Oil extraction in the Amazon basin and exposure to metals in indigenous populations

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Abstract

Most oil extraction areas in the Peruvian Amazon are within indigenous territories. Poor environmental practices have exposed the indigenous population to metals. We conducted a survey in two indigenous Kukama communities to assess body burdens of metals after the occurrence of two major oil spills in 2014. Urine levels above those recommended by the Peruvian Ministry of Health were observed in 50% and 17% of the study population for mercury and cadmium, respectively.

Keywords

Indigenous health; oil extraction; metals; mercury; cadmium; Peru

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Background

The Western Amazon contains large reserves of oil and gas (Finer et al., 2008). In the northern Peruvian Amazon, oil concessions known as Blocks 1AB and 8 were drawn at the late 1960 over the whole of the Corrientes, Pastaza and Tigre river basins (Loreto, Peru), tributary rivers of the Marañón river (figure 1). More than 45,000 Achuar, Kichwa and Urarina indigenous people live in these river basins.

Crude oil, produced waters and drilling muds can contain a number of potentially toxic agents, including heavy metals, such as lead, cadmium, arsenic and mercury amongst others (E&P Forum/UNEP, 1997; Fakhru'l-Razi et al., 2009; Lienemann et al., 2007; Neff, 2002; Wilhelm, 1999). Poor environmental practices by the oil industry, such as the dumping of around 1 million barrels/day of produced water on soils and rivers in the study area, and recurrent oil spills have contaminated the Corrientes, Pastaza, and Tigre river basins, all tributary rivers of the Marañón river (Figure 1) and exposed the indigenous population to metals among other contaminants (Orta-Martínez et al., 2018; Orta Martínez et al., 2007). Since the 80's different Peruvian state agencies reported high levels of hydrocarbons and heavy metals related to oil extraction activities in environmental samples, and high levels of cadmium and lead in blood among the local population of this area (Orta Martínez et al., 2007). Exposure to metals is associated with several negative health outcomes, including neurological, respiratory, renal and cardiovascular effects, and increased risk of cancer (Järup, 2003; Vrijheid et al., 2016). The 30th of June 2014, an oil spill of the Northern Peruvian pipeline (ONP, by its Spanish acronym) released 2,358 barrels of crude oil to the environment, coating over 87,000 square meters of the territory of the indigenous community of Cuninico (Expediente Resolución Directoral No. 844-2015-OEFA/DFSAI Expediente No. 1306-2014-OEFA/DFSAI/PAS. 2015; UTM WGS84 N9474535, E467992). A few months later, the 16th of November 2014, an oil spill in the same region released approximately 7,800 barrels of crude affecting the territory of the indigenous community of San Pedro

(Goldenberg, 2014). Approximately one year after these major spills, we surveyed these two Kukama communities to assess blood and urine levels of metals often found in crude oil.

Methods

In January 2016, CENSOPAS-INS, the centre for occupational and environmental health of the Peruvian National Institute of Health, conducted an assessment of metal concentrations in the inhabitants of Cuninico and San Pedro. Participation was offered to all inhabitants that had been living in these communities during at least the previous six months. The study protocol was reviewed and accepted by the Ethics Committee (Comité Institucional de Ética en Investigación) of the National Institute of Health, Peru. All participating subjects provided written informed consent.

Demographic data and information on involvement in oil clean-up activities were collected through structured questionnaires. Venous blood and urine were collected, and preserved following standardized CENSOPAS-INS procedures (Carreón Valencia et al., 1995; Centers for Disease Control and Prevention, 2016). Concentration of metals were determined using protocols validated by CENSOPAS-INS. Specifically, atomic absorption spectrophotometry (AAS) in graphite chamber was used for lead in blood (Instituto Nacional de Seguridad e Higiene en el Trabajo. Ministerio de de trabajo y asuntos sociales España, n.d.) and for cadmium in urine (adapted version of (NIOSH, 1994)). Flow injection –hydride generation AAS was used for arsenic in urine (adapted version of (Intersociety Committee & Morris Katz, 1989)) and cold vapour AAS was used for mercury in urine (Instituto Nacional de Seguridad e Higiene en el Trabajo. Ministerio de de trabajo y asuntos sociales España, n.d.). Creatinine in urine was measured by mass spectrophotometry using kinetic Jaffe method (Wiener Lab. Ref 1260360).

