Annals of Global Health

Possible Risk Factors and Their Potential Associations with Combined Heavy Metal Exposures in Pregnant Women in the Republic of Suriname

ORIGINAL RESEARCH

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ABSTRACT

Background: The exposure of pregnant women to multiple environmental pollutants may be more disadvantageous to birth outcomes when compared to single-compound contaminations.

Objective: This study investigated the mixed exposures to mercury, manganese, or lead in 380 pregnant Surinamese women. The factors that might be associated with the heavy metal exposures and the relative risk of the potential factors to cause the mixed exposures were explored. The influencing factors of exposures to mixed contaminants assessed were living in Suriname's rural regions, several parts of which are contaminated with heavy metals emitted from artisanal and small-scale gold mining and agricultural activities; the consumption of potentially contaminated foods; advanced maternal age; as well as a relatively low formal educational level and monthly household income.

Methods: Descriptive statistics were used to calculate frequency distributions and $\chi 2$-contingency analyses to calculate associations and relative risks (RR) with 95% confidence intervals (CI).

Findings: Blood levels of two or three of the heavy metals above public health limits were observed in 36% of the women. These women were more often residing in the rural regions, primarily consumed potentially contaminated food items, were 35 years or older, were lower educated, and more often had a lower household income. However, only living in the rural regions (RR = 1.48; 95% CI 1.23–1.77) and a low household income (RR = 1.38; 95% CI 1.15–1.66) significantly increased the risk of exposure exceeding levels of concern to two or three of the heavy metals (by 48% and 38%, respectively).

Conclusion: More comprehensive pharmacological, ecological, and epidemiological studies about exposures to mixed heavy metal contaminations in pregnant women are warranted.

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KEYWORDS:
Suriname; pregnant women; combined heavy metal exposure; educational level; income level; region of residence; public health

TO CITE THIS ARTICLE:
Sewberath Misser VH, Hindori-Mohangoo AD, Shankar A, Lichtveld M, Wickliffe J, Mans DRA. Possible Risk Factors and Their Potential Associations with Combined Heavy Metal Exposures in Pregnant Women in the Republic of Suriname. *Annals of Global Health*. 2024; 90(1): 30, 1–11. DOI: https://doi.org/10.5334/aogh.4402

INTRODUCTION

The detrimental impact of heavy metals on pregnant women, their unborn children, and newborns has been well-established [1]. For instance, elevated levels of mercury or manganese in the blood of pregnant women have been associated with lower birth weight [2, 3], increased maternal blood levels of lead with a higher incidence of preterm birth [4], and too high maternal lead and arsenic blood levels with a low Apgar score [5, 6]. Pregnant women are particularly at risk of exposure to these and other heavy metals in low- and middle-income countries, where policies, legislation, and monitoring of residues in agricultural and industrial substances are insufficient [7, 8].

This is also a concern in the Republic of Suriname, an independent country located on the north-eastern coast of South America. Suriname's leading sources of subsistence are oil drilling, gold mining, agriculture, fishery, and forestry [9], which are mainly carried out in the country's rural-interior and rural-coastal regions [10–12]. These activities substantially contribute to the country's gross domestic income [13] but are accompanied by the release into the environment of the toxic heavy metals mentioned above [14, 15].

Mercury spillage primarily occurs in the country by its use in amalgamating and extracting gold in the widespread small-scale artisanal mining activities [16, 17]. Environmental pollution by lead may be attributed to the emission of fumes from lead-containing gasoline and paint products, residues from lead-based plumbing, and the application of lead-containing cosmetics [18–21]. Exposure of humans and contamination of the environment with manganese may occur during the large-scale production of staple foods such as rice, plantains, and cassava because of the use of illegal and banned agricultural pesticides and herbicides that contain this compound [22]. These compounds are persistent in the environment, accumulate in soils and sediments, and can cause damage to humans or inflict harm after entering the food chain [23–25].

We recently conducted a study with 380 pregnant women in Suriname aimed to determine the effects of prenatal exposure to mercury, manganese, and lead on birth outcomes [26]. For that purpose, an association was sought between levels of heavy metals in the women's blood samples and the occurrence of adverse birth outcomes [26]. The study found no statistically significant relationship between maternal blood levels of these heavy metals and stillbirths, preterm births, low birth weights, or low Apgar scores [26]. However, a considerable proportion of the women had heavy metal blood levels exceeding the reference values of public health concern: 40.5% had mercury levels $\geq$ 3.5 µg/L, 63.9% had manganese levels $\geq$ 13.0 µg/L, and 21.3% had lead levels $\geq$ 3.5 µg/dL [26]. These findings indicate the need for public health measures to safeguard pregnant Surinamese women and their newborns from the harmful effects of exposure to environmental heavy metals.

An important aspect of this issue that deserves more attention is the risk of the simultaneous exposure of pregnant Surinamese women and their unborn children to mercury, manganese, and lead. That exposure to such mixed contaminations may occur in Suriname is not inconceivable when considering their geo-chemo-biological pathways, including their airborne transportation, accumulation in soils and sediments, conversion into highly toxic derivatives, and entry into the food chain following absorption by fish, vegetables, and staple foods, and presence in freshwater resources [22, 23, 27, 28]. Simultaneous exposure to multiple heavy metals may not only be more harmful compared to exposure to single metals but may also carry a greater risk for adverse birth outcomes. For example, the combination of arsenic, cadmium, mercury, manganese, and lead reportedly might increase the risk of congenital heart defects in newborns [29] and the occurrence of asthma in young children [30], and newborns whose mothers had been exposed to lead, mercury, and cadmium had increased blood pressure levels [31].

