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*Full Length Research Paper*

# The cost of environmental lead (Pb) poisoning in Nigeria

**Oladele A. Ogunseitan* and Timothy R. Smith**

Program in Public Health, College of Health Sciences, University of California, Irvine, CA 92697-7070 USA.

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**The pervasiveness of human health impacts and ecosystem effects of lead (Pb) is not controversial, but there are serious arguments about the pace at which Pb should be eliminated from consumer products. Presumably, these arguments can be resolved by converting costs and benefits of Pb use to similar units, a notorious methodological challenge for health impacts in developing countries. To estimate the costs of Pb poisoning attributable to petrochemicals in Nigeria, we conducted a meta-analysis of measured blood lead levels (BLL) and we used published Relative Risk values for disease categories to estimate the proportion of overall disease burden attributable to Pb. We modeled the health costs of Pb exposure and we compared this to the cost of banning Pb. We estimate that Pb exposure accounts for 7 - 25% of the disease burden among Nigerian children, costing the health and education sectors \$0.38 – 1.15 billion year$^{-1}$ for every 1 μg/dL increase in BLL. In comparison, we estimate that a Pb abatement program in Nigeria will cost \$0.076 – 0.23 billion year$^{-1}$. If a Pb phase-out program is instituted now to lower the national BLL to 1 μg/dL by 2020, a savings of \$2.7-8.0 billion would be realized.**

**Key words:** Lead (Pb) poisoning, Cost-benefit analysis, Diseases, Petrochemicals Africa.

## INTRODUCTION

Exposure to Pb is widely recognized as a major risk factor for several human diseases, and the structure of industrial ecological systems have made exposure to Pb unavoidable for most people alive today (Needleman, 1999; Pruss-Ustun et al., 2004; WHO, 2000). In affluent countries, sizable investments in the implementation of environmental policies prohibiting the addition of Pb to many consumer products have resulted in rapid decline of human exposures, demonstrable by observed reductions in the human blood content of Pb (USEPA, 1985; Grosse et al., 2002). Unfortunately, the public health gains from extensive research on the adverse effects of Pb and the remarkable successes of effective policies in these industrialized countries have not yet enveloped developing countries, and the course of gasoline-fueled industrialization remains hazardous to public health (OECD, 1999).

Children throughout Africa are particularly vulnerable to Pb exposure because of unabated use of leaded gasoline and lead- acid batteries in automobiles (Nriagu et al., 1996 and 1997; Omokhodion, 1994), and recently, unregulated cottage industries associated electronic waste recycling (Lincoln et al., 2007). Particular socio-ecological and climatic factors also contribute to high levels of inhalation and ingestion of Pb-laden aerosol and dust (Laidlaw et al., 2005; Ogunfowokan et al., 2004; Ogun-sola et al., 1994; Rankin et al., 2005) . Despite the initiation of phase-out programs in a few countries, the gasoline sold in most African countries contains 0.5 - 0.8 g/l lead, the highest levels in the world (Thomas, 1995). In Nigeria, gasoline with average Pb content of 0.66 g L$^{-1}$ remains in use (Fakayode and Olu-Owolabi, 2003) . In Nigeria's largest city of Lagos, specific emissions of lead exceed 164 kg km$^{-2}$ representing approximately 20% of the 2.46 Gg of lead emissions nationwide (Obioh et al., 1988), and ambient air concentration of Pb ranges up to 9.58 μg m$^{3}$, exceeding WHO recommended annual average of 0.5 μg m$^{3}$ at all locations (Obioh et al., 2005). Furthermore, mean blood lead levels (BPb) measured at

*Corresponding author. E-mail: Oladele.Ogunseitan@uci.edu. Phone: 949-824-6350 Fax: 949-824-2056.

various times and urban locations in Nigeria have ranged from 11.4 – 25 μg $dL^{-1}$; far exceeding the 10 μg $dL^{-1}$ action dose recommended for the U.S. population (Adebamowo et al., 2006; Ademuyiwa et al., 2005; Nriagu et al., 1997).

In addition to automotive and industrial sources, elevated blood lead levels in children have been attributed to paint, household dust, overcrowding and low parental income (Charney, 1982; Kapu et al., 1989; Kristensen et al., 1993; Landrigan et al., 1976; Nriagu and Pacnya, 1988). Previous studies in Africa have also shown that one of the strongest indicators of childhood BPb was the family either owning a car or living in a house located on a tarred road (Nriagu et al., 1996). These factors are typically only encountered in urban centers. However, the geochemical behavior of Pb and its association with suspended particulates suggests that children in remote suburban or rural regions may also suffer from Pb exposure, in which case, the adverse affects of Pb should be widespread. This hypothesis has not been rigorously tested within the African continent. Also, it has been relatively simple to quantify the financial costs associated with Pb-phase out programs, but the economic costs of health effects attributable to lead exposure are typically externalized. This has made it difficult for policymakers to comprehend cost-benefit scenarios used to justify lead abatement programs.

The goal of this research is to provide cost-benefit information to environmental policy makers in Nigeria by employing a quantitative comparison of the health cost of lead-related disease burden to the cost of a national lead abatement program. There are three research objectives:
(1) the determination of the representative blood-lead content of Nigerian children (ages 1 - 6 yrs.) and subsequent contribution of environmental lead exposure to the burden of disease in Nigeria; (2) the estimation of the health costs of environmental lead exposure in Nigeria;
(3) and the estimation of the cost of a national lead-abatement program.

