Annals of Global Health

Urban Green Spaces and Newborns Metal Concentrations in Rio de Janeiro, Brazil

ORIGINAL RESEARCH

ubiquity press

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ABSTRACT

Background: Brazil is the largest country in South and Latin America with an accelerated urbanization process, and the city of Rio de Janeiro is the second most populous. The PIPA Cohort Project is the first prospective study investigating the effects of urban exposure to multiple pollutants on maternal–child health in Brazil.

Objective: This paper describes the relationship between maternal socio-environmental conditions and newborns' umbilical cord blood concentrations of metals (lead, arsenic, and mercury).

Methods: The study population was a convenience sample of all babies born at the UFRJ Maternity Hospital over a period of 12 months from pregnant women aged 16 or older living in Rio de Janeiro. Demographic, socio-economic, lifestyle, work, and housing variables were collected. Metals concentrations were analyzed in umbilical cord blood using the inductively coupled plasma mass spectrometry technique.

Results: There were 844 (93%) eligible births, with 778 (94%) cord blood samples collected. The detection rate of Pb, Hg, and As were 99% (742), 94.5% (708), and 61% (450), respectively. The total green area percentage (PAGT) of urban residence zones was one primary socio-environmental characteristic determinant of high metal exposure (≥median). Newborns living in city zones with lower total green area percentages (PAGT) had equal to or above-median cord blood concentrations of at least one metal (p = 0.026), of lead and mercury (PbHg) at the same time (p = 0.006), or of lead (p = 0.006). The city zones with the worst indicators of greenspace availability also presented human development indexes (HDI) under the city's mean HDI.

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KEYWORDS:
birth cohort, children environmental health, prenatal metals exposure, greenspace, built environment

TO CITE THIS ARTICLE:
Fróes-Asmus CI, Damasceno N, Prata-Barbosa A, Luiz RR, Damacena GN, Meyer A, Rezende J, Amim J, Carvalho D, Medronho R, da Cunha AJLA, Câmara VdM. Urban Green Spaces and Newborns Metal Concentrations in Rio de Janeiro, Brazil. *Annals of Global Health*. 2024; 90(1): 56, 1–16. DOI: https://doi.org/10.5334/aogh.4512

Conclusion: The study provides evidence that the lower availability of urban green spaces in residential zones is associated with greater environmental exposure to pollutants (metals) during pregnancy and can constitute a socio-environmental vulnerability indicator.

BACKGROUND

One of the leading environmental pollution concerns worldwide is the impact of intrauterine exposure to pollutants on human health. The possible harmful effects of this exposure can be expressed at delivery, in the immediate postnatal period, during the childhood and adolescence phases, or only later in adulthood [1–3].

The growing concentration of the world population in big metropolitan areas in countries around the world has brought particular concerns about human exposure to urban environmental pollutants. These regions combine factors potentially hazardous to human health, such as the generation of residues from productive processes, fossil fuel vehicle traffic, and many people living in precarious settlements. In addition, the toxic effects of exposure to multiple pollutants, albeit mainly in small concentrations, are complex to evaluate. These concerns include all life phases, but special consideration should be given to exposure during the most vulnerable periods of human development, such as the prenatal and postnatal periods up to the age of 4 [4, 5].

Living in air pollution environments, the quality of water a pregnant woman consumes and the contaminants in her diet may result in important residue exposures to the fetus and the newborns since some pollutants in the mother's bloodstream can cross the placenta in significant amounts [6]. In a study conducted in the city of Rio de Janeiro with 117 mother–umbilical cord blood pairs analyzing the metals concentrations, Figueiredo et al. (2020) [7] found a positive correlation between metal concentrations in mother and cord blood ($R > 0.7$, $p < 0.001$), indicating that mother metal concentrations are able to determine child metal concentrations.

The growth of cities has a significant impact on the environment. It can be responsible for severe urban problems, including atmospheric pollution, a decrease in green spaces, the contamination of waterways, a lack of sewage and garbage collection, insufficient adequate dwellings, heavy vehicle traffic, and disorganized urban settlements.

Identifying the socio-environmental conditions associated with higher levels of pollutant exposure is key to guiding public policies and actions to prevent this exposure and protect human health [8, 9].

Brazil is the largest country in South and Latin America, and the seventh most populous in the world, and it has an accelerated urbanization process. The population that lives in urban concentrations increased by 9.2 million people from 2010 to 2022 [10, 11]. In 2016, 55% of the country's total energy supply was made up of fossil fuels, with an expected growing demand [12]. Rio de Janeiro is Brazil's second biggest metropolitan region, with 13 million people. The city of Rio de Janeiro is the second most populous in the country (6 million), and 22% of the population lives in inadequate dwellings (slums), the country's highest percentage [10, 13, 14].

Few studies in Brazil have investigated prenatal exposure to metals. Since 2019, the PIPA Cohort Project has been developed at the Maternity Hospital of the Federal University of Rio de Janeiro (UFRJ Maternity). It is a prospective cohort study looking into the effects of exposure to multiple pollutants on children's health from the prenatal period up to the age of 4 years. Growth patterns, neurodevelopment landmarks, and respiratory disorders have been assessed, and maternal and children's samples have been collected for analyses of multipollutant exposure [15, 16].

This paper investigates the relationship between maternal socio-environmental conditions and the concentrations of the umbilical cord blood metals (lead, arsenic, and mercury) of newborn participants in the PIPA Cohort Project.

METHODS

STUDY DESIGN AND POPULATION

It is a sectional study whose population consists of all babies born at the UFRJ Maternity Hospital (UFRJ MH) for 12 months, from July 2021 to June 2022. This study is part of a birth cohort project: the PIPA project.

Inclusion criteria: pregnant women aged 16 or older living in Rio de Janeiro.

ENROLLMENT OF THE STUDY POPULATION

The city of Rio de Janeiro is organized into five urban planning zones: the Central Zone (AP1), the South Zone (AP2), the North Zone (AP3), West Zone 4 (AP4), and West Zone 5 (AP5). The UFRJ Maternity Hospital (UFRJ MH) is located in the South Zone (AP2). It is a reference public hospital for prenatal assistance and delivery for high-risk pregnant women living in all city zones. It is also the reference delivery center for the population living in low-income communities in the city's South Zone (AP2) attending public prenatal assistance care in family health centers.