With this background, descriptive statistics were applied to assess the frequency of contaminations with mercury, manganese, and lead at levels exceeding those of public health concern in the group of pregnant women in Suriname mentioned above. The economic activities associated with the potential spilling of these compounds mainly take place in Suriname's rural-coastal and rural-interior regions [10–12]; the heavy metals may mainly accumulate in certain species of fish, vegetables, and staple foods [23, 25, 28, 32]; and age at delivery, level of education, and household have previously been associated with a higher risk for exposure to contaminant mixtures [33–36].

The distribution of these potential risk factors for the mixed contaminants was also assessed using descriptive statistics. Finally, bivariate and relative risk analyses were used to explore potential associations and calculate relative risk ratios between these factors and the mixed contaminations.

METHODS

STUDY DESIGN AND SETTING

In this study, a group of 380 pregnant Surinamese women who had previously been evaluated for a potential relationship between exposure to mercury, manganese, and lead and adverse birth outcomes [26] was evaluated for the occurrence of combined heavy metals exposures. These women are a subset of the Caribbean Consortium for Research in Environmental and Occupational Health (CCREOH) cohort of 1200 pregnant Surinamese women who had been enrolled during 1 December 2016 to 30 September 2019 in a longitudinal epidemiological study that aims to evaluate the impact of environmental contaminants on birth outcomes and neurodevelopment of their children [37]. The CCREOH study (also known as the MekiTamara Study) was ethically approved by the Institutional Review Board of the Ministry of Health of Suriname (protocol number VG 023-14) and the Institutional Review Board of Tulane University, New Orleans, LA, USA (protocol number 83 093). All participants voluntarily entered the study, agreed to provide a venous blood sample, and provided informed written consent after a thorough explanation of the study's purpose by trained research personnel who documented and witnessed the process. Participants who were under the age of 18 years were assented after the guardian(s) provided consent.

CLASSIFICATION OF COMBINED HEAVY METALS EXPOSURE

During the first or second trimesters, whole blood samples were collected from study participants. Blood levels of three heavy metals (mercury, manganese, and lead) had previously been determined and were categorized as either "low" or "high" based on public health cut-off levels. [26] For mercury, blood levels < 3.5 μg/L were considered "low" and those ≥ 3.5 μg/L were considered "high" [38]. For manganese, blood levels < 13.0 μg/L were considered "low" and those ≥ 13.0 μg/L "high" [39]. Blood levels of lead were considered "low" if < 3.5 μg/dL or "high" if ≥ 3.5 μg/dL [40]. Based on these cut-off points, the occurrence of the various "high-low" heavy metal combinations was recorded for each participant and subsequently categorized into four groups of combined heavy metals exposure: all three low levels; two low levels, and one high level; one low level and two high levels; all three high levels.

MATERNAL CHARACTERISTICS

Information on maternal characteristics was collected at enrollment in the study by trained recruiters through face-to-face interviews using encrypted iPads, following the CCREOH's study protocol [37]. Maternal characteristics deemed relevant to the current study included the region of residence, consumption of certain foods, maternal age at delivery, educational level, and monthly household income.

The region of residence was first categorized as urban-coastal, rural-coastal, and rural-interior according to the classification of the Surinamese General Bureau of Statistics [9] and subsequently as urban versus rural region. Foods that might represent sources of heavy metal contamination were fish, leafy vegetables, as well as staple foods such as rice, plantains, and cassava [41, 42]. Maternal age at delivery was categorized into age groups 16–34 years and 35 years and older; educational level as none or primary education, and secondary or tertiary education; and monthly household income as USD < 75 and ≥ USD 75. These variables were taken as proxies for the socioeconomic status of participants [43].

STATISTICAL ANALYSIS

Descriptive statistics were calculated for combinations of heavy metals exposure (Table 1) and maternal characteristics (Table 2). Contingency tables were constructed to explore associations between maternal characteristics and heavy metal combinations (Table 3). Associations between pairs of variables were evaluated with the $\chi 2$-test and were expressed as p-values applying Fisher›s exact test for sensitivity adjustment. Relative risks (RR) with 95% confidence intervals (CI) were calculated if associations were significant. P values < 0.05 were considered statistically significant. All analyses were done using the Statistical Package for Social Sciences (SPSS version 25 for Windows).

DOI: 10.5334/aogh.4402

NUMBER OF HEAVY METALS ABOVE PUBLIC HEALTH CUT-OFF LEVELS	HEAVY METAL COMBINATIONS	NUMBER OF WOMEN (% OF TOTAL)
0	Hg Low| Mn Low| Pb Low	70 (18.4%)
1	Hg High| Mn Low| Pb Low	37 (9.7%)
	Hg Low| Mn High| Pb Low	131 (34.5%)
	Hg Low| Mn Low| Pb High	6 (1.6%)
2	Hg High| Mn High| Pb Low	61 (16.1%)
	Hg High| Mn Low| Pb High	24 (6.3%)
	Hg Low| Mn High| Pb High	19 (5.0%)
3	Hg High| Mn High| Pb High	32 (8.4%)

Table 1 Number of heavy metals above public health cut-off levels in the pregnant Surinamese women included in the current study, the heavy metal combinations, and the number of women with a blood metal level combination (n = 380).

