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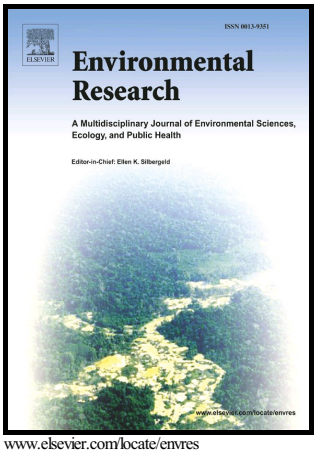

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Preeclampsia and blood lead (and other metals) in Lubumbashi, DR Congo.

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Abstract

Among parturient women in Lubumbashi, blood lead concentrations [geometric means (25^{th}-75^{th} percentiles)] were higher among 40 women with preeclampsia [6.66 µg/dL (5.16-79.4)] than among 39 control women matched for age and gestation duration [5.08 µg/dL (4.27-6.30)]. Blood lead exceeded 5 µg/dL in 33 (83%) preeclamptic women and 17 (44%) control women [odds ratio 6.1 (95%CI 2.1–17.1)]. In another study, we found high levels of lead in surface dust collected in front of homes in Lubumbashi (36/127 samples exceeding 120 µg lead/g dust). Our findings support the conclusions of a systematic review that increased blood lead level increases the likelihood of preeclampsia. Moreover, our study indicates that, as in other urban areas in Africa, exposure to lead is unacceptably high among pregnant women in Lubumbashi. Preventive measures are needed to protect mothers and children from the serious adverse effects of lead exposure.

Keywords

Lead; preeclampsia; pregnancy; metals; global health

Introduction

A recent systematic review published in *Environmental Research* found that blood lead (Pb) concentrations were significantly and substantially associated with preeclampsia (Poropat et al., 2018). From their meta-analysis based on 11 cross-sectional studies, the authors concluded that an increase in blood Pb of 1 µg/dL in pregnant women was associated with a 1.6% increase in likelihood of preeclampsia.

In this brief report, we provide additional data that support the conclusion that Pb exposure may represent a risk of preeclampsia. Our study was performed in Lubumbashi, the capital of the (former) province of Katanga, in the Democratic Republic of the Congo, where we have previously documented high environmental exposure to trace metals as a result of the poorly regulated extraction and processing of copper and cobalt minerals (Banza et al., 2009).

Methods

In a case-control study, we included 80 pregnant women who came to give birth in the University Hospital of the University of Lubumbashi (UNILU). Forty parturient women with a history of preeclampsia during pregnancy (cases) were included between 13/07/2012 and 12/01/2013. The diagnosis of preeclampsia was based on the occurrence, after 20 weeks of gestation, of hypertension (systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥ 90 mmHg) with documented proteinuria (positive dipstick test) and with or without oedema. Forty parturient women without a history of preeclampsia (controls) were included between 03/02/2013 and 25/02/2013. Cases and controls were individually matched for age (± 2 years, as far as possible) and duration of gestation. The study was approved by the Committee for Medical Ethics of the UNILU.

Participants accepting to be included in the study replied to a questionnaire (administered face-to-face) to obtain demographic and other relevant information, clinical data were extracted from patient notes, and each participant, except one control woman, provided, before delivery, a venous blood sample and a spot sample of urine for analysis of trace metals. Blood was collected in 4 mL K2EDTA Vacutainer tubes (Becton Dickinson); urine was collected in 40 mL polystyrene vessels and then aliquoted into 4 mL cryovials. The samples were stored frozen at -18°C, transferred to Belgium in cool boxes, stored frozen at -20°C and then analyzed for the concentration of metals by inductively coupled plasma mass spectrometry (ICP-MS). The laboratory (Louvain Toxicology and Applied Pharmacology) where the metal measurements were performed is ISO15189-certified for ICP-MS analyses of metals in both urine and blood, and it is a reference laboratory for the German External Quality Assessment Scheme (G_EQUAS) (Göen et al., 2012). In urine, 26 elements were measured as previously described (Hoet et al., 2013) and five elements (Mn, Co, Cd, Hg, Pb) were quantified in whole blood. For Be, In, Pt and Bi in urine, nearly all values were below the limit of detection (LOD) and these elements were ignored. For other elements, we attributed a value of LOD/(square root of 2) for values falling below the LOD. Statistical analyses (Mann-Whitney test and Spearman correlation) were performed using SPSS 20.

