Prevalence and Determinants of Childhood Lead Poisoning in Zamfara State, Nigeria

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Background. Lead poisoning is a great public health concern in the Nigerian state of Zamfara due to widespread gold ore mining by artisan miners using rudimentary and unsafe processing techniques. Children aged ≤6 years are especially vulnerable to lead poisoning, which accounts for 0.6% of the global burden of disease. We undertook this study to find out the prevalence and determinants of childhood lead poisoning in Kawaye, a village located in Zamfara's Anka local government area (LGA).

Methods. We conducted a cross-sectional study in April 2013. Using simple random sampling technique, 307 eligible children aged ≤6 years were recruited. Data were collected using interviewer-administered semi-structured questionnaires. Blood specimens were collected via venous draw for blood lead level (BLL) assessment and soil at individual households was tested for presence of lead contamination using a portable X-ray fluorescence spectrometer. Statistical tests of Chi-square and multivariable logistic regression analyses were performed to evaluate factors potentially associated with elevated childhood BLL (≥5 μg/dL).

Results. A total of 307 children ≤6 years old were sampled, with males constituting 51% of the total (171). Mean age of children = 38.5 months ± 18.5 SD. Parents/guardians of the studied children were predominantly farmers (37%) and miners (15%), with 53.7% having some informal education while 4.2% had no education. Processing of ore within the living compound was reported by 4% of the miners; 7.5% returned home wearing working clothes; 7.2% brought tools home. Thirty percent of parents/guardians were living below the poverty line. The prevalence of lead poisoning (BLL ≥5 μg/dL) among the children studied was 92.5%, with 34 children (11.1%) having BLL ≥45 μg/dL. Fourteen percent of the households had soil lead levels >400 mg/kg. Being age 24-35 months, having childhood anemia, using kohl eye cosmetic and the combination of father's/guardian's low level of education and low socioeconomic status were found to be significant risk factors associated with childhood lead poisoning in the regression analyses.

Conclusions. The prevalence of childhood lead poisoning was high in Kawaye, which may be attributable to widespread unsafe mining and ore processing activities in the community. We recommended beginning treatment in all cases where severe lead poisoning was identified, and that further targeted interventions should be designed to address the identified risk factors in order to control and prevent further lead poisoning in the village and the state at large.

Competing Interests. The authors declare no competing financial interests.

Keywords. Prevalence, Determinants, Lead poisoning, Childhood, Zamfara State, Nigeria, Gold Ore, Mining, Artisanal Mining

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Introduction

Lead poisoning remains one of the most significant and prevalent diseases of environmental origin in the world, accounting for 0.6% of the global burden of disease.[1] It is a medical condition that occurs when lead builds up in the body, often over a period of months or years.[2] Children under the age of 6 years are especially vulnerable to lead poisoning, which can severely affect mental and physical development. Elevated blood lead levels (BLL) can trigger serious health conditions, ranging from muscle weakness, gastro-intestinal symptoms, anemia, kidney inflammation, convulsions and brain damage. Even low levels of lead are linked to lower intelligence quotient (IQ) scores and behavioral problems.

A plethora of well-designed prospective epidemiologic studies have convincingly demonstrated that low-level lead exposure (as low as 5 μg/dL) in children less than 6 years of age results in deficits of intellectual performance. For instance, for every incremental increase of 10 μg/dL of lead in the blood, IQ scores decline between 2.5 and 3.0 points.[3]

Individuals with certain risk factors such as calcium deficiency, iron deficiency, and diseases of organs targeted by lead (e.g. the brain or the kidneys), and possibly genetic susceptibility are more susceptible to lead toxicity. Anemia and socioeconomic factors are also important risk factors of lead poisoning.[4] Over 200 children from Nigeria's Zamfara state have reportedly died from lead intoxication since March 2010 and an estimated 18,000 children and adults have been affected by widespread lead contamination resulting from the informal extraction of gold from lead-bearing ore.[5] Children's BLLs in 2 acutely affected villages (Dareta and Yargalma) averaged 119 μg/dL (n = 463), ranging between 33.3–445 μg/dL, with 118 of the 463 resident children dying during May 2009-May 2010.[5-7]

