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Time-trends of blood lead levels from 2020 to 2023 in pregnant and breastfeeding women from Adjara, Georgia—A birth registry-based study

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ABSTRACT

Background: In response to substantial lead exposure, the autonomous republic of Adjara in Georgia initiated complementary blood lead level (BLL) testing for pregnant women as part of their antenatal care services in 2020.

Objectives: To study the background BLLs in pregnant and breastfeeding women in Adjara and explore the time-trends of BLLs from September 2020 to July 2023.

Methods: We used data on BLLs during pregnancy or postpartum from the lead screening program in Adjara, combined with data from the Georgian Birth Registry, totaling 9,510 women. To study the temporal changes in BLLs, we used independent samples t-tests and chi-square tests.

Results: In 2020, the mean (standard deviation [SD]) BLL was 8.8 (5.4) μg/dL, declining annually by 1.0–2.2 μg/dL to reach 3.6 (2.5) μg/dL in 2023. The prevalence of pregnant women with BLLs ≥3.5, ≥5.0, and ≥10.0 μg/dL also decreased from 2020 to 2023. Specifically, 21.2% of women in their first trimester had BLLs ≥10 μg/dL in 2020, compared with 2.3% in 2023. Similarly, 73.5% had BLLs ≥5.0 μg/dL in 2020, which declined to 20.4% in 2023. Lastly, 89.1% had BLLs ≥3.5 μg/dL in 2020, decreasing to 38.6% in 2023.

Discussion: In 2023, nearly 40% of women in their first trimester had BLLs of ≥3.5 μg/dL, a level considered the reference value in the United States (US) and corresponding to the 97.5th percentile among US children. From 2020 to 2023, the mean BLL in pregnant women decreased by 59%, accompanied by a considerable decline in the prevalence of women with BLLs ≥3.5, ≥5.0, and ≥10.0 μg/dL. Despite the encouraging downward trend in BLLs throughout the study period, our data indicate that a considerable number of fetuses continue to be exposed to harmful levels of lead and that lead exposure remains a significant public health challenge in Adjara.

1. Introduction

Exposure to lead has been recognized for decades as a cause of serious harm to humans, especially young children (Agency for Toxic Substances and Disease Registry, 2020). However, despite this knowledge, lead exposure remains a serious problem worldwide, particularly in low- and middle-income countries (Ericson et al., 2021). Elevated blood lead levels (BLLs) in children are associated with an increased risk of damage to the brain and nervous system. Lead is particularly harmful to the developing fetus because it can cross the placental barrier (Al Osman et al., 2019; RísovÁ, 2019). Lead is stored in human bone, and during periods of increased bone turnover, such as pregnancy, bone lead is released into the bloodstream (Gulson et al., 2003). Hence, past exposure can also affect the current fetus. Even relatively low BLLs are associated with decreased intelligence, behavioral difficulties, and learning problems (Al Osman et al., 2019; Jakubowski, 2011); therefore, preventing lead exposure in women of reproductive age and pregnant women is crucial. In adults, past and present lead exposure has been linked to a large number of adverse health effects, including an increased risk of cardiovascular diseases (Agency for Toxic Substances

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and Disease Registry, 2020). In 2019, an estimated 785 million intelligence quotient (IQ) points were lost globally due to lead exposure in children aged <5 years. Furthermore, 5.5 million deaths from cardiovascular diseases were attributable to lead exposure (Larsen and Sánchez-Triana, 2023).

Lead is a naturally occurring metal that is released into the surrounding environment through anthropogenic activities, such as mining and smelting, waste incineration, and the production of lead-containing products, including batteries (Agency for Toxic Substances and Disease Registry, 2020). Historically, leaded gasoline has been a significant source of lead exposure. However, the final stockpile of leaded gasoline was consumed in 2021, leading to the global declaration of freedom from its use (United Nations Environmental Programme, 2021). Other well-known sources of lead exposure include leaded paint, old leaded water pipes, plastic toys, cosmetics, glazed surfaces on pottery, spices adulterated with lead chromate, and natural remedies (Forsyth et al., 2019; Swaringen et al., 2022). Despite its environmental ubiquity, exposure of children to lead can be prevented. Through active surveillance and primary prevention measures, the proportion of children aged 1–5 years in the United States (US) with BLLs ≥5 μg/dL decreased from 99.8% in 1976 to 1.3% in 2016 (Allwood et al., 2022). Currently, 97.5% of US children have BLLs below 3.5 μg/dL, which is referred to as the BLL reference value by the Center of Disease Control and Prevention (Ruckart et al., 2021). Nonetheless, no level of lead exposure is deemed safe (Agency for Toxic Substances and Disease Registry, 2020).