Results

Table 1 shows that the women with preeclampsia and the control women had similar age, anthropometric characteristics and duration of gestation. However, the proportion of primigravidae was higher in the preeclampsia group (32.5%) than among controls (2.5%), thus leading to a lower number of previous gestations in the former group. Only one preeclamptic and two control women reported smoking, but 18 preeclamptic and 10 control women reported drinking alcohol during pregnancy. Only one control woman reported having worked in a mining-related job; two women in each group reported having a husband working

in a mining-related job; five control women and seven women with preeclampsia stated that they lived close to mining activities.

Table 1 Demographic and other characteristics at inclusion

	Control n = 40	Preeclampsia n = 40
Age (y)	31.4 (4.7) [24 – 41]	30.6 (6.4) [17 – 41]
Gestational age (weeks)	37.0 (3.5) [26 – 42]	36.5 (3.8) 26 – 42]
Gravidity	4.6 (2.0) [1 – 9]	3.7 (2.8) [1 – 9]
Primigravidae (n, %)	1 (2.5%)	13 (32.5%)
Gravidae 2-3 (n, %)	12 (30%)	11 (27.5%)
Gravidae >3 (n, %)	27 (67.5%)	16 (40%)
Height (cm)	170 (6) [157 – 182]	167 (7) [152 – 182]
Weight (kg)	81 (9) [66 – 105]	86 (15) [64 – 107]
BMI	28.1 (4.0) [22.4 – 32]	31.0 (5.0) [21.5 – 43.8]
Systolic BP (mmHg)	110 (10) [90 – 130]	174 (17) [140 – 210]
Diastolic BP (mmHg)	65 (8) [50 – 100]	111(16) [90 – 160]
Glycemia (mg/dL)	89 (13) [65 – 128]	92 (12) [69 – 118]
Creatinine urine (g/L)	1.18 (0.90) [0.11 – 3.48]	1.42 (1.19) [0.18 – 4.17]

Legend: *Data are means with (standard deviations) and [range], or n (percentages); BP: Blood pressure; BMI: Body Mass Index. All data were obtained at the time of inclusion (i.e. prior to delivery), except glycemia which was obtained from patient files. Differences between groups are not statistically significant, except for blood pressure (defining criteria) and for gravidity.*

Table 2 shows the concentrations of trace elements measured in urine (with and without creatinine correction) and in blood.

In blood, only Pb differed significantly between the two groups with a 31% higher (p=0.001) geometric mean value in women with preeclampsia (6.7 µg/dL) compared to control women (5.1 µg/dL). Figure 1 shows that the proportion of women with blood Pb levels above 5 µg/dL [the level that should not be exceeded in pregnant women (Holland et al., 2016)] was higher among women with preeclampsia (33/40, 82.5%) than among the control women (17/39, 43.6%), thus giving an odds ratio of 6.1 (95% CI 2.1 – 17.1). This difference in blood concentrations was not reflected in urine, since the urinary concentrations of Pb tended to be higher (with and without creatinine correction) among controls than among women with preeclampsia. Nevertheless, among preeclamptic women the correlation (Spearman) between blood Pb and urinary Pb was highly significant (r=0.52, p= 0.0009) with creatinine correction, but not without creatinine correction (r=0.11, p=0.50); among control women, Pb-B and Pb-U did not at all correlate, regardless of creatinine correction (r=0.16 and 0.15).

With regard to the other trace metals, women with preeclampsia had higher geometric mean urinary concentrations (with creatinine correction) than control women for Sn (3.8-fold), Cu