Method limits of detection (LOD) applied were 2 µg/dL for lead, 2.5 µg/L for arsenic and mercury, and 0.5 µg/L for cadmium. We replaced metal values below the LOD by LOD/2. To account for urinary dilution, we corrected levels of arsenic, cadmium, and mercury with creatinine concentrations, when creatinine values were within acceptable ranges for human biomonitoring (>0.3 - <3.0 g/L) (American Conference Of Governmental Industrial Hygienists (ACGIH), 2017). Samples with creatinine values outside this range were not included in the analysis. For all metals under study, we used as reference values those established by the Peruvian Ministry of Health (MINSA): < 10 µg lead/dL blood, 20 µg arsenic/g creatinine, 2 µg cadmium/g creatinine and 5 µg mercury/g creatinine.

We conducted descriptive analyses of the study population characteristics and levels of metals. We examined the distribution levels of metals among the study population. As levels of metals among the study participants did not follow a normal distribution, we compared median levels of metals according to demographic characteristics using non-parametric tests (i.e. Wilcoxon rank-sum test for variables with two categories and Kruskal-Wallis test for variables with more than two categories). Correlation between levels of metals was tested using Spearman's rank correlation coefficient. Levels of metals were log transformed to approach normal distribution. Association between self-reported involvement in clean-up activities and levels of metals (log transformed) was studied among the overall population using linear regression models adjusted for age and sex.

Results

Nine percent of the population (132/1400) participated in the survey. Blood and urine were collected from 98% and 95% of the study population, respectively. Urine creatinine values for 13 samples were outside the acceptable range and were not included in the analysis.

Median (interquartile range) blood lead levels were 2.4 µg/dL (1.6). Median levels of other metals in urine were: arsenic 3.1 (3.0) µg/g, cadmium 1.1 (1.0) µg/g, and mercury 5.1 (5.3) µg/g. Concentrations of the different metals were not correlated (Spearman's correlation coefficients: lead-arsenic= 0.23; lead-cadmium= 0.10; lead-mercury= 0.04; As-cadmium= - 0.03; As-mercury= 0.02; cadmium-mercury= 0.30). Men had higher levels of lead and arsenic than women. Levels of arsenic and mercury were higher in children $\leq$ 10 years compared with the older population. Participants from the community of San Pedro had higher levels of cadmium and mercury than participants from Cuninico. Participants involved in clean-up activities had higher blood lead than those not involved in clean-up (**Table 1**).

Five per cent of children $\leq$ 10 years exceeded blood lead levels recommended by the MINSA, and 19% exceeded blood lead levels of 5 µg/dL, the threshold used by the American Centers for Disease Control and Prevention (CDC) to identify children with the highest levels of exposure in a population (National Center for Environmental Health. Division of Emergency and Environmental Health Services, 2012). No participant exceeded arsenic benchmarks recommended by the MINSA. 17% and 50% of the study population exceeded levels recommended by the MINSA for cadmium and mercury, respectively. These percentages were higher among children $\leq$ 10 years: 18% and 64% of them had cadmium and mercury levels higher than those recommended, respectively.

There was no association between an individual's body burden of metals and their participation in clean-up activities (**Table 2**).

Discussion

We report high levels of metals, particularly mercury, for the population of two indigenous communities of the northern Peruvian Amazon, located downstream of two

major oil extraction blocks (block 1AB/192 and 8), and in the vicinity of a major oil pipeline (figure 1), 13 and 16 months after two major oil spills that affected their territories. Median levels of urine mercury in the overall population were above reference values established by the MINSA. Overall, 50% of the general population and 64% of children ≤ 10 years had levels of mercury higher than those recommended. These results are concerning as exposure to mercury is associated with neurological and psychological symptoms (, among others health effects including renal, respiratory and cardiovascular effects (Rice et al., 2014). Children (and pregnant women) are especially vulnerable to the effect of mercury, as damages in central nervous system are more critical during early development (Debes et al., 2016; Grandjean and White, 2002).

Crude oil and produced waters can contain mercury (Fakhru'l-Razi et al., 2009; Lienemann et al., 2007; Wilhelm, 1999), and elevated levels of mercury have been reported in the environment and aquatic organisms (i.e. methyl mercury) around oil extraction sites and in areas affected by oil spills (reviewed in (Webb et al., 2016)). A recent study conducted among indigenous peoples living close to oil extraction sites, in communities located upstream from Cuninico and San Pedro (Pastaza and Corrientes river basins), also reported high levels of inorganic mercury in urine (Webb et al., 2016). Nevertheless, some authors have suggested that demethylation of organic mercury (i.e. methyl mercury) can occur in the human body and therefore, part of the mercury detected in urine (i.e inorganic mercury) could come from organic sources such as fish ingestion (Abdelouahab et al., 2008; Passos et al., 2007). Mercury contamination of fish is widely spread in the region and it is well known health risk affecting many of the indigenous peoples living along the Amazonian rivers and tributaries who rely on subsistence fishing (Faial et al., 2015; Olivero-Verbel et al., 2016; Weinhouse et al., 2017).