RESULTS

DISTRIBUTION OF HEAVY METAL CONTAMINATIONS

Table 1 presents the prevalence of heavy metal combinations in the study population. High blood levels of all three heavy metals were found in 32 of the 380 participants (8.4%). More than one-quarter (104 of 380; 27.3%) had two heavy metals at high levels in their blood, and slightly less than half of the participants (174 of 380; 45.8%) had one heavy metal at high levels in their blood. Only 70 participants (18.4%) had low levels of all three heavy metals. Thus, more than one-third of the women examined (136 of 380; 35.8%) had concentrations of two or three heavy metals in their blood that surpassed public health cut-off points.

MATERNAL CHARACTERISTICS

As shown in Table 2, the majority of participants (66.1%) were from Suriname's urban-coastal region, but 129 (or about one-third) were from either the rural-coastal or the rural-interior region. Furthermore, the diet of 94.9% of the women included fish, leafy vegetables, and at least three types of staple food. About 15.3% of the participants were aged above 34 years, while 17.5% had no or only primary education, and less than one-third (31.2%) had a monthly household income of less than USD 75. Thus, approximately one-third of the women lived in a region with potential heavy metal pollution, virtually all consumed diets that could have been contaminated with heavy metals, the majority was in the mid-reproductive age, and most had a relatively high socio-economic status.

CHARACTERISTICS OF WOMEN EXPOSED TO HEAVY METAL MIXTURES	NUMBER OF WOMEN (% OF TOTAL)
Residing in the urban region	251 (66.1%)
Residing in the rural (coastal and interior) region	129 (33.9%)
Consumption of fish, leafy vegetables, and three or more staple food	356 (94.9%)
Aged 16–34 years	322 (84.7%)
Aged 35 years and older	58 (15.3%)
Primary or no formal education	66 (17.5%)
Secondary or tertiary education	312 (82.5%)
Household income < USD 75	112 (31.2%)
Household income ≥ USD 75	247 (68.8%)

Table 2 Distribution of maternal characteristics in the study population (n = 380).

DOI: 10.5334/aogh.4402

ASSOCIATIONS BETWEEN MATERNAL CHARACTERISTICS AND HEAVY METAL COMBINATIONS IN BLOOD

In order to assess potential associations between maternal characteristics and mercury, manganese, and lead blood metal combinations, bivariate analyses were conducted. The results from these analyses are presented in Table 3. Region of residence, educational level, and monthly household income were statistically significantly associated with heavy metal combinations ($p < 0.001$), while no statistically significant associations were found for maternal age at delivery ($p = 0.253$) and the consumption of fish, leafy vegetables, and staple foods ($p = 0.908$) with heavy metal combinations in blood.

Table 3 Associations between maternal characteristics and heavy metals combination (N = 380).

CHARACTERISTICS	BLOOD METAL COMBINATIONS				χ2- TEST RESULT*
	0 ≥ PUBLIC HEALTH LEVEL	1 ≥ PUBLIC HEALTH LEVEL	2 OR 3 ≥ PUBLIC HEALTH LEVEL	TOTAL	
	NUMBER (%)	NUMBER (%)	NUMBER (%)	NUMBER (%)	
Region of Residence					
Urban	57 (22.7%)	121 (48.2%)	73 (29.1%)	251 (100%)	**17.681,**
Rural (coastal and interior)	13 (10.1%)	53 (41.1%)	63 (48.8%)	129 (100%)	**p < 0.001**
Dietary habits					
Consumption of fish, leafy vegetables, and 3 or more types of staple food	66 (21.0%)	161 (45.2%)	129 (36.2%)	356 (100%)	0.300, p = 0.908
Else	4 (18.5%)	9 (47.4%)	6 (31.6%)	19 (100%)	
Maternal age at delivery					
16–34 years	57(17.7%)	153(47.5%)	112 (34.8%)	322 (100%)	2.696, p = 0.253
35 years and older	13 (22.4%)	21 (36.2%)	24 (41.4%)	58 (100%)	
Educational level					
Primary or no education	1(1.5%)	17(25.8%)	48(72.7%)	66(100%)	**50.579,**
Secondary or Tertiary	69(22.1%)	156(50.0%)	87(27.9%)	312(100%)	**p < 0.001**
Household income(USD)					
<75	13(11.6%)	42(37.5%)	57(50.9%)	112(10%)	**15.348,**
> = 75	51(20.6%)	123(49.8%)	73(29.6%)	247(100%)	**p < 0.001**

*Fisher's exact test, $p < 0.05$, is considered significant.

Low levels of all three heavy metals were statistically significantly more often noted in residents of the urban region when compared to those of the rural regions (22.7% vs. 10.1%; $p < 0.001$), in women who had a secondary or a tertiary education when compared to those with only primary education or who had no formal education at all (22.1% vs. 1.5%; $p < 0.001$), and in women who had a household income of 75 USD or more when compared to those with an income less than 75 USD (20.6% vs. 11.6%; $p < 0.001$).

Conversely, two or three high levels of mercury, manganese, or lead were statistically significantly more often observed in women residing in the rural regions when compared to those living in the urban region (48.8% vs. 29.1%; $p < 0.001$), women who had only a primary education or no formal education at all when compared to those with a higher education (72.7% vs. 27.9%; $p < 0.001$), and in women with a household income of less than 75 USD when compared to those with a higher income (50.9% vs. 29.6%; $p < 0.001$).

Next, the statistically significant associations observed in the previous paragraph were further explored by calculating the RRs by comparing two or three high metal combinations against no high metal combinations. Education level was excluded from this calculation as the data did not

DOI: 10.5334/aogh.4402

meet the sample size criteria. As shown in Table 4, living in the rural (coastal and interior) regions (RR = 1.48; 95% CI 1.23–1.77) and having a lower household income (RR = 1.38, 95% CI 1.15–1.66), increased the risk of exposure to two or three high heavy metals during pregnancy with 48% and 38% respectively. Thus, the risks of having a combination of two or three blood heavy metals above the public health cutoff points are statistically significantly higher (48–38%) in women living in the rural (interior and coastal) regions and in women with a low household income.