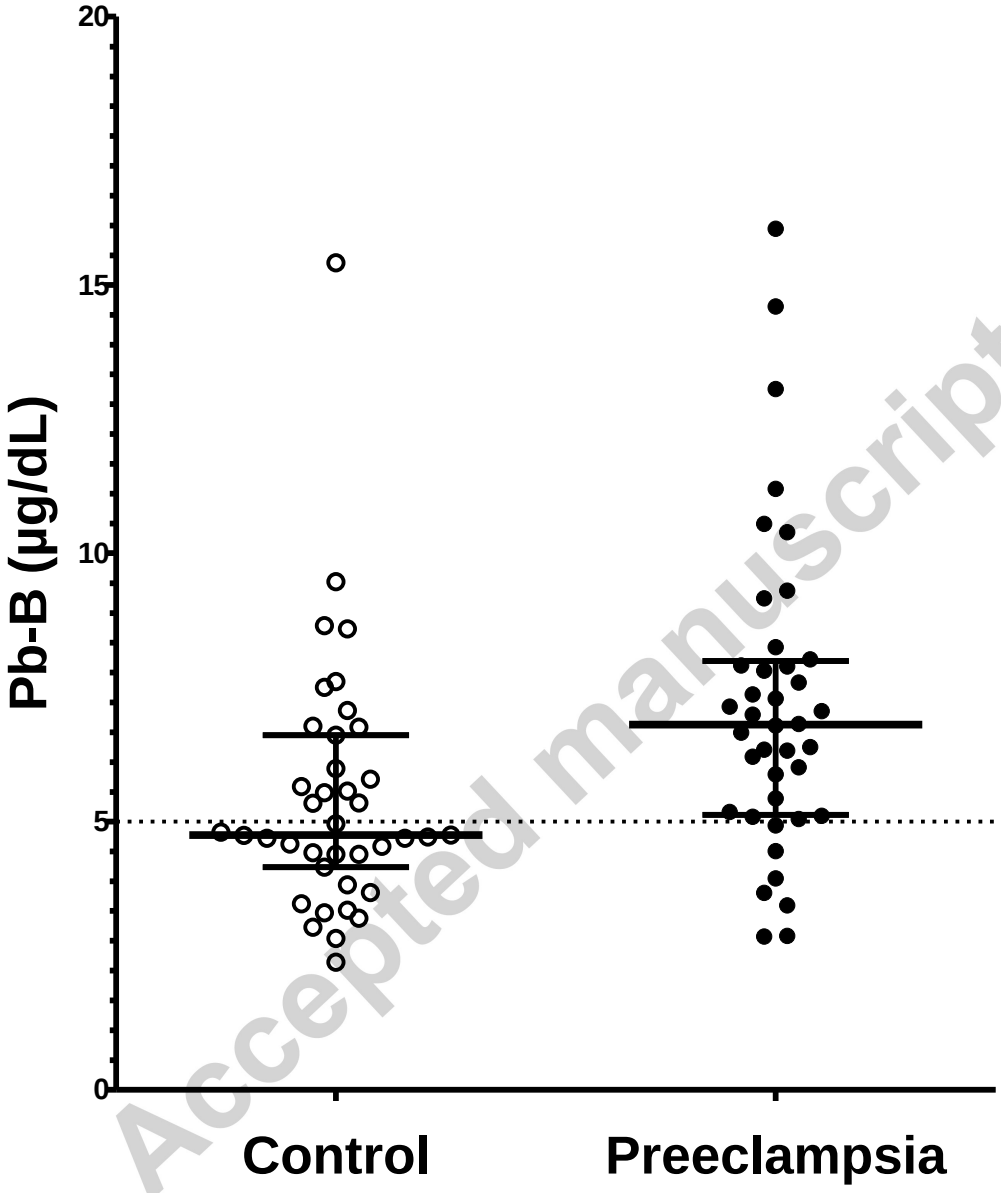
(3.5-fold), Cd (3.1-fold), Sb (1.6-fold) and Zn (1.5-fold); the opposite was the case for Al (4.2-fold lower).