Lead poisoning is a problem of great public health concern in Zamfara, owing to its high prevalence, morbidity and mortality. Children are exposed to lead primarily through hand-to-mouth contact or inhalation of lead dust. A main source of lead exposure in Zamfara is the artisanal gold ore mining and processing activities that are widespread in many villages within the state. The state is blessed with abundant mineral resources, including gold and lead deposits. The activities involved in such gold ore processing include: digging the ore from the ground; pounding and grinding it into powder; mixing the powder with water to separate out gold particles; treating the slurry with mercury to amalgamate gold particles; then heating the gold to separate out the mercury. The ore in some areas of Zamfara is heavily contaminated with lead, and the crude processing technique inadvertently frees lead particles, resulting in the contamination of air, soil and communal water resources (wells, streams and ponds) culminating in the deaths of children.

Abbreviations			
BLL	Blood lead levels	*OR*	Odds ratio
CDC	Center for Disease Control and Prevention	*PCV*	Packed cell volume
CI	Confidence interval	*mg/kg*	Milligram per kilogram
EPA	Environmental Protection Agency	*SD*	Standard deviation
IQ	Intelligence quotient	*SLL*	Soil lead levels
LGA	Local government area	*WHO*	World Health Organization
		μg/dL	Microgram per deciliter

The report into the 2010 outbreak of acute lead poisoning in the 2 most contaminated villages in the state revealed that 97% of children (n = 204) under the age of 5 years had BLLs above 45 μg/dL, the threshold for providing chelation therapy.[8] According to a World Health Organization (WHO) report, over 400 children were reported to have died as a result of the lead poisoning outbreak, 2,000 are currently on treatment and 4,000 remain at risk of poisoning.[6] The high prevalence of lead poisoning and its severe health impacts call for the investigation of the condition so as to find effective measures of control and prevention. This study was therefore undertaken to find out the prevalence of childhood lead poisoning, determine socio-demographic characteristics of children affected by lead poisoning, and identify determinants of childhood lead poisoning in a heretofore unstudied location: the village of Kawaye, a mining/ore-processing community in the Anka local government area (LGA) of Zamfara state.

Methodology

Study Design

A descriptive cross-sectional study was employed. The study population was made up of children aged ≤6 years from the village of Kawaye, Anka LGA of Zamfara state, Nigeria. A simple random sampling technique was used to recruit participants into the study. A mother/child dyad was randomly sampled per eligible household. Fisher's formula for estimating the minimum samples size for descriptive studies ($n = z^2pq/d^2$) was used to obtain the desired sample size, where n = minimum sample size, z = standard normal deviate at α probability (1.96), p = prevalence of lead poisoning in children (25%), q = 1-p and d = precision (0.05).[9,10] The desired sample size was computed to be 317 children aged ≤6 years. However, the total population of Kawaye is less than 10,000; as such, finite population correction was applied to the computed sample size, giving a final sample size of 307. Therefore, 307 children aged ≤6 years were recruited for the study.

Data Collection & Analysis

Data were collected using

interviewer-administered pre-tested semi-structured questionnaires. Respondents were parents/caregivers of children recruited for the study. Blood specimens were collected for assessment of lead and anemia. EDTA vacutainer tubes were used to store 3 mL fresh whole blood samples, which were analyzed using the LeadCare II blood lead analyzer (Magellan Diagnostics, U.S.A.) at the Center of Excellence on Lead and Other Heavy Metals Poisoning, Gusau, Zamfara state. Anemia was determined by drawing blood into a non-heparinized capillary tube which was centrifuged for 5 minutes at 12,000 g. The packed cell volume (PCV) was then determined using a microhematocrit reader. Further, soil samples from the households of all participants were tested for presence of lead. The locations from where the soil was tested included: the main entrance, children's play area, children's sleep area, cooking area, washing area, common area, and other sites, such as under the tree, drinking water pot area, wall plaster and animal area. At least 4 of the above-mentioned areas were tested at each household, using a portable X-ray fluorescence spectrometer.