Table 4 Relative risk (95% CI)) of risk factors (region of residence, and household income) for 2 or 3 blood metal combinations above public health levels in pregnant women.

DETERMINANTS	BLOOD METAL COMBINATIONS				TOTAL	RELATIVE RISK (95% CI)	χ2- TEST RESULT*
	2 OR 3 ≥ PUBLIC HEALTH LEVEL		0 ≥ PUBLIC HEALTH LEVEL				
	NUMBER	%	NUMBER	%			
Region of residence							
Rural (coastal and interior)	63	82.9%	13	17.1%	76	1.48 (1.23 – 1.77)	**17.691, p < 0.001**
Urban	73	56.2%	57	43.8%	130	1 (reference)	
Household income(USD)							
<75	57	81.4%	13	18.6%	70	1.38 (1.15 – 1.66)	**15.348, p < 0.001**
> = 75	73	58.9%	51	41.1%	124	1 (reference)	

*Fisher's exact test, $p < 0.05$, is considered significant.

DISCUSSION

The exposure of pregnant women to combinations of heavy metals may present a greater health risk for adverse birth outcomes when compared to single-agent contaminations [44, 45], requiring increased public health vigilance and public health measures. The current study has assessed the distribution of combined contaminations with mercury, manganese, and lead in Suriname, the potential risk factors of the mixed contaminations (living in a specific part of Suriname, dietary habits, maternal age, and socio-economic status), as well as the relative risks of these factors to cause combined heavy metal exposures in a group of pregnant Surinamese women. Our results showed that more than one-third of the 380 women included in the study had two or three heavy metals in their blood at concentrations above public health levels of concern. Furthermore, a considerable proportion of the study population displayed the potential risk factors for mixed heavy metal exposures. Finally, living in Suriname's rural areas, as well as having a low household income, might increase the risk for multiple exposures above levels of concern, whereas the consumption of fish, leafy vegetables, and staple foods, as well as older maternal age, did not.

The simultaneous exposure to two or three heavy metals at levels above recommended public health action levels—including mercury, manganese, and lead—has been reported before in, among others, Japan [46], the USA [47], and China [29]. In line with the results from the current study, the investigators suggested that education and low income might represent potential risk factors for exposure to multiple contaminants [46, 48]. However, whereas these investigators also suggested that fish consumption and maternal age might represent potential risk factors, this did not seem to be the case in the current study.

The increased risk of exposure to multiple contaminants of pregnant women from the rural areas of Suriname with two or three heavy metals might be attributable to their exposure to the noxious emissions from artisanal gold mining and agricultural activities in particularly these parts of the country [49, 50]. Indeed, the consumption of fish from polluted areas represented an important risk factor for multiple heavy metal intoxications in various parts of the world [46–48]. Furthermore, pesticide residues and heavy metal contaminations of soil and produce have been traced back to large-scale agricultural activities in various countries, including China [51]. The precise factors contributing to a higher risk of contaminations in the rural areas must be investigated in future studies.

Low education and low income (as well as other indicators of an unfavorable socioeconomic status) may also represent potential risk factors for multiple heavy metal exposures above public health levels of concern. This possibility has been reported in Puerto Rico [52] and Uruguay [53]. Low education and low income may limit access to and consciously choosing healthy and safe food [54, 55] and may be associated with inadequate knowledge about the proper use of pesticides [56, 57]. These characteristics have also been associated with the inability to recognize potentially contaminated dietary items [58], a greater risk of occupational exposure to toxic substances [59, 60] and insufficient financial means to take proper protective measures [56, 57].

Surprisingly, the consumption of potentially contaminated fish, leafy vegetables, and staple foods did not seem to carry a statistically significant risk for mixed exposure to mercury, manganese, and/or lead in the current study. Indeed, a previous study detected high mercury concentrations in blood and hair samples of inhabitants from villages in Suriname's interior [61, 62], whose main protein source is predatory fish that consume mercury-contaminated prey [23]. However, another report identified pesticide residues in vegetables that are widely consumed by pregnant Surinamese women that, fortunately, were below the cut-off points of the European Union [32]. This has recently been corroborated by Alcala and coworkers [63], who detected traces of pesticide metabolites in the urine of pregnant Surinamese women, possibly following contamination through food intake, dermal contact, or inhalation. It is important to determine whether urinary levels of heavy metals are also limited to traces rather than potentially dangerous concentrations in the women evaluated in the current study when considering that the majority of them consumed diets that potentially contained multiple heavy metals.

The absence of a statistically significant association between the older age of pregnant women and a higher risk of exposure to mixed heavy metal contaminations noted in the current study is not in agreement with the results from previous studies [46–48]. For instance, in a Chinese investigation that specifically explored the occurrence of heavy metals in different age groups, higher concentrations were found in middle-aged women when compared to younger women [64]. This might be attributable to the increasing susceptibility of the human body to environmental exposures with increasing age [65], particularly in individuals suffering from comorbidities such as hypertension [66]. The discrepancy between the data from the literature and those from the current study may be attributable to the relatively small size of the study population that, in addition, mainly consisted of women of reproductive age.