Table 2 Concentrations of trace metals in blood and in urine

		CONTROL	PREECLAMPSIA	P Mann Whitney
Li	Urine (µg/L)	15.3 (10.9 – 23.6)	15.8 (10.9 – 23.4)	0.73
	(µg/g creat.)	*17.4 (13.9 – 25.0)*	*16.5 (11.3 – 32.0)*	*0.90*
Al	Urine (µg/L)	30.0 (16.9 – 57.6)	8.21 (1.91 – 31.9)	0.004
	(µg/g creat.)	*34.1 (21.5 – 51.5)*	*8.12 (2.98 – 25.4)*	*<0.001*
Ti	Urine (µg/L)	12.9 (8.37 – 29.1)	12.3 (5.45 – 30.4)	0.56
	(µg/g creat.)	*14.7 (11.0 – 22.3)*	*12.5 (9.18 – 18.9)*	*0.30*
V	Urine (µg/L)	0.68 (0.37 – 0.85)	0.79 (0.45 – 1.14)	0.29
	(µg/g creat.)	*0.77 (0.41 – 1.37)*	*0.85 (0.44 – 1.55)*	*0.60*
Cr	Urine (µg/L)	0.62 (0.26 – 1.35)	0.70 (0.29 – 1.21)	0.60
	(µg/g creat.)	*0.70 (0.39 – 1.07)*	*0.67 (0.30 – 1.35)*	*0.48*
Mn	Urine (µg/L)	2.38 (1.19 – 4.06)	2.18 (1.09 – 3.45)	0.66
	(µg/g creat.)	*2.70 (1.75 – 4.47)*	*2.19 (1.13 – 3.40)*	*0.046*
	Blood (µg/dL)	**1.80 (1.54 – 2.19)**	**1.94 (1.50 – 2.43)**	**0.68**
Co	Urine (µg/L)	6.97 (2.98 – 13.0)	7.03 (3.94 – 11.1)	0.94
	(µg/g creat.)	*7.92 (4.85 – 12.5)*	*7.14 (4.30 – 12.5)*	*0.45*
	Blood (µg/dL)	**0.15 (0.09 – 0.24)**	**0.19 (0.11 – 0.34)**	**0.21**
Ni	Urine (µg/L)	2.38 (1.17 – 4.14)	3.20 (1.75 – 4.61)	0.15
	(µg/g creat.)	*2.70 (1.77 – 4.05)*	*3.13 (1.90 – 4.46)*	*0.14*
Cu	Urine (µg/L)	26.9 (16.2 – 48.1)	115 (44.1 – 338)	<0.001
	(µg/g creat.)	*30.6 (19.8 – 41.3)*	*108 (34.7 – 298)*	*<0.001*
Zn	Urine (µg/L)	495 (261 – 1067)	865 (370 – 2020)	0.03
	(µg/g creat.)	*562 (418 – 876)*	*850 (619 – 1148)*	*0.003*
As	Urine (µg/L)	23.6 (10.5 – 55.3)	19.6 (8.72 – 37.3)	0.56
	(µg/g creat.)	*26.8 (16.7 – 42.1)*	*19.3 (10.3 – 36.9)*	*0.67*
Se	Urine (µg/L)	23.3 (12.5 – 41.2)	28.7 (12.1 – 62.7)	0.38
	(µg/g creat.)	*26.5 (22.9 – 31.2)*	*28.3 (23.2 – 35.4)*	*0.38*
Mo	Urine (µg/L)	32.7 (20.0 – 76.3)	31.6 (13.5 – 69.6)	0.70
	(µg/g creat.)	*37.2 (33.1 – 75.6)*	*30.9 (20.5 – 50.5)*	*0.09*
Cd	Urine (µg/L)	0.60 (0.34 – 1.02)	2.13 (0.75 – 7.40)	0.001
	(µg/g creat.)	*0.68 (0.43 – 1.04)*	*2.12 (0.78 – 3.93)*	*<0.001*
	Blood (µg/dL)	**0.07 (0.06 – 0.08)**	**0.07 (0.05 – 0.10)**	**0.64**
Sn	Urine (µg/L)	0.38 (0.02 – 3.42)	1.78 (0.40 – 8.37)	0.008
	(µg/g creat.)	*0.44 (0.06 – 3.78)*	*1.65 (0.37 – 8.86)*	*0.005*
Sb	Urine (µg/L)	0.11 (0.05 – 0.22)	0.20 (0.12 – 0.31)	0.006
	(µg/g creat.)	*0.13 (0.07 – 0.19)*	*0.19 (0.11 – 0.39)*	*0.02*
Te	Urine (µg/L)	0.31 (0.26 – 0.54)	0.31 (0.18 – 0.55)	0.46
	(µg/g creat.)	*0.35 (0.32 – 0.55)*	*0.31 (0.19 – 0.50)*	*0.19*
Ba	Urine (µg/L)	7.75 (3.77 – 12.3)	7.05 (2.03 – 15.5)	0.23
	(µg/g creat.)	*8.81 (3.36 – 18.1)*	*7.03 (1.32 – 25.3)*	*0.11*
Hg	**Blood (µg/dL)**	**0.22 (0.13 – 0.28)**	**0.21 (0.15 – 0.26)**	**0.78**
Tl	Urine (µg/L)	0.24 (0.15 – 0.39)	0.33 (0.19 – 0.58)	0.09
	(µg/g creat.)	*0.28 (0.16 – 0.46)*	*0.34 (0.19 – 0.60)*	*0.29*
Pb	Urine (µg/L)	4.69 (2.43 – 8.14)	3.63 (2.04 – 8.16)	0.16
	(µg/g creat.)	*5.30 (3.40 – 7.10)*	*3.65 (2.54 – 6.09)*	*0.06*
	Blood (µg/dL)	**5.08 (4.27 – 6.30)**	**6.66 (5.16 – 7.94)**	**0.001**
U	Urine (µg/L)	0.021 (0.005 – 0.053)	0.038 (0.018 – 0.062)	0.08
	(µg/g creat.)	*0.024 (0.008 – 0.045)*	*0.041 (0.022 – 0.074)*	*0.06*