We could not assess if demethylation was an important source of inorganic mercury levels in urine. Webb et al. (Webb et al., 2016), concluded that demethylation was not an important source of inorganic mercury in their study population, and suggested that the main source of mercury in for population of area could be related to oil extraction activities (Webb et al., 2016). Nevertheless, several studies have identified deforestation, soil erosion and gold mining as the major sources of mercury emission into the Amazonian ecosystems. Given the presence of such activities (i.e. illegal gold mining and deforestation) in the Marañón River basin (Instituto del Bien Común, 2016), we cannot exclude these sources as other potential sources of mercury contamination in the communities of Cuninico and San Pedro.

The median levels of cadmium in urine in the study population were below the reference values established by MINSA. However, 17% of the study population and 18% of children ≤ 10 years had cadmium levels above these benchmarks. Cadmium exposure causes kidney damage, including chronic renal failure. Long term exposure to high levels of cadmium can cause skeletal damage (itai-itai disease) (Åkesson et al., 2014; Järup, 2003). Also, cadmium is carcinogenic, causing lung, prostate and kidney cancer (IARC, 2012).

Cadmium can be naturally present in oil and produced waters (Fakhru'l-Razi et al., 2009; Lienemann et al., 2007; Neff, 2002). A recently published meta-analysis of water quality data collected by various Peruvian state institutions concluded that produced water was a source of 0.34 Metric tons of cadmium/year in the surface waters of the Corrientes, Pastaza, Tigre, and Marañón rivers (Yusta-García et al., 2017). Also, measurable levels of cadmium were found in sediments near the oil spill two years after its occurrence (SINADA ODLO-0016-2016 / 2016-E01-053799), available from the authors). Cadmium released onto soils or into surface waters can be taken up by plants (i.e. leafy vegetables, root crops, cereals and grains) and thus enter the food chain (Agency for Toxic Substances and Disease Registry, 2008). Human exposure to

cadmium also occurs through consumption of contaminated water or inhalation. Very high levels of cadmium in urine have been previously reported among indigenous peoples living in other areas of the 1AB/192 and 8 oil blocks the Corrientes river basin (DIGESA, 2006).

Another important source of cadmium exposure is cigarette smoking. However, information about cigarette use was not available for our study population but there is a low percentage of smokers in the indigenous communities from these four river basins (< 10%, CENSOPAS-INS unpublished data), and those that do smoke, do so only occasionally (41% of smokers smoke less than one cigarette per week. CENSOPAS-INS unpublished data).

The median levels of lead in blood were 2.4 µg/dL (1.6). Although no blood lead level is considered safe, a benchmark of 5 µg/dL is used by the CDC to identify children at highest risk in a population based on the distribution of blood lead levels in the American population (National Center for Environmental Health. Division of Emergency and Environmental Health Services, 2012). Nineteen percent of children under 10 years in the study population had blood concentrations above this value. The main health effects of lead exposure are neurological and behavioural effects, including reduced intellectual capacity. Also lead is classified as probably carcinogenic to humans by the IARC (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, 2006).

Lead can be present in crude oil and produced waters (Fakhru'l-Razi et al., 2009; Lienemann et al., 2007; Neff, 2002). The meta-analysis by Yusta-Garcia et al (Yusta-García et al., 2017) concluded that produced waters historically were an important source of lead contamination in the Corrientes, Pastaza, Tigre, and Marañon river basins (5.14 Metric tons/year). The presence of lead in the produced waters of the same oil block suggests that lead could be present in the spilled crude oil and could

therefore have been a source of exposure for inhabitants of Cuninico and San Pedro. Moreover, high levels of lead were found in sediments near the oil spill two years after its occurrence (SINADA ODLO-0016-2016 and 2016-E01-053799; available from the authors). High blood lead levels have been previously reported among indigenous peoples from the Corrientes river basin (Anticono et al., 2012; DIGESA, 2006).

Our findings show that levels of metals do not correlate between them. We would expect them to correlate if they were all found in the spilled crude and increased in the environment as a result. However, each metal has different uptake-times and half-lives in the environmental matrices to which the people were exposed (water, vegetables, game and fish amongst others) and different half-lives in the human body. The current study was conducted several months after the oil spills, which might have affected detection of metals with short half-life (such as arsenic). This is the main limitation of the current study. The long time between oils spill and the study, also makes associating participation in clean-up activities and body levels of metals difficult. However, we can not exclude other sources the existence of other sources of these heavy metals, especially for mercury.

