8)	Ref	—	0.6 (0.5, 0.7)	Ref	—	0.8 (0.8, 0.9)	Ref	—	3.3 (2.9, 3.7)	Ref		3.2 (2.9, 3.5)	Ref	—
Yes	92 (40.0)	226 (38.0)	19.7 (16.6, 23.4)	1.14 (0.85, 1.53)	0.399	11.5 (10.3, 12.9)	1.12 (0.95, 1.32)	0.202	0.6 (0.5, 0.7)	1.00 (0.83, 1.22)	0.969	0.8 (0.7, 0.9)	0.96 (0.84, 1.10)	0.569	2.6 (2.3, 3.1)	0.83 (0.66, 1.05)	0.124	2.8 (2.5, 3.1)	0.91 (0.75, 1.09)	0.305
Contact with crude oil in the last 6 months (only ≥12 y old)																				
No	—	513 (86.4)	—	—	—	10.6 (9.9, 11.5)	Ref	—	—	—	—	0.8 (0.8, 0.9)	Ref	—	—	—	—	3.1 (2.8, 3.3)	Ref	—
Yes	—	81 (13.6)	—	—	—	9.8 (8.3, 11.5)	0.89 (0.72, 1.10)	0.301	—	—	—	0.8 (0.7, 0.9)	1.02 (0.85, 1.23)	0.848	—	—	—	2.8 (2.3, 3.4)	0.95 (0.75, 1.20)	0.645
Participation in environmental remediation activities in the last 6 months (only ≥12 y old)[d]																				
No	—	449 (75.6)	—	—	—	10.7 (9.9, 11.5)	Ref	—	—	—	—	0.8 (0.8, 0.9)	Ref	—	—	—	—	3.1 (2.9, 3.4)	Ref	—

Table 1. (*Continued.*)

Category	Study population		As						Cd						Hg					
	<12 y	≥12 y	<12 y			≥12 y			<12 y			≥12 y			<12 y			≥12 y		
	N (%) or mean ± SD	*N* (%) or mean ± SD	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value	GM (95% CI)	GMR (95% CI)	*p*-Value
Yes	—	145 (24.4)	—	—	—	10.0 (8.8, 11.4)	0.95 (0.80, 1.12)	0.532	—	—	—	0.9 (0.8, 1.0)	1.11 (0.95, 1.29)	0.185	—	—	—	2.7 (2.4, 3.1)	0.92 (0.75, 1.12)	0.388
Euclidean distance to closest oil processing facility (×10 km)	2.5 ± 3.9	2.2 ± 3.5	—	0.96 (0.92, 1.00)	0.067	—	1.00 (0.98, 1.03)	0.747	—	0.97 (0.95, 0.99)	0.006	—	0.99 (0.97, 1.01)	0.185	—	1.05 (1.02, 1.08)	0.002	—	1.06 (1.04, 1.09)	<0.001
Minimum upstream fluvial distance processing facility (×10 km)[e]	14.9 ± 19.2	15.8 ± 20.3	—	0.99 (0.98, 1.00)	0.053	—	1.00 (1.00, 1.01)	0.218	—	0.99 (0.99, 1.00)	0.00	—	1.00 (0.99, 1.00)	0.034	—	1.00 (1.00, 1.01)	0.108	—	1.01 (1.00, 1.02)	<0.001

Note: Individual linear regression models adjusted for age and sex, unless otherwise noted. *p*-Values based on Wald test <0.05. Limit of detection was 2.5 μg/L for U-As and U-Hg and 0.5 μg/L for U-Cd. —, Not applicable; CI, confidence interval; GM, geometric mean; GMR, geometric mean ratio; Ref, reference.

[a] Individual model adjusted for sex.

[b] Individual model adjusted for age.

[c] Restricted to total fish consumption ≤7 kg/wk (166 participants <12 y old; 433 participants ≥12 y old).

[d] Environmental remediation activities include handling of solid waste, cleaning of environmental liabilities or contaminated sites, and reforestation of contaminated areas.

[e] Only among those living downstream from central production facilities (161 participants <12 y old; 410 participants ≥12 y old).

Marañón (1,842 g/wk) than in other river basins. Elevated mercury in Amazonian fish has been associated with oil contamination,[5] and there is evidence that consumption of freshwater fish is associated with U-Hg concentrations.[6] However, previous studies from the same region, suggest that the main route of exposure to mercury in the area is through dermal uptake of mercury present in the water.[7] This is consistent with our results given that concentrations of U-Hg were 1.09 and 1.32 times higher among children and adults bathing in river water compared with those bathing in wells, and 1.42 times higher among adults consuming rain water compared with those drinking from a public water source.

U-As concentrations (Table 1) decreased slightly with age in adults, tended to be higher among children who drank well water and, similar to U-Hg, were highest among Kukama, mestizo and other peoples, and among those living around Marañón. Elevated arsenic of geologic origin has been reported in the aquifers of the western Amazon[8] and at relatively high concentrations in crude oil[9]; however, the source of arsenic in the study area remains unknown.

U-Cd concentrations (Table 1) increased with age in adults and were higher in females. The highest concentrations were observed for the Achuar People and among those living around the Corrientes and Tigre river basins. Historically, these two basins have had relatively greater oil extraction activity and higher volumes of produced water released than the Pastaza and Marañón basins (discussed by O'Callaghan-Gordo et al.[3]) Additional factors associated with elevated U-Cd included proximity of residences or vegetable gardens to oil spill sites and participation in oil spill remediation activities. Consumption of contaminated vegetables is a known route of exposure to cadmium, and high levels of cadmium in vegetables are associated with environmental conditions.[10]

Multivariable analyses did not indicate substantially different patterns from the univariable analyses (supporting information). Concentrations without creatinine correction were available for another 211 study participants. Models including noncorrected concentration of metals ($n = 1{,}035$) yielded similar results (supporting information).

A considerable proportion of the population of children and adults exceeded the recommended RV levels. Concentrations of the three metals were associated with the sources of water for consumption and U-Hg was also associated with the sources of water for bathing. Remarkably, mercury can be absorbed through dermal uptake.[7] Participation in oil activities was associated with U-Cd, and the higher levels were observed in Corrientes and Tigre river basins, which are considered the two most polluted river basins.

The strengths of this research are the large sample size, the random sampling of families from different river basins with varying characteristics, and the active participation of the indigenous organizations in this research. Without the cooperation of the indigenous organizations it would not have been possible to conduct such a study in a remote area of the Amazon.

The observed pattern of high concentrations for all metals supports anthropogenic sources of contamination, including oil extraction activities. The identification of high concentrations of metals in a population living in a nonindustrial setting is concerning regarding health effects, such as childhood neurodevelopment and chronic diseases, through long-term exposure. Prevention of these exposures and provision of clean water and ensuring food security are a high priority for the indigenous populations living in these river basins.

Acknowledgments

This study was funded by National Institute of Health of Peru. We acknowledge support from the Spanish Ministry of Science and Innovation through the Centro de Excelencia Severo Ochoa 2019–2023 Program (CEX2018-000806-S). Supporting information can be found at the website of the

project: https://www.isglobal.org/-/levels-of-and-risk-factors-for-exposure-to-heavy-metals-and-hydrocarbons-in-the-inhabitants-of-the-communities-of-the-pastaza-tigre-corrientes-and-mar.

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