All eligible pregnant women who attended the UFRJ MH for delivery from July 2021 to June 2022 were invited to participate in the study. The total eligible population was 1513 pregnant women, and 903 (60%) agreed to participate in the study. There were 844 (93%) births in this period, with 778 (92%) umbilical cord blood samples collected for laboratory analysis of the arsenic, mercury, and lead concentrations (Figure 1: Flowchart).

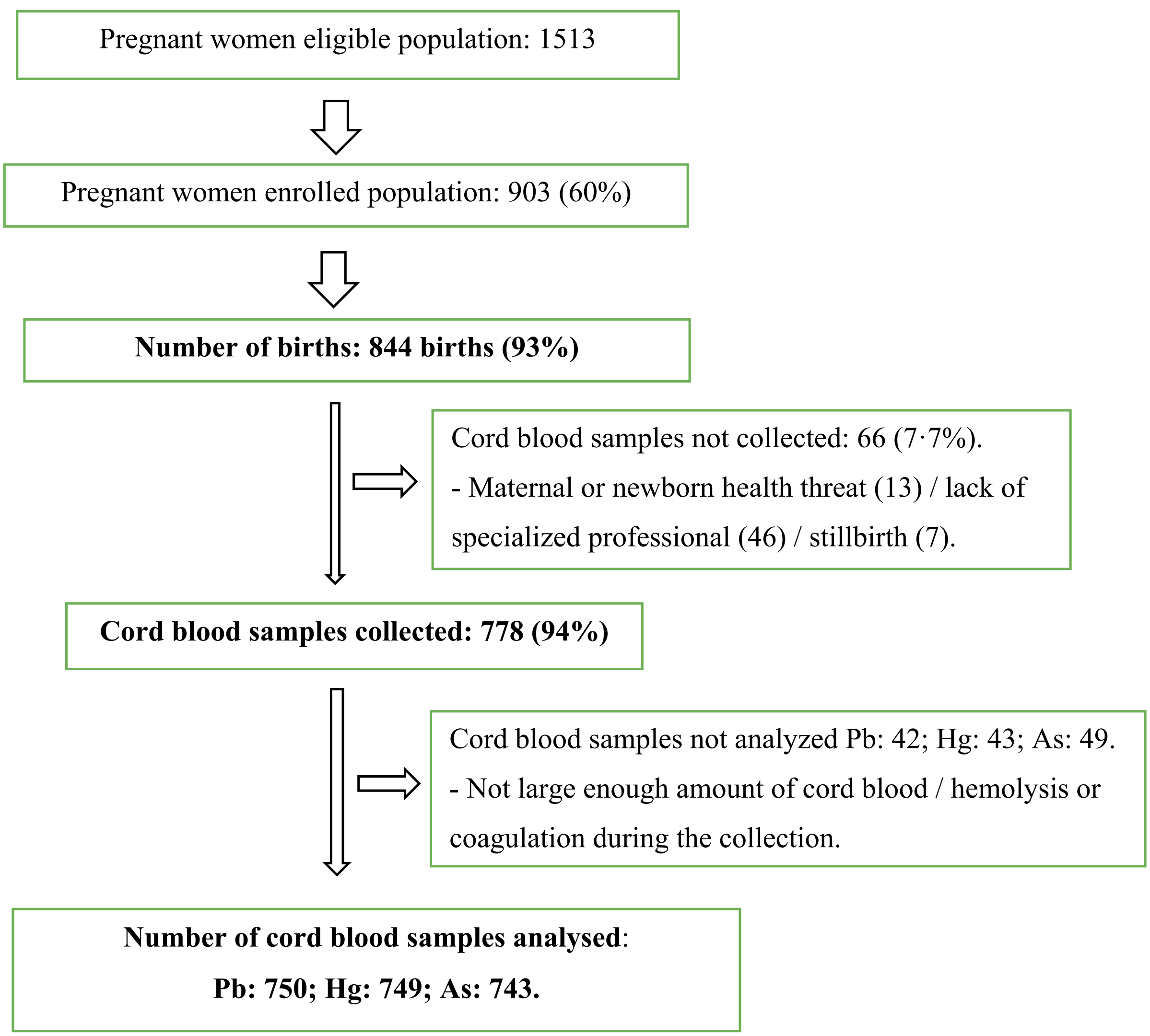

Figure 1 Flowchart.

DATA SOURCE:

1. **Questionnaire:** Trained interviewers applied a questionnaire to all women who agreed to participate in the study in the third trimester of pregnancy. Socio-economic, lifestyle, work, and housing variables were collected and analyzed.

   Socioeconomic characteristics variables: ethnicity (White/non-White), schooling (incomplete high school/complete high school), maternal age (16–29 years/>29 years), Single mother (yes/no), per capita income (up to or higher mean/median income), and government assistance (yes/no). Participants self-reported their ethnicity. For statistical analysis, it was categorized as "white" and "non-white." "Non-white" included all participants who self-described as black, brown, yellow, and indigenous. The "non-white" ethnic group has been associated with poorer socioeconomic conditions in Brazil.

   Variables on lifestyle characteristics: Alcohol (Yes/No), Current smoking during pregnancy (pregnant and family) (Yes/No), and Fish consumption (Consume once a week or more/Not consume).

   Variables on work characteristics: Work (Yes/No), Has salary (Yes/No), Work during pregnancy (Yes/No), and Work activity at home (Yes/No).

   Variables on housing characteristics: Brick house (Yes/No); Sewage treatment (Yes/No); Garbage collection (Yes/No); Time living in the same household (Less than 1 year/More than 1 year); Type of water used (Drinking water/Mineral water/Other); Live in low-income communities (slums) (Yes/No); Live near heavy-traffic streets (Yes/No); House makeover (Yes/No); Live near business establishment (Yes/No); and Urban residence zones ((AP 1) Center/(AP 2) South/(AP 3) North/(AP 4) West 4/(AP 5) West 5).