The data obtained was entered into Epi Info™7 software (CDC, U.S.A.) to generate frequencies, proportions, tables and charts. Statistical tests of Chi-square and regression analysis were also used as appropriate. Epi Info™7 software was used in performing the regression analysis. The response variable was elevated BLL ≥5μg/dL. All possible variables were fitted into the model using the step-wise elimination method and results obtained were reported as appropriate. The final model included interaction terms representing the combined effects of low father's education * low household income and low mother's education * low household income in addition to the main effects of education and income.

Ethical approval to undertake the study was obtained from the Scientific and Ethical committee of Ahmadu Bello University, Zaria. Permission to carry out the study was also granted by the Zamfara State Ministry of Health. In addition, written informed consent was obtained from the parent/guardian of each study participant. The consent form was translated into the local language (Hausa). Literate respondents indicated acceptance by signing the form while non-literate respondents indicated acceptance by affixing right thumbprints on the form in the presence of a literate witness who also appended his signature on the form.

Background Contamination, Accuracy and Precision

The background lead contamination levels were checked by using blood samples that were predetermined as low (<3.3 μg/dL). These samples were used in the field and the laboratory where analysis was done. The bottles containing the low samples were opened and then closed in the field and at the laboratory and were subsequently labeled as BLANK-Field and BLANK-Lab, respectively. The samples were then analyzed together with other collected samples to evaluate for contamination in the field and laboratory respectively.

To ensure precision, blood samples were collected in such a way that every 20th sample was collected in duplicate. The duplicate samples were run one after the other to see whether the analyzer would give similar results for both samples. Any deviation above ± 2 SD was considered as imprecise.

Results

All 307 parents/caregivers approached to participate in the study responded positively, giving us a response rate of 100%. Similarly, 100% of children recruited gave blood samples for analysis.

Baseline Socio-demographic Data

Among the study subjects, 171 (51%) were male. The mean age of the children was 38.5 months (± 18.5 months SD). Children belonging to age groups 48-59 and ≥60 months represented 22% and 24% of the sampled participants, respectively. Fathers/guardians of the studied children were predominantly farmers (37%) and miners (15%), with more than half of them (53.7%) having informal education; few (4.2%) had no education at all (*Table 1*). About 4% of the miners reported processing ore within their living compounds, 7.5% came home wearing working clothes, while 7.2% brought their tools home.

The vast majority, (304, 99%) lived in mud houses; 4.6% of the houses were painted, with 14% of those having flaky paint. Nearly one-third of the parents/guardians of recruited children (30%) lived below poverty line, more than one-third (40%) earned at least the amount set as minimum monthly wage by the Federal Government of Nigeria. About one-third of the participants earned above the monthly minimum wage (*Figure 1*). We used the reported father's monthly income as a proxy for total monthly household income, since mothers in this community typically earn very little cash wages outside the home, contributing little to total household income.

Quality Control of Lead Analysis

Altogether, 20 BLANK samples were used over 5 days, 10 each in the field and laboratory. Evaluation of all the BLANK samples for contamination showed low BLL (<3.3 μg/dL) implying no evidence of sample contamination (*Table 2*).

Gender of Children	Frequency	Percent
Male	157	51.1
Age of Children (Months)	**Frequency**	**Percent**
0-11	16	5.2
12-23	39	12.7
24-35	61	19.9
36-47	51	16.6
48-59	66	21.5
≥60	74	24.1
Father's/Guardian's Occupation	**Frequency**	**Percent**
Farmer	114	37.1
Miner	45	14.7
Cattle rearer	39	12.7
Businessman/Businesswoman	32	10.4
Civil servant	30	9.8
Petty trader	7	2.3
Tailor, driver, mechanic, student, etc.	40	13.0
Father's/Guardian's Educational Level	**Frequency**	**Percent**
None	13	4.2
Informal	165	53.7
Primary	47	15.3
Secondary	53	17.3
Tertiary	29	9.4
Mother's Occupation	**Frequency**	**Percent**
Housewife	124	40
Petty trader	165	54
Civil servant	2	0.7
Businesswoman	5	1.6
Tailoring, weaving, hair plaiting	11	3.6
Mother's Educational Status	**Frequency**	**Percent**
None	16	5.2
Informal	267	87
Primary	18	5.9
Secondary	5	1.6
Tertiary	1	0.3