In 2018, the National Statistics Office of Georgia, United Nations International Children's Emergency Fund (UNICEF), and National Center for Disease Control and Public Health (NCDC) in Georgia conducted the Multiple Indicators Cluster Survey (MICS). The survey involved BLL measurements in a random sample of 1578 children aged 2–7 years. The results indicated that 41% and 16% of children had BLLs ≥5 and > 10 μg/dL, respectively (National statistics office of Georgia, 2019). In the autonomous republic of Adjara in western Georgia, 85% of children had BLLs ≥5 μg/dL. In response to these high BLLs, routine testing of BLLs in pregnant and breastfeeding women was implemented by the Adjara government in 2020. The present study aimed to report background BLLs in pregnant and breastfeeding women in Adjara and explore the time trends from 2020 to 2023.

2. Methods

2.1. Lead biomonitoring program of pregnant and breastfeeding women in Adjara

In fall 2020, the government of Adjara initiated free-of-charge BLL testing for pregnant and breastfeeding women registered as Adjara residents. In the first year, BLL testing was only offered to pregnant and breastfeeding women with suspected high lead exposure. However, from the second half of 2021, BLL testing was implemented as an additional service free of charge for all pregnant women receiving antenatal care (ANC). Women with BLLs >5 μg/dL who were breastfeeding after delivery were offered a repeat BLL test.

2.2. Georgian Birth Registry

The Georgian Birth Registry (GBR) was implemented in 2016 to register health information for mothers and their babies during the antenatal care, delivery, and postpartum periods (Anda et al., 2017). Registering pregnant women in the GBR is mandatory by law. In 2021, the registry covered 99.8% of all deliveries in the country (National Center for Disease Control and Public Health, 2022). The GBR includes more than 400 variables, including information about the mother's education; residency; health conditions before, after, and during pregnancy; as well as all essential information about the fetus and the newborn. All Georgian citizens have unique personal identification numbers that allow for the linkage of information between different health registries and databases.

2.3. Informed consent

BLL screening was integrated into the ANC program in Adjara. Women signed informed consent for all tests performed during pregnancy, childbirth, and postpartum upon initiation of ANC. Georgian law mandates the registration of all information during ANC and childbirth in the GBR and registration cannot be waived.

2.4. Ethical approvals

The current study was approved by the Regional Committee for Medical and Health Research Ethics in Northern Norway (Reference number: 577538), as well as by the ethical board at NCDC (IRB#2023-002).

2.5. Study sample

We included all available BLL data in pregnant and breastfeeding women extracted from the lead biomonitoring program for pregnant and breastfeeding women between September 2020 and July 2023, totaling 10,123 registrations. After excluding duplicate entries (n = 7), 10,116 women who underwent at least one BLL test remained. Using a unique 11-digit personal identification number, the NCDC in Georgia merged the data with all pregnancies registered in the GBR between January 1, 2020, and September 7, 2023 (n = 196,349). We excluded 292 women who had a BLL test result but were not registered in the GBR, as well as 186,817 women who were registered in the GBR but had no BLL test, mainly because they were not residing in Adjara. Furthermore, 243 women who were not residing in, or were not registered residents of, Adjara were also excluded. Based on the BLL test date, date of conception (calculated from the gestational age [GA] at delivery, induced abortion/miscarriage, or registration), and date of delivery, abortion/miscarriage, or pregnancy registration, we matched each BLL test result to the correct pregnancy. We excluded 27 women who underwent the BLL test prior to their first conception and 44 women who underwent their first BLL test post-abortion and prior to the next conception (if any). This left 9510 women with at least one BLL test during pregnancy or postpartum and residing in or registered as residents of Adjara (Fig. 1).