Legend: *Data are geometric means with 25th – 75th percentiles. 40 participants in each group, but two missing urines in controls, and two missing creatinines in preeclampsia; one missing blood in controls.*

Figure 1 Blood lead levels (µg/dL) in women with preeclampsia and control women.



Legend*: individual values of blood lead (Pb-B) in pregnant women without preeclampsia (control) and women with preeclampsia. The difference between control and preeclampsia is statistically significant (p<0.001, Mann-Whitney test). Dotted line at 5 µg/dL is the level that should not be exceeded in healthy women* (Holland et al., 2016).

Discussion

In women who gave birth in the university hospital in Lubumbashi, we found that those who had had a clinical diagnosis of preeclampsia had 31% higher blood Pb levels than well-matched control women without past hypertension during their pregnancy. In practice, 83% women with preeclampsia had a blood Pb level above 5 µg/dL, as compared to 44% control women.

The latter high "background" value is in itself worrisome given the known adverse effects of Pb on the infant brain (Grandjean and Herz, 2015). High blood levels compared to those currently prevailing in the USA or Europe have been reported from low- and middle-income countries, including from sub-Saharan Africa. Thus, in a systematic review of nine studies, conducted in Nigeria, Kenya, South-Africa and DR Congo, Ngueta and Ndjaboue (Ngueta and Ndjaboue, 2013) obtained a weighted mean blood lead level of 13 µg/dL among children below 6 years. In Nigeria, Ikechikwu et al. (Ikechukwu et al., 2012) and Obi et al (Obi et al., 2014) reported average blood lead levels in maternal blood at delivery of 26.3 µg/dL and 6.2 µg/dL, respectively; in contrast, maternal blood lead concentrations were much lower (geometric mean 1.32 µg/dL) in South-Africa (Röllin et al., 2017).

We do not know the exact sources of Pb in the urban women of Lubumbashi. The intense and generally poorly regulated mining and smelting activities in the town have led to serious environmental pollution and we have documented high human exposure to various trace metals in people living close to mines or smelters in the area (Banza et al., 2009). Although Pb is not a major component of the ores that are mined in the area (Mees et al., 2013), the widespread use of smelter slags for roads and other surfaces may represent a substantial source of Pb.

The other most likely sources of lead are, as elsewhere in Africa, dust contaminated by the past use of leaded gasoline or lead-containing paint, and other activities such as battery recycling (Nweke and Sanders III, 2009)(Gottesfeld et al., 2018). In an as yet unpublished study, we found that surface dust collected outdoors in front of 127 homes throughout Lubumbashi contained a median (25^{th} – 75^{th} percentile) of 73 (44-128) mg Pb/kg dust (95^{th} percentile 367 mg/kg, maximum value 2,902 mg/kg); 36 samples (28%) exceeded the Canadian standard (120 µg/g) for surface soil for residential property use (CME, 2011). In that study, out of 29 samples of drinking water only two contained levels of Pb above the limit of quantification (0.24 µg/L), i.e. 1 and 7 µg/L.