2. **Built environment:** information about building density, percentage of green areas, and index of green areas were obtained from Rio de Janeiro Municipality City Hall [17, 18].

   For each urban residence zone, the following variables were established: size of area (number of hectares _ Ha); built-up area (number of square meters _m^2); number of inhabitants (hab); building density (number of square meters per hectare _ m^2/Ha); and population density (number of inhabitants per hectare _ hab/Ha).

   Green areas were defined as all types of natural and anthropic-origin vegetal formations except street afforestation and squares. Variables on: IAGT_ total green areas index (m^2/hab): sum of areas of all vegetal formations divided by the total number of inhabitants in each city zone = the number of square meters of total green area per inhabitant per zone; PAGT _ total green area percentage (%): percentage of total green area in each urban zone and in the city.

3. **Umbilical cord blood:** The UFRJ MH obstetric center team collected umbilical cord blood at birth to evaluate newborns' exposure to environmental pollutants.

   Variables on prenatal exposure to metals: concentrations of arsenic (µg/L), lead (µg/dL), and mercury (µg/L).

STATISTICAL ANALYSIS

The sample size was determined by convenience, according to the duration of the study. Demographic, socio-economic, lifestyle, work, and housing variables were described as proportions, means and standard deviation, medians, and interquartile range.

The number of examinations, detection rate, minimum and maximum value, median, and percentiles described the profile of metal concentrations.

The detection rate, defined as the percentage of samples in which the metal was detected in the total number of samples in which this metal was analyzed, was calculated for each metal. The concentration of metals was classified into three categories: undetectable (metal detection = 0), lower concentration (values less than the median of detectable values), and higher concentration (values equal to or greater than the median of detectable values).

Composite indicators were calculated for the analysis of metals, with different combinations between the categories with the highest concentration for the three measured metals (Yes/No): 1) Highest concentration of all three metals at the same time; 2) Highest concentration of at least one of the three metals; and 3) Highest concentration of two metals at the same time: arsenic and lead or arsenic and mercury or lead and mercury.

The prevalence of the categories with the highest concentration for each measured metal and the composite indicators were calculated according to socio-economic, living, and lifestyle characteristics. The association between them was calculated using Pearson's chi-square test. Crude and adjusted prevalence ratios were calculated using the Poisson model with robust variance for the categories with the highest concentration of each measured metal and for composite indicators for each urban zone of the city (Reference: South Zone—AP2) and socio-environmental conditions. Adjustments were made by maternal age, schooling, and living in poor communities (slums).

The additional material presents analyses of socioeconomic, housing, and lifestyle characteristics according to fish consumption per week and the prevalence ratios of exposure to environmental pollutants according to these characteristics.

Statistical analyses were performed using SPSS (version 21).

LABORATORY ANALYSIS

A total volume of 20 mL of umbilical cord blood was collected after umbilical cord clamping. This volume was divided into two types of tubes: K2EDTA tubes and no-additive tubes. The samples were stored at 2 °C to 7 °C for a maximum of 48 h. They were transported in isothermal boxes with recyclable ice for analysis in the DB Laboratory (Certificates: ISO9001:2015/DICQ; PALC) using the inductively coupled plasma mass spectrometry technique. Lead and mercury were analyzed in total blood, and arsenic was analyzed in serum. The considered detection limits and quantification were equal for the measured metals: As: 0.1 µg/L, Pb: 1 µg/dL, and Hg: 0.1 µg/L.

RESULTS

The socio-environmental profile of the newborns' families is described in Table 1. The mean maternal age was 29 years ± 6.9 years, with 52.4% (397) aged between 16 and 29. The mean per capita income was US$188.00 ± US$168.69, and 62% (391) of families received less than the mean per capita income. Most of the population (74% [565]) self-declared as non-white, 69.5% (528) had at least 12 years of study, 56.5% (430) worked during pregnancy, 22% (167) received government financial assistance ("bolsa-familia"), and 18% (135) were single mothers.

Most of the mothers (49% [372]) lived in the South Zone of the city, 55% (417) in low-income communities, 43.5% (330) near heavy-traffic streets, and 57% (434) reported living near business establishments. Alcohol use during pregnancy was reported by 40% (307) and exposure to tobacco by 29% (221) of the population. Most women reported consuming fish once a week or more (63.7%).

The distribution profile of metal concentrations in the umbilical cord blood is presented in Table 2. The detection rate of lead was 99% (742), while that of mercury was 94.5% (708), and that of arsenic was 61% (450). Among the newborns with detectable concentrations of metals, 81% (617) had at least one metal concentration equal to or above the median (Pb: ≥0.80 µg /dL; Hg: ≥0.80 µg /L; As: ≥0.23 µg /L), and 58% (437) had lead, 50% (376) had mercury, and 31% (232) had arsenic concentrations, equal to or above the median. The proportion of newborns with detected combinations of two metal concentrations equal to or above the median was 32% (238) for PbHg and 18% (138) for AsHg and AsPb. In 11% (87) of newborns, cord blood concentrations of all three metals (PbAsHg) simultaneously were at or above the median.

In our study, two socio-environmental characteristics were primary determinants of high metal exposure: the urban residence zone and fish consumption frequency (Table 3).