2.6. Chemical analysis

Venous blood samples were collected in 6 mL test tubes with EDTA buffer for trace element analysis. Blood samples were shipped to the Mediprime LLC Medical Laboratory in Tbilisi, Georgia, an ISO15189 certified medical laboratory. Briefly, 100 μL of whole blood was transferred to an Eppendorf tube. Next, 100 μL of 2% ultra-pure nitric acid (HNO_3, 70%, purified by redistillation, ≥99.999% trace metals basis, MERCK) was added to the test tube along with 900 μL of modifier solution. The mixture was then vortexed at 5000 rpm for 1 min. Next, 300–500 μL of the supernatant was transferred to another test tube and analyzed using a graphite furnace Agilent 280Z Atomic Absorption Spectrometer with Zeeman background correction (Agilent Technologies, California, USA). The modifier solution was prepared from 400 mL of deionized water, 25 mL of TRITON™ X-100 (v/v) 10% solution (J. T. Baker®), 5 mL of a 20% ultra-pure ammonium dihydrogen phosphate ($NH_4H_2PO_4$) solution (99.9%, trace metals basis, Thermo Scientific), and 1 mL of concentrated HNO_3. This mixture was then diluted to 500 mL with deionized water. Blank samples of whole blood (blank control, ACQ Science) and samples of reference material (Seronorm™Trace Element serum, Sero) were prepared using the same method in parallel with the blood samples. The absolute concentration of the certified reference material did not differ more than ± 10% from the certified values. The method detection limit (MDL) was 0.9 μg/dL.

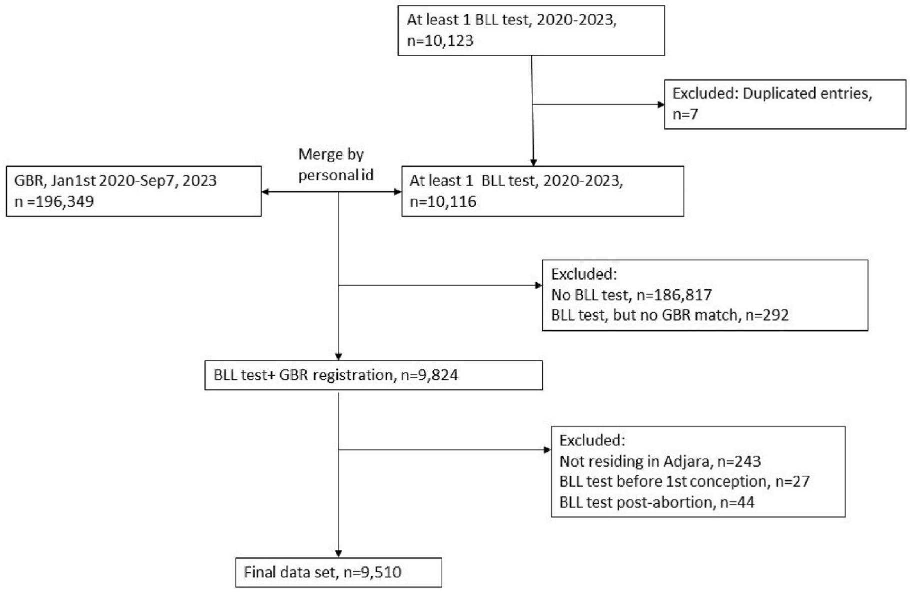

Fig. 1. Flow chart of the study sample selection procedure. Data from the lead biomonitoring program of pregnant and breastfeeding women in Adjara and the Georgian Birth Registry, 2020–2023.

2.7. Variables

We included data on the results of the first BLL test performed during pregnancy and registered during the study period between September 2020 and July 2023. Most pregnancies resulted in deliveries; however, some were terminated by induced abortion or miscarriage. Several pregnancies were ongoing at the time of data extraction, and their outcomes are unknown. We estimated the GA in weeks for the first BLL test by calculating the time from the BLL test date to the date of delivery, induced abortion/miscarriage, or pregnancy registration (for ongoing pregnancies). This number was then subtracted from the GA week at delivery, induced abortion/miscarriage, or pregnancy registration. The GA at BLL test was further grouped into pregnancy trimesters using the following cut-offs: first trimester, GA <13 weeks; second trimester, GA 13–27 weeks; and third trimester, GA ≥28 weeks. We extracted information on the municipality of residency, maternal age, and parity (nullipara/multipara) from the GBR and calculated the test year from the BLL test date. BLLs below the MDL were replaced by $MDL/\sqrt{2}$.