The study has several strengths. We report for the first time levels of four different metals measured simultaneously among indigenous communities of the Amazon living in the vicinity of an oil pipeline where oil spills are recurrent. We used standardized and validated protocols of CENSOPAS-INS to assess exposure and we sampled individuals from all ages, which allowed us to better describe exposure in the population overall.

Conclusion

In conclusion, individuals in these two communities located close to the North Peruvian pipeline have levels of mercury, cadmium and lead that can be detrimental to health.

Recurrent oil spills, may be a source of exposure to these metals, although we cannot exclude the existence of other sources of exposure, especially for mercury. Assessing the specific source of exposure to these metals was not within the scope of this survey and future studies designed to elucidate the sources of contamination are warranted to help prevent continued exposure to inhabitants in this oil production zone. We recommend that human bio-monitoring be started soon after an oil spill in order to collect data that better reflects occupational and incidental exposure to oil-related contaminants.

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Table 1. Description of study population and median concentration of lead (Pb) in blood and arsenic (As), cadmium (Cd) and mercury (Hg) in urine by study population characteristics

Variables	n (%), n = 132	Pb (µg/dL), n = 129*		As (µg/g creatinine), n = 113**		Cd (µg/g creatinine), n = 113**		Hg (µg/g creatinine), n = 113**	
		Median (IQR)	p-value §	median (IQR)	p-value §	median (IQR)	p-value §	median (IQR)	p-value §
Sex									
Men	69 (52)	3.17 (2.37)		3.61 (2.40)		1.00 (0.94)		4.84 (5.41)	
Women	63 (48)	2.00 (1.44)	<0.001	2.07 (2.07)	<0.001	1.22 (0.88)	0.104	5.27 (5.62)	0.982
Age (years)									
≤ 10	37 (28)	2.48 (2.36)		3.61 (3.77)		0.92 (1.04)		6.85 (6.60)	
11 – 20	24 (18)	2.00 (2.27)		3.25 (2.51)		0.77 (0.61)		3.76 (4.01)	
21 – 30	15 (11)	3.13 (2.83)		3.32 (3.12)		1.00 (0.65)		3.13 (4.89)	
31 – 40	18 (14)	2.12 (2.46)		2.09 (2.92)		1.18 (0.7)		6.21 (4.00)	
41 – 50	15 (11)	2.00 (2.96)		2.07 (1.05)		1.13 (0.85)		4.45 (3.16)	
> 50	23 (17)	2.56 (1.61)	0.257	2.55 (2.80)	0.040	1.66 (1.30)	0.011	5.10 (6.02)	0.060
Children									
Yes (≤ 10 years)	37 (28)	2.48 (2.36)		3.61 (3.77)		0.92 (1.04)		6.85 (6.60)	
No (> 10 years)	95 (72)	2.21 (2.54)	0.072	2.60 (2.78)	0.009	1.15 (0.86)	0.158	4.45 (4.19)	0.047
Community									
Cuninico	115 (87)	2.30 (1.47)		2.91 (3.17)		1.02 (0.88)		4.45 (5.11)	
San Pedro	17 (13)	3.35 (4.88)	0.243	3.55 (2.34)	0.222	1.64 (1.06)	0.010	7.38 (4.96)	0.015
Clean-up activities									
No	101 (80)	2.16 (2.35)		3.19 (2.83)		1.17 (1.05)		5.40 (5.65)	
Yes	26 (20)	3.30 (2.02)	0.004	2.29 (2.97)	0.400	0.99 (0.60)	0.325	3.96 (3.41)	0.102

*Measurement of lead levels in blood was not available for 3 participants; **Measurement of As, Cd and Hg in urine was not available for 19 participants; § Wilcoxon rank-sum test for variables with two categories and Kruskal wallis test for variables with more than two categories. IQR: inter quartile range

Table 2. Association between blood or urine metal concentrations and participation in clean-up activities.

Exposure (log transformed)	Clean-up activities	N (%)	Regression coefficient (95% CI)*
Lead (µg/dL)	No	101 (80)	
	Yes	26 (20)	0.08 (-0.2, 0.37)
Arsenic (µg/g creatinine)	No	87 (78)	
	Yes	24 (22)	-0.31 (-0.61, -0.01)
cadmium (µg/g creatinine)	No	87 (78)	
	Yes	24 (22)	-0.28 (-0.59, 0.03)
Mercury (µg/g creatinine)	No	87 (78)	
	Yes	24 (22)	-0.34 (-0.7, 0.02)

*Adjusted for age and sex

Figure 1. Map of the study area