Socioeconomic characteristics					
Ethnicity (760)*	White: 25.7% (195)			Non White: 74.3% (565)	
Schooling (760)*	Incomplete high school: 30.5% (232)			Complete high school: 69.5% (528)	
Maternal age (757)*	Mean: 29 years ± 6·86y (Min: 16y–Max: 46y)				
	16–29 years: 52.4% (397)			> 29 years: 47.6% (360)	
Single mother (760)*	Yes: 17.8% (135)			No: 82.2% (625)	
Percapta income (631)*	Mean: USD$188.00 ± US$168.69 (Min: ·00–Max: 1,987.00); Median: USD$142.00				
	Up to USD$142.00: 49.3% (311)			> USD$142.00: 50.7% (320)	
	Up to USD$188.00: 62% (391)			> USD$188.00: 38% (240)	
Government assistance (761)*	Yes: 21.9% (167)			No: 78.1% (594)	
Lifestyle characteristics					
Alcohol (761)*	Yes: 40.3% (307)			No: 59.7% (454)	
Current smoking during pregnancy (pregnant and her family) (765)*	Yes: 28.9% (221)			No: 71.1% (544)	
Fish consumption per week (765)*	Consume once a week or more: 63.7% (490)			Not consumed: 36.3% (275)	
Work characteristics					
Work (759)*	Yes: 47.7% (362)			No: 52.3% (397)	
Has salary (761)*	Yes: 52.7% (401)			No: 47.3% (360)	
Work during pregnancy (761)*	Yes: 56.5% (430)			No: 43.5% (331)	
Work activity at home (760)*	Yes: 17% (129)			No: 83% (631)	
Housing characteristics					
Brick house (759)*	Yes: 78.3% (594)			No: 21.7% (165)	
Sewage treatment (740)*	Yes: 97.2% (719)			No: 7% (21)	
Garbage collection (760)*	Yes: 90.4% (687)			No: 9.6% (73)	
Time living in the same household (739)*	Less than 1 year: 10.7% (79)			More than 1 year: 89.3% (660)	
Type of water used (756)*	Drinking water: 61.1% (462)	Mineral water: 32% (242)		Other: 6.9% (52)	
Live in low-income communities (slums) (759)*	Yes: 54.9% (417)			No: 45.1% (342)	
Live near heavy-traffic streets (759)*	Yes: 43.5% (330)			No: 56.5% (429)	
House makeover (760)*	Yes: 39.5% (300)			No: 60.5% (460)	
Live near business establishment (765) *	Yes: 56.7% (434)			No: 43.3% (331)	
Urban zones residence (765)*	(AP 1) Center 10.7% (82)	(AP 2) South 48.6% (372)	(AP 3) North 27.2% (208)	(AP 4) West 4 5.8% (44)	(AP 5) West 5 7.7% (59)

Table 1 Baseline socioeconomic, lifestyle, work, and housing characteristics of PIPA newborns. PIPA Cohort Project, Rio de Janeiro, Brazil.

METALS	N	DETECTION RATE*	MEDIAN	MIN-MAX	P5	P10	P25	P75	P90	P95	P97.5	P99
Arsenic (µg/L)	743	60.6 (450)	0.1300	0.00–11.32	0.0000	0.0000	0.0000	0.2900	0.6600	1.0300	1.6260	2.7352
Lead (µg/dL)	750	98.9 (742)	0.8000	0.00–13.70	0.4000	0.4000	0.6000	1.2000	1.9000	2.4000	3.4225	5.2470
Mercury (µg/L)	749	94.5 (708)	0.8000	0.00–11.60	0.000	0.2000	0.4000	1.5000	2.9000	4.0000	4.8250	6.800

Concentration category	**Undetectable**	**Lower concentration**[1]	**Higher concentration**[2]	**Median**[3]
Arsenic	39.4% (293)	29.3% (218)	31.2% (232)	0.2300
Lead	1.1% (8)	40.7% (305)	58.3% (437)	0.8000
Mercury	5.5% (41)	44.3% (332)	50.2% (376)	0.8000

Higher concentration[2]	**Yes**	**No**
Higher concentration of all three metals at the same time (PbAsHg)	11.4% (87)	88.6% (678)
Higher concentration of at least one of the three metals	80.7% (617)	19.3% (148)
Higher concentration of two metals at the same time—Arsenic and Lead (AsPb)	18% (138)	82% (627)
Higher concentration of two metals at the same time—Arsenic and Mercury (AsHg)	18.2% (139)	81.8% (626)
Higher concentration of two metals at the same time—Lead and Mercury (PbHg)	31.7% (238)	68.3% (512)

Table 2 Profile of metals concentrations in newborns' cord blood. PIPA Cohort Project, Rio de Janeiro, Brazil.

P5: 5th percentile; P10: 10th percentile; P25: 25th percentile; P75: 75th percentile; P90: 90th percentile; P97.5: 97.5th percentile; P99: 99th percentile.

*Detection rate: percentage of samples in which the metal was detected in the total number of samples in which this metal was analyzed.

[1] Lower concentration is given by values less than the median of detectable values.

[2] Higher concentration is given by values greater than, or equal to, the median of detectable values.

[3] Median among detectable.

<table>
<tr><th></th><th colspan="5">SOCIO-ENVIRONMENTAL CONDITIONS: % (N)</th><th>P-VALUE*</th></tr>
<tr><td colspan="7">Arsenic (n = 232)</td></tr>
<tr><td>Maternal age</td><td colspan="2">Up to 29 years: 28.4% (110)</td><td colspan="3">30 years or more: 34.8% (122)</td><td>0.065</td></tr>
<tr><td>Living near heavy-traffic streets</td><td colspan="2">Yes: 28.1% (91)</td><td colspan="3">No: 33.9% (141)</td><td>0.054</td></tr>
<tr><td>Fish consumption per week</td><td colspan="2">Does not consume: 25% (68)</td><td colspan="3">Consume once a week or more: 35.3% (156)</td><td>0.002</td></tr>
<tr><td colspan="7">Lead (n = 437)</td></tr>
<tr><td>Mother's schooling</td><td colspan="2">Incomplete high school: 53.7% (122)</td><td colspan="3">Complete high school or more: 60.4% (313)</td><td>0.053</td></tr>
<tr><td>Urban zones residence</td><td>(AP 1) Center: 67.1% (55)</td><td>(AP 2) South: 52.9% (191)</td><td>(AP 3) North: 66.8% (137)</td><td>(AP 4) West 1: 54.5% (24)</td><td>(AP 5) West 2: 51.7% (30)</td><td>0.006</td></tr>
<tr><td>Live in low-income communities</td><td colspan="2">Yes: 54.3% (221)</td><td colspan="3">No: 62.9% (212)</td><td>0.011</td></tr>
<tr><td>Live near heavy-traffic streets</td><td colspan="2">Yes: 63.3% (205)</td><td colspan="3">No: 54.3% (228)</td><td>0.014</td></tr>
<tr><td>Live near business establishment</td><td colspan="2">Yes: 61.1% (262)</td><td colspan="3">No: 54.5% (175)</td><td>0.072</td></tr>
<tr><td>Worked during the pregnancy</td><td colspan="2">Yes: 61.4% (258)</td><td colspan="3">No: 54.3% (177)</td><td>0.050</td></tr>
<tr><td>Pregnancy tobacco exposure (the mother or some parent was an active smoker)</td><td colspan="2">Yes: 65.7% (142)</td><td colspan="3">No: 55.2% (295)</td><td>0.008</td></tr>
<tr><td colspan="7">Mercury (n = 376)</td></tr>
<tr><td>Maternal age</td><td colspan="2">Up to 29 years: 45.1% (176)</td><td colspan="3">30 years or more: 56.4% (198)</td><td>0.002</td></tr>
<tr><td>Worked during the pregnancy</td><td colspan="2">Yes: 53.8% (226)</td><td colspan="3">No: 45.5% (148)</td><td>0.025</td></tr>
<tr><td>Pregnancy tobacco exposure (the mother or some parent was an active smoker)</td><td colspan="2">Yes: 56% (121)</td><td colspan="3">No: 47·8% (255)</td><td>0·043</td></tr>
</table>