2.8. Statistical analysis

Maternal characteristics are presented as mean and standard deviation (SD) for continuous variables and frequencies and percentages for categorical variables. Differences in characteristics across test years were compared using independent samples t-tests and chi-square tests. BLLs are reported as mean (SD), median, interquartile range, and minimum (min) and maximum (max) concentrations. We compared mean BLLs across test years and timing of BLL testing using independent samples t-tests. Additionally, differences in prevalences of BLLs ≥3.5, ≥5.0, and ≥10.0 μg/dL across test years were assessed using chi-square tests. We conducted an additional analysis of differences in BLLs across pregnancy trimesters and postpartum measurements, excluding the first year of measurements (Sep 2020–Sep 2021) as BLL testing was not offered to all pregnant and breastfeeding women until the second half of 2021. All statistical analyses were conducted using Stata version 18.0 (StataCorp LCC, College Station, Texas, United States). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Study sample characteristics

Between September 1, 2020, and September 7, 2023, 25,202 women registered as pregnant in the GBR were either residing in or registered as residents of Adjara. Of these, 9,510 underwent at least one BLL test during pregnancy or in the postpartum period between September 1, 2020, and July 19, 2023. This represents a BLL testing coverage of 37.7%. From September 2021, the coverage increased to 39.5%. Most study participants underwent BLL testing in 2021, accounting for 45.4% of all tests, followed by 28.9% in 2022. A higher percentage of women underwent BLL testing during the third trimester of pregnancy in 2020 (43.3%) and 2021 (24.4%) than in 2022 (4.2%) and 2023 (6.5%; Table 1). Accordingly, a higher percentage of women underwent BLL testing in the first trimester of pregnancy in 2022 (68.2%) and 2023 (62.1%) than in 2020 (21.4%) and 2021 (31.4%). The mean maternal age was 28 years in 2020 and increased slightly with time to almost 29 years in 2023. Most women were multiparous and had secondary education. In 2022 and 2023, a higher percentage of women had higher education than in previous years. However, a larger proportion of missing information about parity and education in 2022 and 2023 compared to previous years resulted from ongoing pregnancies at the time of data extraction. The percentage of women from various municipalities was relatively stable over time, although the proportion of women from Batumi decreased and the percentage of women from Shuakhevi and Khulo increased over time (Table 1).

3.2. Changes in BLLs through pregnancy and childbirth

Across the entire study sample, regardless of the year of testing, the mean BLL during the first trimester of pregnancy was 5.2 μg/dL, with an SD of 3.7 μg/dL. BLLs increased with advancing GA. Specifically, from the first to the second trimester, the mean increase was 0.4 μg/dL (95 % confidence interval [CI]: 0.24 to 0.58). From the second to the third trimester the mean increase was 2.07 μg/dL (95% CI: 1.82 to 2.33). Lastly, from the third trimester of pregnancy to the postpartum measurements, the mean BLL increase was estimated to be 0.37 μg/dL (95% CI: 0.13 to 0.87). Accordingly, the mean (SD) BLL in the third trimester of pregnancy was estimated to be 7.7 (5.0) μg/dL. After excluding

Table 1
Study sample characteristics, stratified by year of blood lead level (BLL) test. Data from the lead biomonitoring program of pregnant and breastfeeding women in Adjara, Georgia, and the Georgian Birth Registry (2020–2023).

	2020	2021	2022	2023	p
n (%)	938 (9.9)	4317 (45.4)	2750 (28.9)	1505 (15.8)	
Time of first BLL test, n (%)					<0.001
1st trimester	21.4	31.4	68.2	62.1	
2nd trimester	30.1	35.4	24.5	30.2	
3rd trimester	43.3	24.4	4.2	6.5	
Post-delivery	5.2	8.8	3.2	1.2	
Age, mean (SD)	28.0 (5.4)	28.4 (5.5)	28.7 (5.7)	28.8 (5.7)	0.001[a]
Parity (%)					<0.001
Primipara	37.2	34.8	39.5	17.5	
Multipara	62.6	65.1	57.5	23.7	
Missing	0.2	0.1	3.0	58.8	
Education (%)					<0.001
Primary	4.3	3.0	1.4	1.3	
Secondary	69.8	73.1	45.2	19.0	
Higher	19	16.9	34.6	47.2	
Unknown	6.9	7.1	18.8	32.5	
Municipality of residency (%)					<0.001
Batumi	55.3	51.6	54.1	52.5	
Keda	3.5	3.7	4.1	4.3	
Kobuleti	15.6	17.0	16.9	14.6	
Khelvachauri	18.0	20.7	15.6	16.9	
Shuakhevi	2.7	2.6	3.6	4.3	
Khulo	4.7	4.2	5.2	7.3	
Missing	0.2	0.4	0.6	0.1	
Outcome of pregnancy (%)					<0.001
Delivery	99.8	99.9	97.0	41.3	
Induced abortion/miscarriage	0.2	0.1	1.9	1.5	
On-going			1.1	57.3	

n, frequency; BLL, blood lead level; SD, standard deviation.
[a] The p value refers to the comparison between pregnancies in 2020 and 2023.