In summary, the results from the current study suggest that particularly women living in the rural areas of Suriname and women with a low household income were at risk for exposure to combined heavy metal contaminants. However, despite suggestions about the sources of the mixed heavy metal contaminants (particularly widespread artisanal gold mining and large-scale agriculture), the precise nature of the geo-chemo-biological pathways involved in the contaminations, and their combined pharmacological effects on humans, including pregnant women and their offspring are not clear [67, 68]. The small sample size of the study population also makes it difficult to extrapolate the findings to the general population.

Nevertheless, the results from the current study emphasize the need for improved insights into exposure to mixed heavy metal contaminants. Notably, such exposures (including those with mercury, manganese, and/or lead) are also believed to be involved in the development of chronic ailments such as Parkinson's disease, hypertension, and chronic kidney disease [66, 69, 70], presumably by perturbing metal homeostasis in the body and causing cell degeneration [71, 72]. So far, studies on their effects on pregnant women, their unborn children, and their newborns are limited. Therefore, it is important to identify the precise geo-chemo-biological pathways involved in these phenomena and to understand their toxicokinetics and toxicodynamics better in order to implement the proper public health interventions.

CONCLUSION

About one-third of the 380 pregnant Surinamese women evaluated in the current study had a combination of mercury, manganese, and/or lead in their blood at levels exceeding those of public health concern. Women living in the rural areas of Suriname and women who had a low household income ran a risk of 38–48% being exposed to one of these heavy metal combinations. More comprehensive pharmacological, ecological, and epidemiological studies about mixed heavy metal contaminations of pregnant women are warranted.

DATA ACCESSIBILITY STATEMENT

Data are available upon request after approval of the CREEOH research team and permissions of the ethical boards.

FUNDING INFORMATION

The Fogarty International Center of the National Institutes of Health (NIH) funded this research (grant numbers U01TW010087 and U2RTW0 0104). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

VS and DM are Joint Senior Authors.

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REFERENCES

1. **Nakayama SF, Espina C, Kamijima M,** et al. Benefits of cooperation among large-scale cohort studies and human biomonitoring projects in environmental health research: an exercise in blood lead analysis of the Environment and Child Health International Birth Cohort Group. *Int J Hyg Environ Health*. 2019; 222(8): 1059–1067. DOI: https://doi.org/10.1016/j.ijheh.2019.07.005
2. **Eum JH, Cheong HK, Ha EH,** et al. Maternal blood manganese level and birth weight: A MOCEH birth cohort study. *Environ Health*. 2014; 13(1): 31. DOI: https://doi.org/10.1186/1476-069X-13-31
3. **Vigeh M, Nishioka E, Ohtani K,** et al. Prenatal mercury exposure and birth weight. *Reprod Toxicol*. 2018; 76: 78–83. DOI: https://doi.org/10.1016/j.reprotox.2018.01.002
4. **Taylor CM, Golding J, Emond AM.** Adverse effects of maternal lead levels on birth outcomes in the ALSPAC study: a prospective birth cohort study. *BJOG*. 2015; 122(3): 322. DOI: https://doi.org/10.1111/1471-0528.12756
5. **Abdel Hameed ER, Sherif LS, Awad AH,** et al. Arsenic and cadmium levels in maternal and umbilical cord blood and their associations with birth outcomes. *Biomed Pharmacol J*. 2020; 13(1): 61–69. DOI: https://doi.org/10.13005/bpj/1861
6. **Mohany KM, El-Asheer OM, Raheem YFA, Sayed AAE, El-Baz MAEHH.** Neonatal heavy metals levels are associated with the severity of neonatal respiratory distress syndrome: a case–control study. *BMC Pediatr*. 2022; 22(1). DOI: https://doi.org/10.1186/s12887-022-03685-5
7. **Munir N, Jahangeer M, Bouyahya A,** et al. Heavy metal contamination of natural foods is a serious health issue: a review. *Sustainability*. 2022; 14(1): 161. DOI: https://doi.org/10.3390/su14010161