(Contd.)

SOCIO-ENVIRONMENTAL CONDITIONS: % (*N*)						*P*-VALUE*
Fish consumption per week	Does not consume: 37.4% (102)	Consume once a week or more: 58.9% (264)				**<0·001**
Higher concentration to all three metals at the same time (*n* = 87)						
Fish consumption per week	Does not consume: 7.2% (20)	Consume once a week or more: 14.7% (67)				**0.002**
Higher concentration to at least one of the three metals (*n* = 617)						
Urban zones residence	(AP 1) Center: 89% (73)	(AP 2) South: 76.1% (283)	(AP 3) North: 84.6% (176)	(AP 4) West 1: 81.8% (36)	(AP 5) West 2: 83.1% (49)	**0.026**
Live in low-income communities	Yes: 78.2% (326)	No: 83.6% (286)				0.059
Live near heavy-traffic streets	Yes: 84.5% (279)	No: 77.6% (333)				**0.017**
Worked during the pregnancy	Yes: 83% (357)	No: 77.6% (257)				0.062
Fish consumption per week	Does not consume:75.6% (211)	Consume once a week or more: 83.6% (382)				**0.024**
Higher concentration to two metals at the same time—Arsenic and Lead (AsPb) (*n* = 138)						
Fish consumption per week	Does not consume:14% (39)	Consume once a week or more: 20.6% (94)				**0.021**
Higher concentration to two metals at the same time—Arsenic and Mercury (AsHg) (*n* = 139)						
Maternal age	Up to 29 years: 16·1% (64)	30 years or more: 20·8% (75)				0.094
Fish consumption per week	Does not consume: 11·5% (32)	Consume once a week or more: 23·2% (106)				**<0.001**
Higher concentration to two metals at the same time—Lead and Mercury (PbHg) (*n* = 238)						
Maternal age	Up to 29 years: 27.9% (109)	30 years or more: 36.2% (127)				**0.015**
Urban zones residence	(AP 1) Center: 39% (32)	(AP 2) South: 27.4% (99)	(AP 3) North: 39.5% (81)	(AP 4) West 1: 18.2% (8)	(AP 5) West 2: 31% (18)	**0.006**
Live in low-income communities	Yes: 28.7% (117)	No: 35.6% (120)				0.046
Live near a business establishments	Yes: 35.7% (153)	No: 26.5% (85)				**0.007**
Worked during the pregnancy	Yes: 34.8% (146)	No: 27.9% (91)				0.046
Fish consumption per week	Does not consume: 27.7% (148)	Consume once a week or more: 41.7% (90)				**<0.000**

Table 3 Socio-environmental conditions and higher concentrations[1] of metals in newborns' cord blood. PIPA Cohort Project, Rio de Janeiro, Brazil.

**p*-value: *p*-value of Pearson's chi-square test.

**No statistically significant association.

[1] Higher concentration is given by values greater than, or equal to, the median of detectable values.

Newborns living in the Central and North city zones have higher cord blood concentrations (≥median) of at least one metal ($p = 0.026$), of lead and mercury (PbHg) at the same time ($p = 0.006$), or of lead ($p = 0.006$) than those living in the other zones (Table 3). The prevalence of newborns with a higher concentration of one metal (at least) is 17% higher in the Central Zone (PR: 1.173; CI: 1.066, 1.290) and 9% higher in the North Zone (PR: 1.093; CI: 1.004, 1.191) than in the South Zone. For ≥median PbHg concentration, this prevalence is 43% higher in the Central Zone (PR: 1.432; CI: 1.039, 1.975) and 35% higher in the North Zone (PR: 1.357; CI: 1.062, 1.734). The prevalence of newborns with a high Pb cord blood concentration (≥median) is 26% higher in the Central (PR: 1.263; CI: 1.053, 1.515) and 23% higher in the North (PR: 1.236; CI: 1.072, 1.425) Zones than in the South Zone (additional material: Table A1).

Fish consumed once a week or more was significantly associated with a higher concentration (≥median) of all three metals together (PbAsHg) ($p = 0.002$). It was also associated with a higher concentration (≥median) of PbHg ($p < 0.000$), AsHg ($p < 0.001$), AsPb ($p = 0.021$), Hg ($p < 0.001$), and As ($p = 0.002$) in the cord blood (Table 3). The prevalence of ≥median PbAsHg cord blood concentration together was two times higher among newborns with mothers who consumed fish once a week or more during pregnancy (PR: 2.000; CI: 1.246, 3.210) than among those who did not consume fish. Among newborns whose mothers consumed fish, the prevalence of high cord blood mercury concentration was 53% higher (PR: 1.536; CI: 1.295, 1.822), and that of high cord blood arsenic concentration was 39% higher (PR: 1.391; CI: 1.090, 1.774), than among those who did not consume fish (additional material: Table A2).