measurements from the first year, the trend remained similar, although the estimates changed slightly, especially for the postpartum measurements: the mean BLL increased from the first to the second trimester by 0.25 μg/dL (95 % CI: 0.05 to 0.44). From the second to the third trimester, the mean BLL increase was 1.35 μg/dL (95% CI: 1.01 to 1.69). Lastly, from the third trimester of pregnancy to the postpartum measurements, the estimated BLL increase was 1.18 μg/dL (95% CI: 0.60 to 1.76). Notably, when stratified by year, BLLs were lowest in the second trimester of pregnancy, except in 2022 (Supplementary Table 1).

3.3. Time-trends of BLLs

In 2020, the mean BLL among study participants was 8.8 μg/dL (with an SD of 5.4 μg/dL), ranging from below the MDL to 34.1 μg/dL. From 2020 to 2023, a steady decline in BLLs was observed across all pregnancy trimesters as well as in postpartum measurements (Fig. 2 & Supplementary Table 1). In the whole study sample, the mean decline from 2020 to 2021 was 1.9 μg/dL (95% CI: 2.2 to −1.6); from 2021 to 2022, it was 2.2 μg/dL (95% CI: 2.4 to −2.1), whereas from 2022 to 2023, the estimated decline in BLLs across all groups was estimated to be 1.0 μg/dL (95% CI: 1.2 to −0.85). Accordingly, in 2023, the mean (SD) BLL among pregnant and breastfeeding women was 3.6 (2.5) μg/dL, ranging from below the MDL to 27.3 μg/dL.

The observed decrease in BLLs was consistent across all municipalities in Adjara (Fig. 3). This downward trend among women in the first

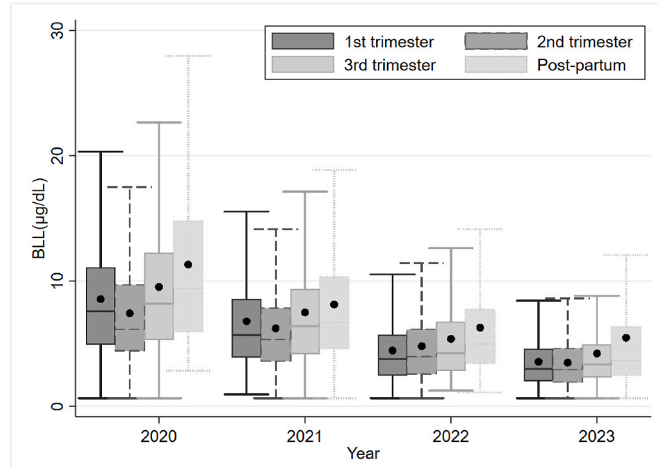

Fig. 2. Blood lead levels (BLL, μg/dL) in Adjara, Georgia, across years (2020–2023) and pregnancy trimesters or postpartum measurements. Each box represents the interquartile range of BLLs, with the bottom line indicating the first quartile and the upper line indicating the third quartile of BLLs. The vertical lines within the boxes represent the median BLLs, while the black filled circles represent the arithmetic mean in each group. The whiskers extend to the lowest/highest datapoints that are within 1.5 times of the interquartile range below/above the first/third quartile, depicting the spread of data points in the lower/upper 25% of the data. Note that extreme values are not included in the plot.

trimester of pregnancy was statistically significant (independent samples t-tests, $p < 0.05$) throughout the study period for all years and municipalities, except Batumi, Keda, Khulo, and Shuakhevi in 2020–2021, as well as Keda and Shuakhevi in 2022–2023.