In addition, the widespread habit of eating clay during pregnancy (geophagy) may also contribute to the high blood levels of lead, as suggested by two other studies in DR Congo (Tuakuila et al., 2013)(Gundacker et al., 2017). This factor was not investigated in the present study. Canned food is unlikely to have contributed, because this type of food is rarely consumed in the area.

Surprisingly, urinary Pb was not higher among preeclamptic women than control women. If anything, the reverse was true. We have no explanation for this finding that seems to contradict another study in DR Congo (Elongi Moyene et al., 2016); the latter study was done in Kinshasa (more than 1,500 km from Lubumbashi) and showed a 9-fold higher Pb concentration (in 24-hour urine collections) among women with preeclampsia (geometric mean 72 µg/L) than among healthy control women (8 µg/L). We also have no explanation why a strong correlation was found between creatinine-corrected urinary Pb and blood Pb among preeclamptic women, but not among controls.

These apparent discrepancies may indicate that preeclampsia is accompanied by – or even causes – changes in the toxicokinetics of Pb, e.g. by enhancing the pregnancy-related

release of Pb from skeletal stores or by affecting the renal clearance of Pb. In other words, the consistent association between high blood Pb levels and preeclampsia (Poropat et al., 2018) could be due either to preeclampsia causing high Pb concentrations in blood, or to Pb causing (or precipitating) preeclampsia. Although the latter mechanism is plausible, it would be interesting to conduct prospective studies of the incidence of preeclampsia in relation to markers of past and ongoing Pb exposure both before and during pregnancy.

We also found that the concentrations of several other metals were higher in urine (but not in blood) of preeclamptic women. This was most pronounced (2- to 4-fold higher values) for tin, copper and cadmium and could be due to proteinuria with an increased excretion of protein-bound metals. However, it is worth noting that an association has been reported between preeclampsia and placental levels of cadmium (Laine et al., 2015).

In conclusion, in an area of high metal pollution we found higher blood Pb levels in women with preeclampsia thus adding to the available epidemiological evidence as published in a recent systematic review (Poropat et al., 2018).Moreover, our study indicates that, as in other urban areas in Africa, exposure to lead is unacceptably high among pregnant women in Lubumbashi. Preventive measures are urgently needed to protect mothers and children from the serious adverse effects of lead exposure.

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Contributions: PMO compiled and analysed data; TKK helped analyse data; VH was responsible for analyses by ICP-MS; CBLN and BN conceived and supervised the study; PMO and BN wrote the article; all authors commented on and approved the article.

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Banza, C.L.N., Nawrot, T.S., Haufroid, V., Decrée, S., De Putter, T., Smolders, E., Kabyla, B.I., Luboya, O.N., Ilunga, A.N., Mutombo, A.M., Nemery, B., 2009. High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo. Environ. Res. 109. https://doi.org/10.1016/j.envres.2009.04.012

CME (Canadian Ministry of the Environment). *Soil, Ground Water and Sediment Standards for Use under Part XV.1 of the Environmental Protection Act (PIBS#7382e01)*. (2011). Available at https://www.ontario.ca/page/soil-ground-water-and-sediment-standards-use-under-part-xv1-environmental-protection-act (Accessed 22/02/2017)

Elongi Moyene, J.-P., Scheers, H., Tandu-Umba, B., Haufroid, V., Buassa-Bu-Tsumbu, B., Verdonck, F., Spitz, B., Nemery, B., 2016. Preeclampsia and toxic metals: A case-control study in Kinshasa, DR Congo. Environ. Heal. A Glob. Access Sci. Source 15. https://doi.org/10.1186/s12940-016-0132-1

Göen, T., Schaller, K.-H., Drexler, H., 2012. External quality assessment of human biomonitoring in the range of environmental exposure levels. Int. J. Hyg. Environ. Health 215, 229–232. https://doi.org/10.1016/J.IJHEH.2011.08.012

Gottesfeld, P., Were, F.H., Adogame, L., Gharbi, S., San, D., Nota, M.M., Kuepouo, G., 2018. Soil contamination from lead battery manufacturing and recycling in seven African countries. Environ. Res. 161, 609–614. https://doi.org/10.1016/j.envres.2017.11.055