Working during pregnancy was associated with higher (≥median) PbHg concentrations (p = 0.046) and with higher Pb (p = 0.05) and Hg medians (p = 0.025). Pregnancy tobacco exposure (use by the pregnant woman or indirectly via her family) was associated with higher (≥median) PbHg concentrations (p = 0.046), ≥median Pb (p = 0.008), and ≥median Hg (p = 0.043) concentrations.

Greater fish consumption was associated with older than 29 years (p = 0.036). There is no significant difference in fish consumption related to ethnicity (p = 0.748), per capita income (p = 0.700), schooling (p = 0.574), living in a low-income community (p = 0.898), and working during pregnancy (p = 0.066) (additional material: Table A3).

Additional analysis on socio and housing characteristics by city zone (Table 4) showed a higher number of women reporting living near heavy-traffic streets in the North (57.5%) and West 2 (52.5%) zones (p < 0.000). Also, the number of women reporting living near business establishments is greater in the West 2 (77.4%) and North (66.2%) Zones (p < 0.000). Newborns of mothers living near streets with heavy traffic presented higher cord blood concentrations of at least one metal (p = 0.017) and lead (p = 0.014). Living near business establishments is associated with a higher concentration of PbHg (p = 0.007).

SOCIO-ENVIRONMENTAL CONDITIONS	CENTER		SOUTH ZONE		NORTH ZONE		WEST 1		WEST 2		*P*-VALUE
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	
Personal characteristics											
Maternal age											
16–29 years	61	**61.6**	226	**56.5**	109	48	24	**51.1**	24	39.3	**0.019**
>29 years	38	38.4	174	43.5	118	**52**	23	48.9	37	**60.7**	
Schooling											
Up to 12 years	33	33.3	149	36.6	53	23.2	15	31.3	11	17.7	**0.001**
>12 years	66	66.7	258	63.4	175	**76.8**	33	68.8	51	**82.3**	
Current smoking during pregnancy (pregnant and family)											
No	68	68.7	283	69.5	166	72.8	35	72.9	45	72.6	0.883
Yes	31	31.3	124	30.5	62	27.2	13	27.1	17	27.4	
Work during pregnancy											
No	47	47.5	175	43.4	103	45.4	14	29.2	26	42.6	0.288
Yes	52	52.5	228	56.6	124	54.6	34	70.8	35	57.4	
Race											
White	26	26.3	106	26	52	22.8	18	37.5	16	25.8	0.340
Non-White	73	73.7	301	74	176	77.2	30	62.5	46	74.2	
Per capita income											
≤Median	41	41.4	177	43.5	101	44.3	13	27.1	22	35.5	0.175
>Median	58	58.6	230	56.5	127	55.7	35	72.9	40	64.5	
Fish consumption per week											
Does not consume	32	32.3	144	35.4	94	41.2	13	27.1	23	37.1	0.287
Consume once a week or more	67	67.7	263	64.6	134	58.8	35	72.9	39	62.9	

(Contd.)

SOCIO-ENVIRONMENTAL CONDITIONS	CENTER		SOUTH ZONE		NORTH ZONE		WEST 1		WEST 2		*P*-VALUE
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	
Housing characteristics											
Live in low-income communities											
Yes	54	**54.5**	279	**69.6**	99	43.4	17	35.4	12	19.7	**<0.000**
No	45	45.5	122	30.4	129	**56.6**	31	**64.6**	49	**80.3**	
Live near heavy-traffic streets											
Yes	47	47.5	145	36.1	130	**57.5**	20	41.7	32	**52.5**	**<0.000**
No	52	**52.5**	257	**63.9**	96	42.5	28	**58.3**	29	47.5	
Live near a business establishment											
Yes	62	**62.6**	187	45.9	151	**66.2**	31	**64.6**	48	**77.4**	**<0.000**
No	37	37.4	220	**54.1**	77	33.8	17	35.4	14	22.6	

Table 4 Socio and housing characteristics during pregnancy of PIPA cohort participants by city zone. PIPA Cohort Project, Rio de Janeiro, Brazil.

p-value: *p*-value of Pearson's chi-square test.

PLANNING ZONE[(1)]	AREA (HA)	BUILT-UP AREA(M^2)—2013	INHABITANTS (HAB)—2010	BUILDING DENSITY (M^2/HA)	POPULATION DENSITY (HAB/HA)	IAGT (M^2/HAB)[(1)] 2014	PAGT (%)[(2)]2014
Total RJ	93 179	396 166 938	6 265 942	4 252	67	117.5	61.1
Center	2 851	35 360 779	291 912	**12 405**	102	**35.31**	**31**
South	4582	69 672 848	1 009 013	15 207	220	66.09	69.3
North	19 094	**114 686 049**	**2 400 148**	6 006	**126**	**22.97**	**27.2**
West 1	18 188	74 628 294	860 096	4 103	47	224.95	69.9
West 2	48 464	101 818 968	1 704 773	2 101	35	240.43	68.8

Table 5 Building density, population density, total green area index (IAGT) per inhabitant, and total green area percentage (PAGT). City of Rio de Janeiro (RJ) and planning urban zones. Brazil, 2024.

Ha: Hectare; m^2: square meter; hab: inhabitants.

[(1)]Total Green Areas Index (IAGT): sum of areas of all vegetal formations divided by the total number of inhabitants in each city zone = the number of square meters of total green area per inhabitant per zone.

[(2)]Total Green Area Percentage (PAGT): percentage of total green area in each urban zone and in the city.

Most pregnant women living in the South (69.6%) and Central (54.5%) zones reported residing in low-income communities, unlike those living in the other zones ($p < 0.000$). Not living in low-income communities is associated with a higher lead concentration ($p = 0.011$).

In all city zones, a significantly high number of women have had more than 12 years of study, higher in the West 2 (AP5: 82%) and North (AP3: 77%) zones. More years of schooling (completed high school or more) were associated with a higher Pb concentration ($p = 0.053$).