Table 1 — Socio-Demographic Characteristics of Children (N = 307) and Parents/Guardians From Kawaye Village, Zamfara State , Nigeria

Prevalence of Lead Poisoning and Associated Factors

Based on current Center for Disease Control and Prevention's (CDC's) definition of childhood lead poisoning (BLL ≥5 µg/dL), the prevalence of lead poisoning among children in the community was found to be high (92.5%), with 34 children (11.1%) having BLL ≥45 µg/dL. Median BLL= 19.7 µg/dL, range= <3.3- 372.3 µg/dL.

Soil Lead Contamination

The highest SLL recorded was used in assessing the level of contamination in a household. Overall, 14% of the households in the community had SLLs exceeding the limit set by the U.S. Environmental Protection Agency (EPA) for residential areas of 400 mg/kg.[11,12] The median household SLL was 61 mg/kg (range <4 – 24,000 mg/kg). Eighty six percent of the households had SLL< 400 mg/kg, 11% had mild-moderate contamination (400-1,200 mg/kg), while 2.9% were severely contaminated (>1,200 mg/kg).

Determinants of Childhood Lead Poisoning

There was no significant difference in the prevalence of lead poisoning across gender ($\chi2 = 0.0129$, $p = 0.4547$). However, the prevalence of lead poisoning was significantly different (94.9%) among those children whose parents/guardians had low educational level (none/informal) ($\chi2 = 2.84$, $p = 0.046$) and those whose parents/guardians engaged in mining ($\chi2 = 17.05$, $p < 0.0001$); prevalence was lowest among children whose parents/guardians reared cattle (71.8%). There was no statistically significant difference in the prevalence of lead poisoning among children of farmers compared to other occupations ($\chi2 = 0.6523$, $p = 0.2096$).

Children whose parents/guardians lived below the poverty line (95.7%) had a higher prevalence of lead

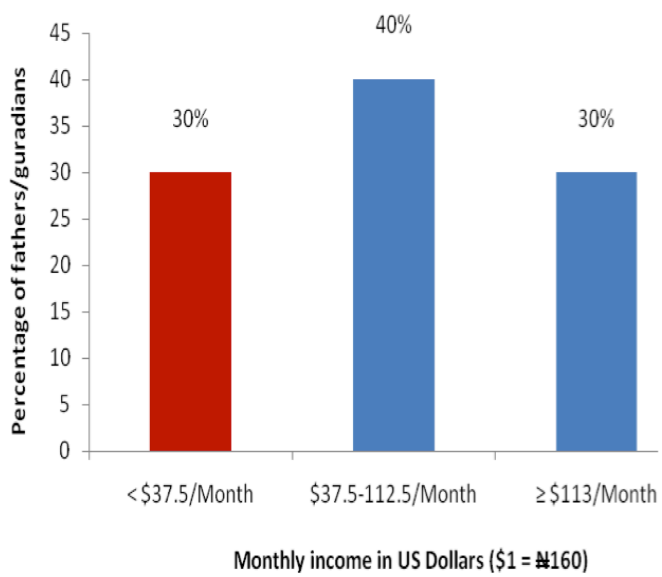

Figure 1 — Distribution of children according to monthly income of fathers/guardians in Kawaye village, Zamfara, Nigeria

poisoning compared to those whose fathers/guardians lived above the poverty line or earned at least the minimum wage approved by the Federal Government of Nigeria (91.2%) [p = 0.0172]. Furthermore, the households where parents/ guardians were miners and traders had significantly higher soil lead contamination, while households where parents /guardians were cattle rearers had the lowest levels of soil lead contamination [$\chi2 = 23.79$, $p = 0.0006$].