Additionally, the prevalence of pregnant or breastfeeding women with BLLs ≥3.5, ≥5.0, and ≥10.0 μg/dL declined considerably from 2020 to 2023 (Fig. 4). In 2020, 21.2% of women in the first trimester of pregnancy had BLLs ≥10 μg/dL; 2021, 17.0%; 2022, 4.7%; and 2023, 2.3 % (Fig. 4A). Similarly, in 2020, 73.5% of women in the first trimester of pregnancy had BLLs ≥5.0 μg/dL; 2021, 59.1%; 2022, 32.3%; and 2023, 20.4% (Fig. 4B). In 2020, 89.1 % of women in the first trimester of pregnancy had BLLs ≥3.5 μg/dL; 2021, 80.9%; 2022, 54.2%; and 2023, 38.6% (Fig. 4C). All observed differences were statistically significant (chi square tests, $p < 0.01$).

4. Discussion

This registry-based study demonstrates persistent lead exposure among pregnant and breastfeeding women in Adjara, Georgia, despite a marked reduction in BLLs from 2020 to 2023. In 2023, approximately 40% of women in the first trimester of pregnancy had BLLs of ≥3.5 μg/dL, and the median BLL was 4.2 μg/dL. Because lead can cross the placental barrier, maternal and fetal BLLs are typically highly correlated (Agency for Toxic Substances and Disease Registry, 2020), suggesting that newborns in Adjara may exhibit similar BLLs. As a comparison, only 2.5% of US children aged 1–5 years had BLLs above 3.5 μg/dL during the period 2015–2018 (Ruckart et al., 2021). However, from 2020 to 2023, we observed a 59% reduction in mean BLLs in Adjara, accompanied by a decline in the prevalence of pregnant women with BLLs ≥3.5, ≥5.0, and ≥10.0 μg/dL. This reduction in BLLs was evident across all municipalities in the region. Despite the encouraging downward trend in BLLs throughout the study period, our data indicate that lead exposure remains a significant public health challenge in Adjara.

The observed median BLL in women from Adjara was higher than that reported in relatively recent studies conducted in other parts of the world. A large study from Japan (n = 16,243), measured a median BLL of 0.63 μg/dL (min-max: 0.16–7.4 μg/dL) in pregnant women sampled

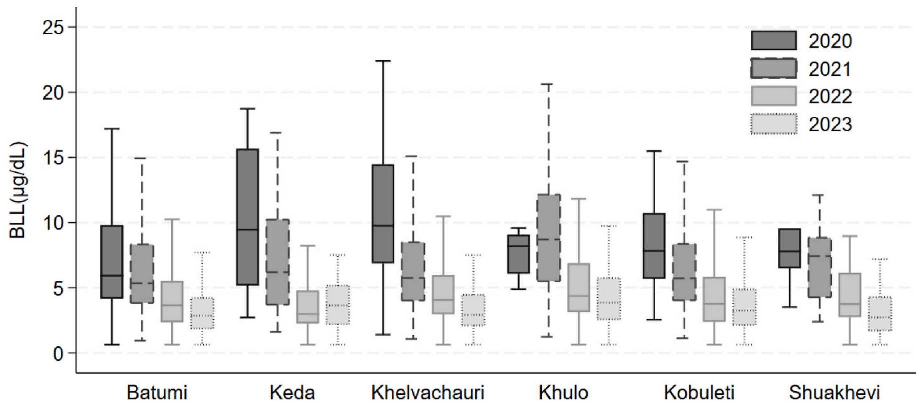

Fig. 3. Blood lead levels (BLL, µg/dL) in the first trimester of pregnancy across test years (2020–2023) and municipalities of residence. Each box represents the interquartile range of BLLs, with the bottom line indicating the first quartile and the upper line indicating the third quartile of BLLs. The vertical lines within the boxes represent the median BLLs, while the black filled circles represent the arithmetic mean in each group. The whiskers extend to the lowest/highest datapoints that are within 1.5 times of the interquartile range below/above the first/third quartile, depicting the spread of data points in the lower/upper 25% of the data. Note that extreme values are not included in the plot.