The West 2 and North zones also have a greater number of women older than 29, at 61% and 52%, respectively ($p = 0.019$). Older maternal age (30 or more) was associated with higher (≥median) PbHg concentrations ($p = 0.015$) and with higher Hg concentrations ($p = 0.002$). The city zones did not present significant differences in per capita income ($p = 0.175$), work during pregnancy ($p = 0.288$), pregnancy tobacco exposure ($p = 0.883$), ethnicity ($p = 0.340$), and fish consumption frequency ($p = 0.287$).

Table 5 presents building and population density information, the total green area index (IAGT), and the total green area percentage (PAGT) of Rio de Janeiro and city zones. The PAGT in the

Central Zone is 31%, in the North Zone it is 27%, while in Rio de Janeiro it is 61%. The North Zone (AP3) has the city's highest total built-up area, the highest population, and the second-highest population density. The Central Zone (AP1) has the second-highest building density. Both zones include non-residential areas like commercial and industrial spaces. The South Zone (AP2) has the highest building and population density, with a PAGT of 69%. In West 1 and West 2 zones, the PAGT is also over 60%.

DISCUSSION

According to the mothers' residence zones in the city, there is a significant difference in prenatal exposure to the measured metals. The Central (AP1) and North (AP3) zones presented the highest prevalence of newborns with at least one above-median metal concentration (AP1: 89%, AP3: 85%_; $p = 0.026$), higher above-median PbHg concentrations (AP3: 39.5%, AP1: 39%_; $p = 0.006$), and higher above-median lead concentrations (AP3: 67%, AP1: 67%; $p = 0.006$). The study did not find differences between the city zones for fish consumption, per capita income, pregnancy tobacco exposure, and work during pregnancy.

Ventilation is one of the main meteorological factors associated with city air quality. Building density, building verticality, and green spaces may influence the atmospheric pollutant concentration, affecting ventilation and impairing the dispersion of respiratory particles [19, 20]. Figure 2 displays a map of the city's urban planning zones, illustrating the distribution of green areas in these zones.

Central Zone: AP 1.0; South Zone: AP 2.1/2.2; North Zone: AP 3.1/3.2/3.3; West Zone 4: AP 4.0; West Zone 5: AP 5.1/5.2/5.3.

Reference: City of Rio de Janeiro—Health Secretary: Health City Plan 2014–2017, p. 20. Date accessed August 15, 2024. Available on: https://www.rio.rj.gov.br/dlstatic/10112/3700816/4128745/PMS_20142017.pdf

The value of the total green area index (IAGT) of the city of Rio de Janeiro (117.5 m^2/hab) is near the median values of European cities (104 m^2/hab) [17]. The European Environmental Agency believes there is unequal access to urban green space in European cities, with lower-income urban neighborhoods having less green space available than higher-income ones [21]. A similar situation is observed in the city of Rio de Janeiro. The Central and North zones have the city's lowest indexes of green area per habitant (IAGT), at 35 m^2/hab and 22 m^2/hab, respectively, and

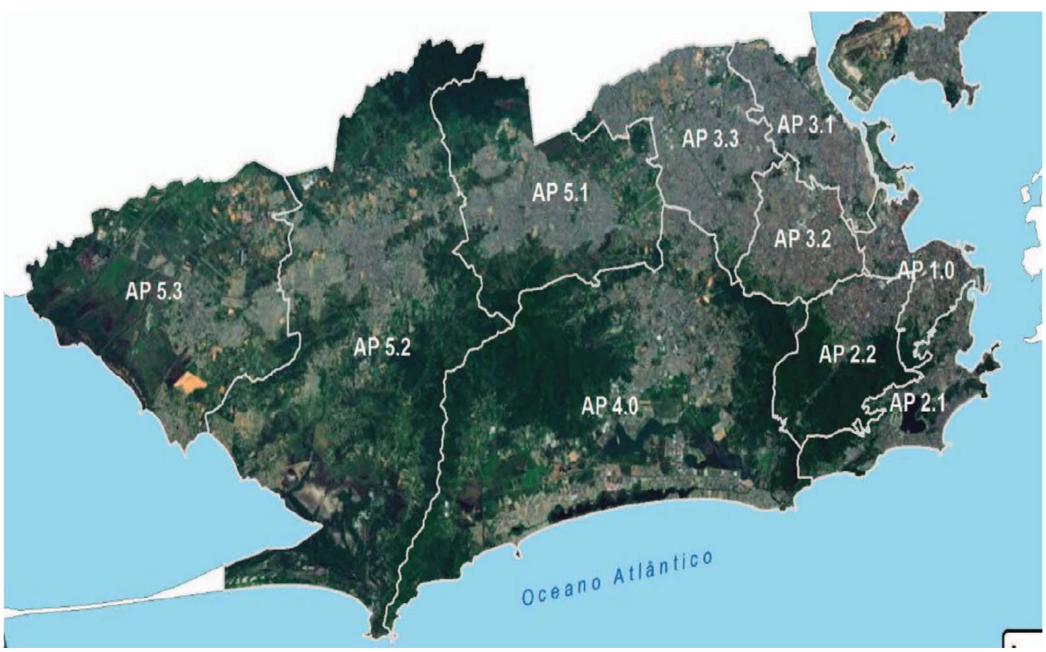

Figure 2 Health urban planning zones map of Rio de Janeiro, Brazil, 2023.

their human development indexes (HDI) are under the city's mean HDI (0.799), being 0.760 and 0.771, respectively. On the other hand, the South Zone has the city's highest HDI (0.901) and an IAGT two to three times higher (66 m^2/hab) than the urban zones [22].

The Central Zone has the highest proportion of people living in low-income communities (29%) in this study, and the North Zone has the highest number and area of slums in the city. For every two people living in slums in Rio de Janeiro, one person lives in the North Zone, proportionally 49.9% of the total population living in the city's slums [23]. However, in this study, more than half (56.6%) of the North Zone study population reported not living in low-income communities, although living near streets with heavy traffic (57.5%) or near business establishments (66%). These findings can be associated with the high lead exposure (p = 0.011) and high PbHg exposure (p = 0.046) observed in newborns not living in low-income communities.

The West 2 Zone also has most people reporting living near streets with heavy traffic (52.5%) or business establishments (77.4%), but it also has the highest IAGT of the city (240.43 m^2/hab) and the lowest building (2.101 m^2/Ha) and population (35 hab/Ha) density. Maia, Neto, and Costa [24] pointed out that building verticality is one of the factors associated with pollutant concentration.