8. **Veber T, Dahal U, Lang K, Orru K, Orru H.** Industrial air pollution leads to adverse birth outcomes: a systematized review of different exposure metrics and health effects in newborns. *Public Health Rev*. 2022; 43: 23. DOI: https://doi.org/10.3389/phrs.2022.1604775
9. **General Bureau of Statistics.** *Statistisch Jaarboek 2018–2019 Suriname*. General Bureau of Statistics; 2020. https://statistics-suriname.org/wp-content/uploads/2020/06/Statistisch-Jaarboek-2018-2019v1.pdf.
10. **The Amazon Conservation Team.** Amazon Gold Rush: Gold Mining in Suriname. Published 2015. Accessed June 15, 2023. https://www.amazonteam.org/maps/suriname-gold/.
11. **Carribean Community (Caricom) secretariat.** Suriname – Caribbean Agri-Business. Accessed June 15, 2023. https://agricarib.org/suriname-2/.
12. **Global Forest Watch.** Suriname Deforestation Rates & Statistics | GFW. Published 2023. Accessed June 15, 2023. https://www.globalforestwatch.org/dashboards/country/SUR/.
13. **The World Bank.** Agriculture, forestry, and fishing, value added (% of GDP) - Suriname | Data. Published 2021. Accessed June 15, 2023. https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=SR.
14. **Ericson B, Hu H, Nash E, Ferraro G, Sinitsky J, Taylor MP.** Blood lead levels in low-income and middle-income countries: a systematic review. *Lancet Planet Health*. 2021; 5(3): e145–e153. DOI: https://doi.org/10.1016/S2542-5196(20)30278-3
15. **Heemskerk M, Negulic E, Duijves C.** *Reducing the use and release of mercury by artisanal and small-scale gold miners in Suriname*. Artisanal Gold Council; 2016.
16. **United Nations Development Programme (UNDP).** Effectively managing gold mining in Suriname | United Nations Development Programme. Accessed June 15, 2023. https://www.undp.org/suriname/news/effectively-managing-gold-mining-suriname.
17. **Gray JE, Labson VF, Weaver JN, Krabbenhoft DP.** Mercury and methylmercury contamination related to artisanal gold mining, Suriname. *Geophys Res Lett*. 2002; 29(23): 20–21. DOI: https://doi.org/10.1029/2002GL015575
18. **Eichler A, Gramlich G, Kellerhals T, Tobler L, Schwikowski M.** Pb pollution from leaded gasoline in South America in the context of a 2000-year metallurgical history. *Sci Adv*. 2015; 1(2): e1400196. DOI: https://doi.org/10.1126/sciadv.1400196
19. **CDC (National Center for Environmental Health).** Sources of lead | Lead | CDC. Published 2022. Accessed February 1, 2022. https://www.cdc.gov/nceh/lead/prevention/sources.htm.
20. **U.S Food and Drug Administration.** Lead in cosmetics | FDA. Published 2022. Accessed February 2, 2022. https://www.fda.gov/cosmetics/potential-contaminants-cosmetics/lead-cosmetics.
21. **Suriname Water Company.** *Resultaten SWM Waterkwaliteit Na de Zuivering 2019*. Suriname Water Company; 2019.
22. **Abdoel Wahid F, Wickliffe J, Wilson M,** et al. Presence of pesticide residues on produce cultivated in Suriname. *Environ Monit Assess*. 2017; 189(6): 303. DOI: https://doi.org/10.1007/s10661-017-6009-0
23. **Ouboter PE, Landburg GA, Quik JHM, Mol JHA, Van Der Lugt F.** Mercury levels in pristine and gold mining impacted aquatic ecosystems of Suriname, South America. *Ambio*. 2012; 41(8): 873–882. DOI: https://doi.org/10.1007/s13280-012-0299-9
24. **Reeuwijk NM, Klerx WNM, Kooijman M, Hoogenboom LAP, Rietjens IMCM, Martena MJ.** Levels of lead, arsenic, mercury and cadmium in clays for oral use on the Dutch market and estimation of associated risks. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess*. 2013; 30(9): 1535–1545. DOI: https://doi.org/10.1080/19440049.2013.811297
25. **Wickliffe J, Landburg G, Fortes-Soares L,** et al. Mercury concentrations and sourcing mercury exposures in pregnant women from the Republic of Suriname, South America. *Environ Epidemiol*. 2019; 3: 439. DOI: https://doi.org/10.1097/01.EE9.0000610948.88495.2d
26. **Sewberath Misser VH, Hindori-Mohangoo AD, Shankar A, Wickliffe JK, Lichtveld MY, Mans DRA.** Prenatal exposure to mercury, manganese, and lead and adverse birth outcomes in Suriname: a population-based birth cohort study. *Toxics*. 2022; 10(8): 464. DOI: https://doi.org/10.3390/toxics10080464
27. **Wickliffe J, Landburg GA, Fortes-Soares L,** et al. Mercury concentrations and sourcing mercury exposures in pregnant women from the Republic of Suriname, South America. *Environ Epidemiol*. 2019; 3: 439. DOI: https://doi.org/10.1097/01.EE9.0000610948.88495.2d
28. *Global Assessment of Soil Pollution*. FAO and UNEP; 2021. DOI: https://doi.org/10.4060/cb4827en
29. **Wang C, Pi X, Yin S,** et al. Maternal exposure to heavy metals and risk for severe congenital heart defects in offspring. *Environ Res*. 2022; 212: 113432. DOI: https://doi.org/10.1016/j.envres.2022.113432
30. **Hsieh CY, Jung CR, Lin CY, Hwang BF.** Combined exposure to heavy metals in PM2.5 and pediatric asthma. *J Allergy Clin Immunol*. 2021; 147(6): 2171–2180. e13. DOI: https://doi.org/10.1016/j.jaci.2020.12.634
31. **Wang W, Xie X, Yuan T,** et al. Epidemiological trends of maternal hypertensive disorders of pregnancy at the global, regional, and national levels: a population-based study. *BMC Pregnancy Childbirth*. 2021; 21(1): 364. DOI: https://doi.org/10.1186/s12884-021-03809-2