Grandjean, P., Herz, K.T., 2015. Trace elements as paradigms of developmental neurotoxicants: Lead, methylmercury and arsenic. J. Trace Elem. Med. Biol. 31, 130–134. https://doi.org/10.1016/J.JTEMB.2014.07.023

Gundacker, C., Kutalek, R., Glaunach, R., Deweis, C., Hengstschläger, M., Prinz, A., 2017. Geophagy during pregnancy: Is there a health risk for infants? Environ. Res. 156, 145–147. https://doi.org/10.1016/j.envres.2017.03.028

Hoet, P., Jacquerye, C., Deumer, G., Lison, D., Haufroid, V., 2013. Reference values and upper reference limits for 26 trace elements in the urine of adults living in Belgium. Clin. Chem. Lab. Med. 51, 839–849. https://doi.org/10.1515/cclm-2012-0688

Holland, M.G., Cawthon, D., ACOEM Task Force on Blood Lead Levels, 2016. Workplace Lead Exposure. J. Occup. Environ. Med. 58, e371–e374. https://doi.org/10.1097/JOM.0000000000000928

Ikechukwu, I.C., Ojareva, O.I.A., Ibhagbemien, A.J., Okhoaretor, O.F., Oluwatomi, O.B., Akhalufo, O.S., Oluwagbenga, A.T., Chigaekwu, M.N., 2012. Blood Lead, Calcium, and Phosphorus in Women With Preeclampsia in Edo State, Nigeria. Arch. Environ. Occup. Health 67, 163–169. https://doi.org/10.1080/19338244.2011.619212

Laine, J.E., Ray, P., Bodnar, W., Cable, P.H., Boggess, K., Offenbacher, S., Fry, R.C., 2015. Placental Cadmium Levels Are Associated with Increased Preeclampsia Risk. PLoS One 10, e0139341. https://doi.org/10.1371/journal.pone.0139341

Mees, F., Masalehdani, M.N.N., De Putter, T., D'Hollander, C., Van Biezen, E., Mujinya, B.B., Potdevin, J.L., Van Ranst, E., 2013. Concentrations and forms of heavy metals around two ore processing sites in Katanga, Democratic Republic of Congo. J. African Earth Sci. 77, 22–30. https://doi.org/10.1016/j.jafrearsci.2012.09.008

Ngueta, G., Ndjaboue, R., 2013. Blood lead concentrations in sub-Saharan African children below 6 years: systematic review. Trop. Med. Int. Heal. 18, 1283–1291. https://doi.org/10.1111/tmi.12179

Nweke, O.C., Sanders III, W.H., 2009. Modern Environmental Health Hazards: A Public

Health Issue of Increasing Significance in Africa. Environ. Health Perspect. 117, 863–870. https://doi.org/10.1289/ehp.0800126

Obi, E., Orisakwe, O.E., Okafor, C., Igwebe, A., Ebenebe, J., Afonne, O.J., Ifediata, F., Nils, B., Nriagu, J., 2014. Towards Prenatal Biomonitoring in Eastern Nigeria: Assessing Lead Levels and Anthropometric Parameters of Newborns. J. UOEH 36, 159–170. https://doi.org/10.7888/juoeh.36.159

Poropat, A.E., Laidlaw, M.A.S., Lanphear, B., Ball, A., Mielke, H.W., 2018. Blood lead and preeclampsia: A meta-analysis and review of implications. Environ. Res. 160, 12–19. https://doi.org/10.1016/j.envres.2017.09.014

Röllin, H.B., Olutola, B., Channa, K., Odland, J.Ø., 2017. Reduction of in utero lead exposures in South African populations: Positive impact of unleaded petrol. PLoS One 12, e0186445. https://doi.org/10.1371/journal.pone.0186445

Tuakuila, J., Lison, D., Mbuyi, F., Haufroid, V., Hoet, P., 2013. Elevated blood lead levels and sources of exposure in the population of Kinshasa, the capital of the Democratic Republic of Congo. J. Expo. Sci. Environ. Epidemiol. 23, 81–87. https://doi.org/10.1038/jes.2012.49