All children whose households reported SLL ≥400 mg/kg had lead poisoning of varying severity ([$\chi2 = 0.0246$, $p = 0.0493$] *Table 3*). The logistic regression showed that the following variables were independently associated with an increased risk of childhood lead poisoning: being aged 24-35 months (OR = 9.4, 95% CI: 1.591-56.132); having childhood anemia (OR= 3.96, 95% CI: 1.215-12.886); using of kohl eye cosmetic (OR= 6.4, 95% CI: 1.784-49.873); and the combination of the father's/ guardian's low level of education and low monthly household income (OR= 19.18, 95% CI: 1.156-318.071). Living in a home with a mud floor, on the other hand, was found to be protective against childhood lead poisoning (OR= 0.09, 95% CI: 0.024-0.309 [*Table 4*]).

Discussion

The prevalence of childhood lead poisoning in the village of Kawaye was found to be high (92.5%). This finding is in line with results of a 2010 study conducted in the state of Zamfara to determine risk factors for mortality among lead-poisoned children, which reported a 100% prevalence of lead poisoning among children tested for lead.[8] The mean age of the studied children was 38.5 months ± 18.5 with a male preponderance. Lead poisoning was found to be significantly higher among children aged 24-35 months. Though a similar study conducted in Otukpo, Nigeria, among children aged 1-6 years showed preponderance of lead poisoning among males, it also found BLLs to be evenly distributed across the different age groups.[13] According to Bellinger in 2004, BLLs usually peak around the age range of 12-36 months, which corresponds with the age of active hand-to-mouth behavior in children.[14]

It is worthy of note that more than half of the parents/guardians of studied children had informal education (53.7%) with few of them having no education (4.2%). The prevalence of lead poisoning was found to be higher among children whose parents/ guardians had low educational levels (no education or informal education). Anecdotally, the low educational status of parents/guardians might have resulted in limited awareness of the sources of exposure and dangers of lead to the human body. The findings of this study are similar to that of a study conducted in Ottawa County, Oklahoma, U.S.A. to determine lead sources, behaviors and socioeconomic factors in relation to blood lead of Native American and Caucasian children which demonstrated a strong association between less-educated caregivers and elevated blood lead levels (OR 7.3; 95% CI 1.4–38.4).[15] A study conducted in Otukpo, Nigeria showed a significant relationship between maternal literacy and mean children's BLL. Literate mothers had children with an average BLL that was approximately 1.1 mg/dL lower than illiterate mothers.[13] In another study, the level of education of the child's primary caregiver was found to be a predictor of log BLL after adjustment for age and sex.[16]

In terms of monthly income of the male parent/guardian, nearly one-third lived below the poverty line (US$1.25 per day) and about the same proportion (30.3%) earned at least the monthly minimum wage set by the Federal Government of Nigeria. This study found that low level of education

Background Contamination — BLL Results (μg/dL)		
Field Days	Blank Field	Blank Lab
Day 1	<3.3	<3.3
	<3.3	<3.3
Day 2	<3.3	<3.3
	<3.3	<3.3
Day 3	<3.3	<3.3
	<3.3	<3.3
Day 4	<3.3	<3.3
	<3.3	<3.3
Day 5	<3.3	<3.3
	<3.3	<3.3

Precision — Actual Specimen BLL Result (μg/dL)			
Field Days	Actual Specimen	Mean 1	SD 1
Day 1	55.1 4.1 36.8	32.0	25.8
Day 2	48.8 21.6 7.8	26.1	20.9
Day 3	21.3 23.2 15.8	20.1	3.8
Day 4	45.9 7.4 4.4	18.8	23.1
Day 5	6.6 16.3 19.5 21.3	15.9	6.6

Precision — Duplicate Specimen BLL Result (μg/dL)				
Field Days	Duplicate Specimen	Mean 2	SD 2	SD 1—SD 2
Day 1	56.3 3.8 39.0	33.0	26.8	-0.9
Day 2	47.3 24.0 8.1	26.5	19.7	1.1
Day 3	21.7 23.6 15.3	20.2	4.3	-0.5
Day 4	45.9 9.6 5.1	20.2	22.4	0.8
Day 5	6.4 15.8 20.2 22.0	16.1	7.0	-0.4

Table 2 — Results of Background Contamination and Precision Assessments

and low monthly household income interacted to increase the odds of having childhood lead poisoning. This finding is corroborated by findings from a study conducted in a Mexican smelting community which showed that the amount of income and education level of the primary caregiver are important predictors of children's BLLs.[17] Similarly, another study showed that a caregiver's earning below the U.S. federal poverty level was associated with elevated BLLs in children.[15]