32. **Abdoel Wahid FZ, Wickliffe J, Wilson M, Hawkins WB, van Sauers AM, Lichtveld MY.** Dietary exposure of pregnant women in Suriname to pesticides in produce. *Ann Glob Health*. 2017; 83(1): 8. DOI: https://doi.org/10.1016/j.aogh.2017.03.017
33. **Bao S, Xia W, Xu S,** et al. Multiple metal exposure and platelet counts during pregnancy: a repeated measure study. *Environ Int*. 2020; 136. DOI: https://doi.org/10.1016/j.envint.2020.105491
34. **Figueroa R, Caicedo D, Echeverry G, Peña M, Méndez F.** Socioeconomic status, eating patterns, and heavy metals exposure in women of childbearing age in Cali, Colombia. Article in Spanish. *Biomedica*. 2017; 37(3): 341–352. DOI: https://doi.org/10.7705/biomedica.v37i3.3286
35. **Pipoyan D, Stepanyan S, Beglaryan M, Stepanyan S, Mendelsohn R, Deziel NC.** Health risks of heavy metals in food and their economic burden in Armenia. *Environ Int*. 2023; 172: 107794. DOI: https://doi.org/10.1016/j.envint.2023.107794
36. **Szynkowska M, Pawlaczyk A, Leśniewska E, Paryjczak T.** Toxic metal distribution in rural and urban soil samples affected by industry and traffic. *Pol J Environ Stud*. 2009; 18(6): 1141–1150. http://www.pjoes.com/Toxic-Metal-Distribution-in-Rural-and-Urban-Soil-r-nSamples-Affected-by-Industry,88338,0,2.html.
37. **Zijlmans W, Wickliffe J, Hindori-Mohangoo A,** et al. Caribbean Consortium for Research in Environmental and Occupational Health (CCREOH) cohort study: influences of complex environmental exposures on maternal and child health in Suriname. *BMJ Open*. 2020; 10(9): e034702. DOI: https://doi.org/10.1136/bmjopen-2019-034702
38. **Mahaffey KR, Clickner RP, Bodurow CC.** Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. *Environ Health Perspect*. 2004; 112(5): 562–570. DOI: https://doi.org/10.1289/ehp.6587
39. **Lucchini RG, Aschner M, Kim Y, Šarić M. Manganese.** In: Nordberg GF, Fowler BA, Nordberg M, (eds.), *Handbook on the toxicology of metals*. Vol 2. Academic Press; 2015: 975–1011. DOI: https://doi.org/10.1016/B978-0-444-59453-2.00045-7
40. **CDC (National Center for Environmental Health).** Blood Lead Reference Value | Lead | CDC. Published 2021. Accessed April 11, 2022. https://www.cdc.gov/nceh/lead/data/blood-lead-reference-value.htm.
41. **Koch W, Czop M, Iłowiecka K, Nawrocka A, Wiącek D.** Dietary intake of toxic heavy metals with major groups of food products—results of analytical determinations. *Nutrients*. 2022; 14(8). DOI: https://doi.org/10.3390/nu14081626
42. **Ohiagu FO, Lele KC, Chikezie PC, Verla AW, Enyoh CE.** Bioaccumulation and health risk assessment of heavy metals in Musa paradisiaca, Zea mays, Cucumeropsis manii and Manihot esculenta cultivated in Onne, Rivers State, Nigeria. *Environ Anal Health Toxicol*. 2020; 35(2): e2020011. DOI: https://doi.org/10.5620/eaht.e2020011
43. **Lindberg MH, Chen G, Olsen JA, Abelsen B.** Combining education and income into a socioeconomic position score for use in studies of health inequalities. *BMC Public Health*. 2022; 22(1): 1–11. DOI: https://doi.org/10.1186/s12889-022-13366-8
44. **Shih YH, Chen HY, Christensen K, Handler A, Turyk ME, Argos M.** Prenatal exposure to multiple metals and birth outcomes: an observational study within the National Children's Study cohort. *Environ Int*. 2021; 147: 106373. DOI: https://doi.org/10.1016/j.envint.2020.106373
45. **Liu J, Ruan F, Cao S, Li Y, Xu S, Xia W.** Associations between prenatal multiple metal exposure and preterm birth: comparison of four statistical models. *Chemosphere*. 2022; 289: 133015. DOI: https://doi.org/10.1016/j.chemosphere.2021.133015
46. **Nakayama SF, Iwai-Shimada M, Oguri T,** et al. Blood mercury, lead, cadmium, manganese and selenium levels in pregnant women and their determinants: the Japan Environment and Children's Study (JECS). *J Expo Sci Environ Epidemiol*. 2019; 29(5): 633–647. DOI: https://doi.org/10.1038/s41370-019-0139-0
47. **Tung PW, Burt A, Karagas M,** et al. Prenatal exposure to metal mixtures and newborn neurobehavior in the Rhode Island Child Health Study. *Environmental Epidemiology*. 2022; 6(1): e194. DOI: https://doi.org/10.1097/EE9.0000000000000194
48. **Wang J, Yang Y, Zhang J, Liu N, Xi H, Liang H.** Trends of blood lead levels in US pregnant women: the National Health and Nutrition Examination Survey (2001–2018). *Front Public Health*. 2022; 10: 2001. DOI: https://doi.org/10.3389/fpubh.2022.922563
49. **Bouterse J, Kadirbaks S, Soerohardjo M, Nojodimedjo R, De Carvalho Junior W, Fraga da Silva E.** Agro Economical Zoning Suriname. *Planning Office Suriname*. 2017. https://www.planningofficesuriname.com/publicaties/agro-ecological-zoning-of-north-suriname-2017/.
50. **Stevens L.** *National Action Plan for Agriculture GHG Inventory Improvement: Suriname*. Inter-American Institute for Cooperation on Agriculture; 2023.
51. **Alengebawy A, Abdelkhalek ST, Qureshi SR, Wang MQ.** Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics*. 2021; 9(3): 1–34. DOI: https://doi.org/10.3390/toxics9030042