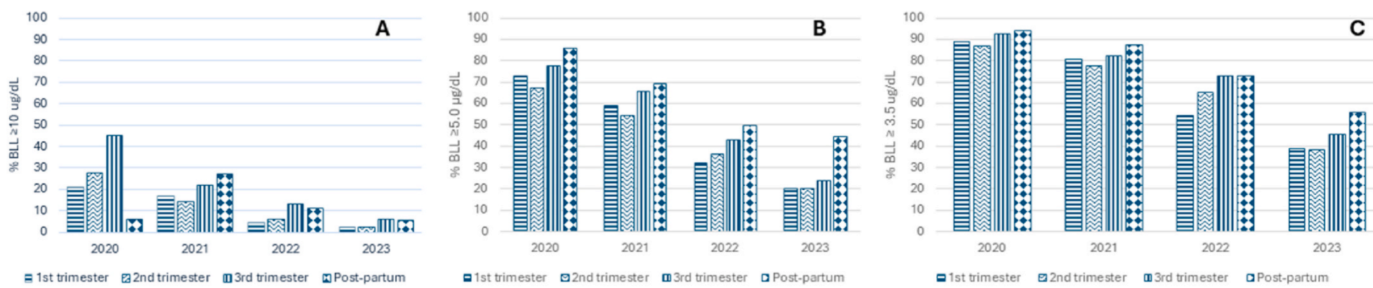

Fig. 4. Prevalence of BLLs ≥10.0 (A), ≥5.0 (B), and ≥3.5 µg/dL (C) in pregnant and breastfeeding women in Adjara, Georgia, 2020–2023.

between 2011 and 2014 (Goto et al., 2021). A US study from 2022 reported a mean BLL of 0.53 µg/dL for pregnant women (n = 1230) during the period 2017–2018, with 0.76% of the women having BLLs >2.0 µg/dL (Wang et al., 2022). However, a recent study from southern Thailand reported a mean BLL of 5.1 µg/dL among 28 first-trimester pregnant women in 2021, which is slightly higher than that observed in Adjara (Waeyeng et al., 2022). In 99 pregnant women in Mexico City, sampled between 2007 and 2011, the median BLL in the third trimester of pregnancy was 2.9 µg/dL (Niedzwiecki et al., 2021), whereas the median BLL in third-trimester pregnant women in China (n = 121) was 2.5 µg/dL during the period 2019–2020 (Li et al., 2021). In comparison, third-trimester pregnant women in Adjara had a median BLL of 3.7 µg/dL in 2023. In Libya, mean BLLs in 236 pregnant women varied between 5.9 and 6.8 µg/dL depending on city of residence (Alemam et al., 2022). Although the mean BLL was higher in Libya than in Adjara, the maximum BLL measured in Adjara was considerably higher (27 µg/dL) than that measured in Libya (13.1 µg/dL). Nonetheless, the variability in sample size and representativeness within each respective country across the aforementioned studies should be considered when interpreting their findings.

The clinical implications of the observed BLLs in this study may be significant. During pregnancy, the potential impacts may include increased risks of miscarriage (Kaur et al., 2022; Ren et al., 2023) and preterm birth (Habibian et al., 2022). In adults, elevated BLLs are associated with a wide range of health effects including neurological, renal, reproductive, hematological, and cardiovascular effects (Agency for Toxic Substances and Disease Registry, 2020; Cook et al., 2022). While the mechanism is not completely understood, it is evident that the placenta is an insufficient barrier for lead (RÍsovÁ, 2019). Hence, maternal BLLs may influence the fetus and contribute to neurological effects, including reduced IQ, learning difficulties, and behavioral issues in children (Agency for Toxic Substances and Disease Registry, 2020; Crump et al., 2013). Additionally, elevated BLLs may affect children's iron status due to competition for intestinal absorption of divalent metal ions (Bressler et al., 2004), further impacting cognitive development and the immune system (Abbaspour et al., 2014).

Along with the potential increase in miscarriages and preterm births, the substantial number of children born with pre- and perinatal lead exposure also poses a serious risk of cognitive losses in future generations, underscoring the extensive public health implications of elevated BLLs. It is also evident that lead exposures continue after birth in children (National statistics office of Georgia, 2019) and lead is present in adults in Adjara. This could, in turn, contribute to the leading cause of death in Georgia which was circulatory system diseases in 2023 (National Statistics Office of Georgia, 2023). Hence, it seems evident that effective measures to reduce lead exposures could significantly enhance population health.