The parents/guardians of children most affected by lead poisoning were farmers (37.1%) and miners (14.7%); and these 2 occupations were found to be significantly associated with higher prevalence of childhood lead poisoning. This may be connected with the observation that the major source of lead contamination in Zamfara was artisanal gold mining, as demonstrated by previous studies.[8] The mining activities contaminate soil and water bodies, thereby posing an obvious risk to children, adults and even the animals living in these environs. However, the findings of this study are in contrast with those of a study among children aged 1-6 years attending an immunization clinic in Otukpo, Nigeria, which showed no significant association between parental occupation and mean BLL of children.[13]

It is worthy of note that all children living in a household with soil contaminated by lead had lead poisoning. We also found that households where the fathers/guardians were miners had higher soil lead contamination levels, while households of cattle rearers had the lowest levels of soil lead contamination. This may be due, in part, to the fact that cattle rearers were living in an area that, though a part of the village, is detached from the main settlement.

Use of kohl eye cosmetic on children

Variable	BLL ≥5 μg/dL Count (%) (n = 284)	BLL <5 μg/dL Count (%) (n = 23)	P value (Chi Square Test)
Gender			
Male	145 (51.1)	12 (52.2)	0.4547
Father's/Guardian's Educational Level			
None/Informal	169 (94.9)	9 (5.1)	0.0460
Mother's Educational Status			
None/Informal	261 (92%)	21 (96%)	0.4683
Father's/Guardian's Occupation			
Mining	41 (97.6)	1 (2.4)	< 0.0001
Mother's Occupation			
Petty trader	158 (56%)	7 (30%)	0.0627
Housewife	113 (40%)	14 (61%)	
Household Soil Lead Level			
>400 mg/kg	44 (100)	0(0)	0.0493
Monthly Household Income			
<N 6000/month	88 (95.7)	4 (4.3)	0.0172
Anemia Status			
Anemia+	249 (87.7)	16 (69.6)	0.0172

Table 3 — Relationships Between Different Variables and Childhood Lead Poisoning in Kawaye Villgae, Zamfara, Nigeria (N = 307)

was found to be an independent risk factor for childhood lead poisoning. Kohl is a silvery black ore that is dug from the ground and is ground up and directly applied to the inner part of the eye lids as a local cosmetic; it is a common source of lead.[18,19] On the other hand, having a mud floor in the house was found to be protective against childhood lead poisoning.

Conclusion and Recommendations

This study found a very high prevalence of childhood lead poisoning with varying degrees of household lead contamination in the Nigerian village of Kawaye. These may be attributable to unsafe mining and ore processing activities that are rife in the community. The majority of the children studied were males belonging to the age groups 48-59 and ≥60 months. Significant risk factors associated with childhood lead poisoning in the community included: being aged 24-35 months, suffering from childhood anemia, using kohl eye liner, and the combination of the father's/guardian's low level of education and low monthly household income.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. The Zamfara State Ministry of Health should institute treatment programs of all cases of severe lead poisoning (BLL ≥45 μg/dL) identified by this study;

2. The State Ministry of Health should monitor all children with elevated blood lead levels (BLL ≥10 - 44.9 μg/dL) identified by this study;

3. The State Ministry of Health, in collaboration with partners, should establish sustainable public health programs aimed at controlling and preventing lead poisoning. These programs should include, among other activities, surveillance and treatment of cases, continuous health education of miners and parents/guardians on lead poisoning, enforcement of legislation and bans on both illegal mining and mining within communities, respectively;

4. The State Ministry of Environment and Solid Minerals should ban all mining activities within the boundaries of villages. The industrial and artisanal miners should be organized into cooperative associations and registered, and their activities regulated and properly supervised;

5. The State Ministry of Environment and Solid Minerals should promote safer low-tech mining practices in Kawaye;

6. The State Ministry of Environment and Solid Minerals should commence plans for the complete characterization of Kawaye with a view to remediating the entire community;

7. The State Ministry of Education and Agency for Mass Education should collaborate to improve the literacy level of the people of Kawaye, particularly in the areas of adult and secondary and tertiary education;

8. The State Ministry of Rural Development, in collaboration with the National Poverty Eradication Program (NAPEP), Small and Medium Enterprises Development Agency of Nigeria (SMEDAN), State Ministries of Works and Agriculture and other major stakeholders, should improve the socioeconomic status of the people of Kawaye through improvement of agricultural practices, microcredit disbursement, jobs creation and provision of social amenities, among others.