The PIPA cohort project's findings indicate that building (m^2/Ha) and population (hab/Ha) density, associated with a low green area percentage, and the proximity of streets with heavy traffic are the most significant factors determining prenatal exposure to metals, mainly associated with lead exposure in the study population. It is essential to point out that the two zones (North and Central) that present the worst indicators of these conditions also have low human development indexes (HDI).

The discussion about socio-environmental vulnerability should embrace urban planning to avoid accumulating multiple social and environmental problems in specific neighborhoods. In a systematic review study, Twohig-Bennett and Jones [25] concluded that greenspaces are associated with multiple health benefits, including a decreased risk of preterm birth and small size for gestational age. The World Health Organization (WHO) [26] recommends that urban residents should have access to at least 0.5–1 ha of public green space within 300 m of their homes. The study of the environmental health inequalities related to exposure to environmental pollutants should go far beyond the established socio-economic factors. It should include urban planning and the availability of green spaces. The specific objective of creating inclusive green spaces should be integrated into urban planning and housing development [27, 28].

Maternal fish consumption once a week or more is associated with higher levels of mercury and arsenic (≥median). Bauer et al. [29] evaluated the mercury contamination of marine fish species from the Rio de Janeiro coast. The authors reported that all samples presented total mercury concentrations below the limits established by Brazilian and international regulations, and the Hg intake did not exceed the provisional tolerable weekly intake. However, they also warned that the ocean's mercury levels have risen and highlighted the importance of monitoring the mercury levels in the fish species most consumed by humans.

It is important to draw attention to the high number of women exposed to tobacco throughout their pregnancy. According to Domingues, Figueiredo, and Leal [30], based on data produced from a Brazilian nationwide hospital-based study ("Birth in Brazil") conducted in 2011–2012, there was a prevalence of 9.6% of smoking at any time during pregnancy. Far beyond the maternal and fetal risks already pointed out by the authors by tobacco exposure, the PIPA's data showed that it is also related to higher levels of mercury and lead in the newborns' cord blood.

The PIPA cohort project presents some limitations. It was developed at a university hospital (UFRJ Maternity School), and it is a hospital-based cohort that may not represent the entire population of Rio de Janeiro. However, the socio-demographic information characteristics in the PIPA cohort project were similar to those in the Rio de Janeiro municipality database [31].

CONCLUSION

The PIPA cohort project results indicate that lower availability of urban green spaces in residential zones is associated with higher environmental exposure to metals (lead, arsenic, and mercury) during pregnancy. The lack of urban green spaces can be seen as a socio-environmental vulnerability indicator. Understanding this is fundamental to policymakers considering urban planning as an environmental determinant of health. We hope this study can contribute to this.

ACKNOWLEDGMENTS

The authors would like to acknowledge the UFRJ Maternity School team for their broad support of the PIPA project and the study participants' contributions.

DECLARATIONS

ETHICS APPROVAL

This research involved human participants. The Federal University of Rio de Janeiro (UFRJ) Maternity School Ethics Committee approved all procedures (reference number: 6.494.730). Before any procedure was performed, all participants signed an informed consent form.

CONSENT FOR PUBLICATION

All authors agree with the publication of this manuscript.

DATA SHARING

The data collected for the study will be available to others at the end of the study, in December 2026, by filling out a request form (PIPA Database request form, PIPA Proposal submission form) from https://pipaufrj.me.ufrj.br/en/scientific-production-regiment/. The study protocol, statistical analysis plan, questionnaires, and informed consent form are also available from https://pipaufrj.me.ufrj.br/en/scientific-production-regiment/.

COMPETING INTERESTS

The authors have no competing interests to declare.

FUNDING

The Brazilian government provided funding: the National Council for Scientific and Technological Development (grant 409275/2018-2), the Science and Technology Department (grant 4041608/2019-1), and the Surveillance Health Secretary (grant 733663/19-002), Ministry of Health and the Rio de Janeiro State Foundation to Support Research (grant E-26/010.001894/2019). The funding sources had no involvement in any step of study development.

CONTRIBUTORS

CIRFA coordinated the study and conceptualized the manuscript. GND and ND are responsible for collecting the data, performing the statistical analyses, and accessing and verifying the data. All authors are responsible for the conception and study design, interpretation of results, manuscript preparation, and critical revision of the manuscript for important intellectual content. All authors had full access to all the data in the study and were ultimately responsible for deciding to submit this manuscript for publication.

This manuscript is original research and has not been submitted to, nor is it under review at, another journal or other publishing venue.

ADDITIONAL FILES

The additional files for this article can be found as follows:

- **Supplementary File 1.** Table A1. Prevalence ratio of exposure to environmental pollutants of newborns by urban zones of the city. PIPA Cohort Project, Rio de Janeiro, Brazil. DOI: https://doi.org/10.5334/aogh.4512.s1.
- **Supplementary File 2.** Table A2. Prevalence ratio of exposure to environmental pollutants of newborns by socio-environmental conditions. PIPA Cohort Project, Rio de Janeiro, Brazil. DOI: https://doi.org/10.5334/aogh.4512.s2.
- **Supplementary File 3.** Table A3. Personal and housing characteristics during pregnancy of PIPA Cohort participants by fish consumption per week. PIPA Cohort Project, Rio de Janeiro, Brazil. DOI: https://doi.org/10.5334/aogh.4512.s3.

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TO CITE THIS ARTICLE:
Fróes-Asmus CI, Damasceno N, Prata-Barbosa A, Luiz RR, Damacena GN, Meyer A, Rezende J, Amim J, Carvalho D, Medronho R, da Cunha AJLA, Câmara VdM. Urban Green Spaces and Newborns Metal Concentrations in Rio de Janeiro, Brazil. *Annals of Global Health*. 2024; 90(1): 56, 1–16. DOI: https://doi.org/10.5334/aogh.4512

Submitted: 11 July 2024
Accepted: 19 August 2024
Published: 13 September 2024