52. **Ashrap P, Watkins DJ, Mukherjee B,** et al. Maternal blood metal and metalloid concentrations in association with birth outcomes in Northern Puerto Rico. *Environ Int*. 2020; 138: 105606. DOI: https://doi.org/10.1016/j.envint.2020.105606
53. **Kordas K, Queirolo EI, Ettinger AS, Wright RO, Stoltzfus RJ.** Prevalence and predictors of exposure to multiple metals in preschool children from Montevideo, Uruguay. *Sci Total Environ*. 2010; 408(20): 4488. DOI: https://doi.org/10.1016/j.scitotenv.2010.06.041
54. **Drewnowski A, Darmon N.** Food choices and diet costs: an economic analysis. *J Nutr*. 2005; 135(4): 900–904. DOI: https://doi.org/10.1093/jn/135.4.900
55. **Lawrence W, Skinner C, Haslam C,** et al. Why women of lower educational attainment struggle to make healthier food choices: the importance of psychological and social factors. *Psychol Health*. 2009; 24(9): 1003–1020. DOI: https://doi.org/10.1080/08870440802460426
56. **Benaboud J, Elachour M, Oujidi J, Chafi A.** Farmer's behaviors toward pesticides use: insight from a field study in Oriental Morocco. *Environ Health Toxicol*. 2021; 36(1): 1–9. DOI: https://doi.org/10.5620/eaht.2021002
57. **Mubushar M, Aldosari FO, Baig MB, Alotaibi BM, Khan AQ.** Assessment of farmers on their knowledge regarding pesticide usage and biosafety. *Saudi J Biol Sci*. 2019; 26(7): 1903. DOI: https://doi.org/10.1016/j.sjbs.2019.03.001
58. **von Stackelberg K, Li M, Sunderland E.** Results of a national survey of high-frequency fish consumers in the United States. *Environ Res*. 2017; 158: 126–136. DOI: https://doi.org/10.1016/j.envres.2017.05.042
59. **Pure Earth, Global Alliance on Health and Pollution.** *Reducing the Threat of Toxic Pollution to Women and Girls in Low-and Middle-Income Countries*. Published 2023. Accessed April 1, 2024. https://www.pureearth.org/wp-content/uploads/2021/03/PEWomenPollution_V3-1.pdf.
60. **The Blacksmith Institute, Global Alliance on health and pollution.** *The Poisoned Poor: Toxic Chemicals Exposures in Low- and Middle-Income Countries*. 2014. Accessed July 19, 2023. https://www.pureearth.org/the-poisoned-poor-global-alliance-highlights-invisible-sufferers/.
61. **Abdoel Wahid FZ, Hindori-Mohangoo AD, Covert HH,** et al. Geographic differences in exposures to metals and essential elements in pregnant women living in Suriname. *J Expo Sci Environ Epidemiol*. 2023; 33(6): 911–920. DOI: https://doi.org/10.1038/s41370-023-00526-0
62. **Ouboter P, Landburg G, Satnarain G,** et al. Mercury levels in women and children from interior villages in Suriname, South America. *Int J Environ Res Public Health*. 2018; 15(5): 1007. DOI: https://doi.org/10.3390/ijerph15051007
63. **Alcala CS, Lichtveld MY, Wickliffe JK,** et al. Characterization of urinary pesticide metabolite concentrations of pregnant women in Suriname. *Toxics*. 2022; 10(11). DOI: https://doi.org/10.3390/toxics10110679
64. **Ali MU, Wang C, Li Y,** et al. Human biomonitoring of heavy metals exposure in different age- and gender-groups based on fish consumption patterns in typical coastal cities of China. *Ecotoxicol Environ Saf*. 2023; 262: 115316. DOI: https://doi.org/10.1016/j.ecoenv.2023.115316
65. *Aging and Toxic Response: Issues Relevant to Risk Assessment*. U.S. Environmental Protection Agency; 2006. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=156648.
66. **Kim K, Park H.** Co-exposure to heavy metals and hypertension among adults in South Korea. *Expo Health*. 2022; 14(1): 139–147. DOI: https://doi.org/10.1007/s12403-021-00423-7
67. **Du G, Zhou F, Ouyang L,** et al. Pregnancy and lactation mixed exposure to lead, cadmium, and mercury alters maternal-offspring single heavy metal load: a factorial design. *Int J Hyg Environ Health*. 2023; 248: 114113. DOI: https://doi.org/10.1016/j.ijheh.2023.114113
68. **Kabamba M, Tuakuila J.** Toxic metal (Cd, Hg, Mn, Pb) partition in the maternal/foetal unit: a systematic mini - review of recent epidemiological studies. *Toxicol Lett*. 2020; 332: 20–26. DOI: https://doi.org/10.1016/j.toxlet.2020.06.007
69. **Díaz García JD, Arceo E.** Daño renal asociado a metales pesados: trabajo de revisión. *Revista Colombiana de Nefrología*. 2017; 5(1): 43. DOI: https://doi.org/10.22265/acnef.5.2.254
70. **Félix da Graça Silva VA.** *Pesticide Residues in EU Soils and Related Risks*. Wageningen University; 2022. DOI: https://doi.org/10.18174/568702
71. **Björkblom B, Adilbayeva A, Maple-Grødem J,** et al. Parkinson disease protein DJ-1 binds metals and protects against metal-induced cytotoxicity. *J Biol Chem*. 2013; 288(31): 22809–22820. DOI: https://doi.org/10.1074/jbc.M113.482091
72. **Karri V, Schuhmacher M, Kumar V.** Heavy metals (Pb, Cd, As and MeHg) as risk factors for cognitive dysfunction: A general review of metal mixture mechanism in brain. *Environ Toxicol Pharmacol*. 2016; 48: 203–213. DOI: https://doi.org/10.1016/j.etap.2016.09.016

TO CITE THIS ARTICLE:
Sewberath Misser VH, Hindori-Mohangoo AD, Shankar A, Lichtveld M, Wickliffe J, Mans DRA. Possible Risk Factors and Their Potential Associations with Combined Heavy Metal Exposures in Pregnant Women in the Republic of Suriname. *Annals of Global Health*. 2024; 90(1): 30, 1–11. DOI: https://doi.org/10.5334/aogh.4402

Submitted: 19 January 2024
Accepted: 08 March 2024
Published: 09 April 2024