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Variable	Odds Ratio	95% CI		P-Value
Anemia in child ***(Yes/No)***	3.96	1.215	12.886	0.023
Age of child 24-35 months ***(Yes/No)***	9.45	1.591	56.132	0.014
Farming occupation of father/guardian ***(Yes/No)***	2.66	0.760	9.295	0.126
Household SLL ≥ 400mg/kg ***(Yes/No)***	2548828	0.000	>1.0E12	0.955
Low father/guardian education [None/Informal] ***(Yes/No)***	2.69	0.814	8.888	0.105
Low household income [< $37.5/month] ***(Yes/No)***	0.84	0.158	4.483	0.839
Low mother education [None/Informal] ***(Yes/No)***	0.29	0.032	2.600	0.268
Male gender of child ***(Yes/No)***	1.49	0.531	4.177	0.449
Mining occupation of father/guardian ***(Yes/No)***	6.88	0.779	60.762	0.083
Mud floor type ***(Yes/No)***	0.09	0.024	0.309	0.002
Use of kohl eye cosmetic on child ***(Yes/No)***	6.40	1.784	49.873	0.041
Low father education ***(Yes/No)*** **Low household income** ***(Yes/No)***	19.18	1.156	318.071	0.039
Low household income ***(Yes/No)*** **Low mother education** ***(Yes/No)***	6304755	0.000	>1.0E12	0.963

Table 4 — Results of Logistic Regression of Childhood Lead Poisoning (BLL ≥5 μg/dL) Among Children ≤6 Years (N = 307) In Kawaye Village, Zamfara, Nigeria