The sources of lead exposure in Adjara, and Georgia in general, have not been fully identified. However, several studies have indicated that illegal adulteration of spices constitutes a significant source of lead exposure in the country (Ericson et al., 2020; Hore et al., 2019). Additionally, lead in soil, paint, and dust have been cited as potentially important sources of exposure for children (Laycock et al., 2022; Leonardi et al., 2023). Furthermore, lead has been detected in numerous consumer products commonly found in Georgian households, including cosmetics, glazed ceramics, toys, and construction materials (Avkopashvili, 2019). In 2014, the maximum permissible lead content in gasoline in Georgia was reduced to 0.005 g/L (The Government of Georgia, 2004). Legislation banning the use of lead in construction materials in kindergartens was enacted in 2017 (The Government of Georgia, 2017). Subsequently, a ban on the sell of unpacked and unlabeled spices in bazars was implemented in February 2018 (The

Government of Georgia, 2018). After the release of the MICS survey results in 2019, public awareness of lead exposure as a public health concern in Georgia increased considerably. This was largely due to active public awareness campaigns by the government, nongovernmental organizations, and media. In 2019, the Georgian government also implemented free-of-charge BLL testing for "high-risk" children up to the age of 7 years, doctor's consultations, and iron, calcium, and multi-vitamin supplements to children with elevated BLLs (Chkhaidze et al., 2019). In early 2020, the government approved regulations for lead in toys (The Government of Georgia, 2020). Given the absence of large-scale exposure source investigations in Georgia, attributing the observed decrease in BLLs to preventative actions is challenging. However, the collective impact of more stringent regulations and increased public awareness of lead pollution may have contributed to the downward trend in BLLs.

In this study, we also observed that the BLLs varied according to the timing of blood sampling during pregnancy or after birth. Overall, BLLs increased during pregnancy and peaked after birth. However, the increase in BLLs from the first to the second trimester was small. When stratified by sampling year, a decline in BLLs from the first to the second trimester of pregnancy was observed in all years, except for 2022 (Supplementary Table 1). A decrease in BLLs from the first to the second trimester of pregnancy has also been observed by other studies and may be explained by a combination of increased blood volume, organ weight, and changes in metabolism (Gulson et al., 2016; Lagerkvist et al., 1996; Rothenberg et al., 1994; Schell et al., 2000). The increase in BLLs during the third trimester of pregnancy and postpartum period aligns with the findings of previous studies (Gulson et al., 2003, 2004; Lagerkvist et al., 1996; Schell et al., 2000). This increase can be attributed to the release of lead from the bones, which is intensified by bone remodeling to supply the heightened calcium needs of the fetus and newborn, particularly towards the end of pregnancy and during breastfeeding(Gulson et al., 2003, 2016; Rothenberg et al., 1994). Hence, past lead exposure contributes as an endogenous source of lead for the fetus and newborn, especially in late pregnancy and after birth. This underscores the importance of implementing primary prevention measures to minimize lead exposure in the entire Georgian population and prevent the accumulation of lead in the bones of young and fertile women, who will later give birth.

The main strengths of this study lie in its large sample size and linkage to the GBR, which ensures high-quality individual-level data. The main limitation was that only selected women were included in the first year, potentially introducing selection bias. However, because the data were stratified by year, we do not consider this a major problem. Additionally, after excluding data from the first year, the declining trend in BLLs remained. Another limitation was the inability to determine the exact GA for BLL sampling due to the way BLL data were registered. Instead, we could determine the pregnancy trimester during which blood samples for lead analysis were extracted.

To our knowledge, this is the first study to investigate BLLs in pregnant women in Georgia. This research is pivotal for understanding the extent of lead exposure in the country and serves as a benchmark for future studies. Despite the encouraging decreasing trend in BLLs among pregnant and breastfeeding women in Adjara over the last four years, we conclude that lead exposure remains a significant public health concern. This is underscored by the fact that almost 40% of first-trimester pregnant women had BLLs $\geq$3.5 μg/dL. To safeguard current and future generations from lead exposure, large-scale exposure source investigations including studies of lead in major food groups, combined with primary prevention measures to eliminate lead exposure, should be implemented.

CRediT authorship contribution statement

Charlotta Rylander: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Nona Ephadze:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Tinatin Manjavidze:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Erik Eik Anda:** Writing – review & editing, Investigation. **Nino Dzotsenidze:** Writing – review & editing, Investigation. **Rusudan Shavishvili:** Writing – review & editing, Project administration, Investigation, Data curation, Conceptualization.

Data availability

Data can be shared upon request to the principal investigator if legal and ethical requirements are fulfilled.

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Appendix A. Supplementary data

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