References

1. **WHO**. **Lead**. World Health Organization [Internet]. 2013 [cited 2013 August 27]. Available from http://www.who.int/ipcs/assessment/public_health/lead/en/#
2. **CDC**. **Response to the advisory committee on childhood lead poisoning prevention report: low level lead exposure harms children**. *Morbidity Mortality Weekly Rep* [Internet], 2012 May 25 [cited 2013 Oct 31];61(20):383-4. Available from: http://www.dhs.wisconsin.gov/lead/doc/MMWRannouncement5mcgdL.pdf
3. **Nriagu, O, Blankson L, Ocran K**. **Childhood lead poisoning in Africa: a growing public health problem**. *Sci Total Environ 1996*;181(2):93-100.
4. **Nriagu J, Afeiche M, Linder A, Arowolo T, Ana G, Sridhar MK, Oloruntoba EO, Obi E, Ebenebe JC, Orisakwe OE, Adesina A**. **Lead poisoning associated with malaria in children of urban areas of Nigeria**. *Int J Hyg Environ Health* [Internet]. 2008 October [cited 2013 Oct 31]; 211(5-6):591-605. Available from: http://www.sciencedirect.com/science/article/pii/S1438463908000321 Subscription required to view.
5. **Clune AL, Falk H, Riederer AM**. **Mapping global environmental lead poisoning in children**. *J Health Pollut* [Internet]. 2011 [cited 2013 Nov 1];1(2). Available from: http://www.journalhealthpollution.org/ojs/ojs2.2.4/index.php/journalhealthpollution/article/view/43/64
6. **World Health Organization**. **Nigeria: Mass lead poisoning from mining activities, Zamfara State**. *Environ Health in Emerg* [Internet]. 2010 Jun 22 [cited 2013 Nov 1]. Available from: http://www.who.int/environmental_health_emergencies/events/nigeria_lead/en/
7. **Medecins Sans Frontieres**. **Lead poisoning crisis in Zamfara State Northern Nigeria**. *MSF Brief Pap* [Internet]. 2012 May [cited 2013 Nov 1]. Available from: http://www.msf.org/sites/msf.org/files/old-cms/fms/article-documents/MSF-Nigeria-Lead.pdf
8. **Dooyema CA, Neri A, Lo Y, Durant J, Dargan P I, Swarthout T, Biya O, Gidado SO, Haladu S, Sani-Gwarzo N, Nguku PM, Akpan H, Idris S,. Bashir AM, Brown MJ**. **Outbreak of fatal childhood lead poisoning related to artisanal gold mining in Northwestern Nigeria**. *Environ Health Perspect* [Internet]. 2011 Dec 20 [cited 2012 May 4];120:601-7. Available from http://dx.doi.org/10.1289/ehp.1103965.
9. **Lwanga SK, Lemeshow S**. **Sample size determination in health studies': A practical manual** [Internet]. Geneva: World Health Organization; 1991 [cited 2013 Nov 1]. 80 p. Available from: http://www.tbrieder.org/publications/books_english/lemeshow_samplesize.pdf
10. **Nriagu J, Afeiche M, Linder A, Arowolo T, Ana G, Sridhar MK, Oloruntoba EO, Obi E, Ebenebe JC, Orisakwe OE, Adesina A**. **Lead poisoning associated with malaria in children of urban areas of Nigeria**. *Int J Hyg Environ Health*. 2008 Oct; 211(5-6):591-605.
11. **Tarrago O**. **Case studies in environmental medicine: Lead toxicity [Internet]**. Atlanta, GA: Agency for Toxic Substances and Disease Registry; 2007 August 20 [updated 2010 Aug 20; cited 2013 Nov 1]. 71 p. Available form: http://www.atsdr.cdc.gov/csem/lead/docs/lead.pdf
12. **UNICEF programme cooperation agreement: Environmental remediation – lead poisoning in Zamfara: Final report [Internet]**. New York: Blacksmith Institute; 2010 Sep – 2011 Mar [cited 2013 Nov 1]. Available from: http://www.blacksmithinstitute.org/files/FileUpload/files/Additional%20Reports/Zamfara-Nigeria-Report.pdf
13. **Ogunseitan OA, Smith TR**. **Social and ecological mediators of environmental lead exposure in Nigeria**. *African J Environ Sci Tech*. 2007;1(3):53-8.
14. **Bellinger DC**. **Lead**. *Pediatr* [Internet]. 2004 Apr [cited 2013 Nov 1];113 (4 Suppl):1016-22. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15060194
15. **Malcoe LH, Lynch RA, Kegler CM, Skaggs VJ**. **Lead sources, behaviors, and socioeconomic factors in relation to blood lead of Native American and white children: A community-based assessment of a former mining area**. *Environ Health Perspect* [Internet], 2002 Apr [cited 2013 Nov 1];110(2):221–31. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241167/
16. **Albalak R, Noonan G, Buchanan S, Flanders WD, Gotway-Crawford C, Kim D Jones RL, Sulaiman R, Blumenthal W, Tan R, Curtis G, McGeehin MA**. **Blood lead levels and risk factors for lead poisoning among children in Jakarta, Indonesia**. *Sci Total Environ*. 2003 Jan 1;301(1-3):75-85.
17. **Albalak R, McElroy RH, Noonan G, Buchanan S, Jones RL, Flanders WD Gotway-Crawford C, Kim D, Dignam T, Daley WR, Jarrett J, Eduardo E, McGeehin MA**. **Blood lead levels and risk factors for lead poisoning among children in a Mexican smelting community**. *Arch Environ Health*. 2003 Mar;58(3):172-83.
18. **CDC**. **Infant lead poisoning associated with use of tiro, an eye cosmetic from Nigeria — Boston, Massachusetts, 2011**. *Morbidity Mortality Weekly Rep* [Internet]. 2012 Aug 3 [cited 2013 Nov 1];61(30):574-5. Available from: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6130a3.htm
19. **Parry C, Eaton J**. **Kohl: A lead-hazardous eye makeup from the third world to the first world**. *Environ Health Perspect* [Internet]. 1991 Aug [cited 2013 Nov 1]; 94:121-3. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1567936/