## METHODS

### Assessment of lead exposure

Children (ages 1 – 6 years; N = 306) were recruited for this study through the scheduled immunization clinic in the semi-rural region of Otukpo, Nigeria (total population of approximately 136,800 people, of which 45% are younger than 14 years for the study period (Population Reference Bureau, 2006). Blood lead concentrations were determined by means of an automatic blood lead analyzer with a sensitivity range of 1.4 - 65 µg $dL^{-1}$ based on blood sample volume of 50 µl (LeadCare, ESA Inc., Chelmsford, MA and AndCare Inc., Durham, NC. The equipment was kindly provided by the U.S. Centers for Disease Control and Prevention, Atlanta, Georgia). The necessary size of the population sample was estimated within the desired margin of error for predicting the population mean according to Moore and McCabe (2005):

$$n = \left(\frac{Z \times s}{m}\right)^2 = \left(\frac{2.96 \times 3.8}{.65}\right)^2 = 300$$

where:
Z = z-score (2.96, 99% CI) ; s = standard deviation (3.8 µg $dL^{-1}$; Nriagu et al., 1996); m = desired margin of error (± 0.65 µg $dL^{-1}$)

Informed consent was obtained for all human subjects according to standard research ethics, and as approved by the Institutional Review Board. Exclusion categories included those previously treated for Pb poisoning, those who had not been living in the same residence for at least the past 6 months, those who are being treated for severe illness, and those not accompanied by a legal guardian. In addition to the determination of BPb concentrations, a questionnaire was completed by each child subject with the legal guardian to record demographic and socioeconomic statistics and to assess predictors of Pb exposure and the predominant pathways for such exposures. The questionnaire survey was modified from the standard instrument used by U.S. Center for Disease Control and Prevention to better capture the social, economic, and cultural environment of Nigeria. With written consent, the nurse/phlebotomist administered the survey and offered the subject a fact sheet containing health information on lead exposure in children.

### Association of lead exposure and disease burden

Lead exposure is implicated in several disease burden categories including systemic effects such as hypertension, gastrointestinal effects, anemia, nephropathy, and nervous system effects such as Intelligence Quotient (IQ) defects and encephalopathy (ATSDR, 1999; Schwartz, 1991, 1993, 1994; Schwartz et al., 1986). We estimated the contribution of Pb exposure to the following disease categories in Nigeria: genito-urinary disease, prematurity, dental caries, nervous system cancers, congenital anomalies, hypertension, cerebrovascular disease, low birth weight, and mild mental retardation (MMR; IQ levels 50-69) . Nine of the 106 disease categories included in the World Health Organization's Global Burden of Disease study were included in this study (Murray and Lopez, 1996; but see Cooper et al., 1998). A population-adjusted, disease burden for Nigeria was estimated from the regional burdens for relative risk analysis. The numerical model DISMOD® was used to estimate disease burden for two disease categories that were not included in the GBD, prematurity and mild mental retardation (http://www.hsph.harvard.edu/organizations/bdu/DisMod.html).

Our estimate of Pb-associated MMR presented a special challenge. Pruss-Ustun et al. (2004) estimated the prevalence of mental retardation and cognitive impairment from known, non-congenital causes (those mentioned above), compared values of developed and developing countries, and estimated a rate accounting for the increase of risk of mental retardation in developing countries, as follows:

$$AR = \frac{P_R - P_{baseline} \pm P_{MR\ standard}}{P_{MR\ standard}}$$

Where: *MR* = mental retardation; $P_R$ = region-specific prevalence of MR from known causes; $P_{baseline}$ = prevalence of MR from known, non-congenital causes in developed countries; $P_{MR\ standard}$ = prevalence of MR according to the standard distribution of IQ score; *AR* = adjustment ratio

That lead exposure contributes to IQ deficit is universally accepted, but there is no consensus on the dose response relationship (Lanphear et al., 2000; Moore et al., 1977; Pocock et al., 1994;

**Table 1**. Variables for the cost of lead abatement in Nigeria.

| | | Cost ($/liter) | Consumption |
|---|---|---|---|
| **Abatement Factors** | Unleaded Gasoline | 0.01 | *6,837 |
| | Non-Pb Additive | 0.01 | 6,837 |
| | Refinery Retooling | 0.006 | 1,408 |
| | Tetraethyl Lead (TEL) | 0.002 | 6,837 |
| **Gasoline Source** | Domestic Gasoline | 0.16 | 1,408 |
| | Foreign Gasoline | 0.16 | 5,429 |
| | Total Gasoline | 0.16 | 6,837 |

*(U.S. DoE, 2000)

Lynn and Vanhanen, 2002; Stouthard et al., 1997). Based on the meta-analysis conducted by Popcock et al. (1994) and by Schwartz (1994), we relied on the following categories defined by three levels of exposure to Pb measured by blood Pb content. Children with relatively low BLLs (5 - 8 μg/dL) suffer a 1.0 IQ deficit; those with medium BLL (9 - 15 μg/dL) suffer 2.0 IQ deficits, and children in the high Pb exposure category (> 16 μg/dL) suffer 3.0 IQ deficit.

Pruss-Ustun et al. (2004) estimated lead-induced MMR to be 0.385/1000 for Sub-Saharan Africa (SSA) populations, compared to 0.256 per 100 people in Europe. We judged this estimate to be inadequate for Nigeria based on the assumption of global average IQ score of 100. Instead, we relied on the baseline IQ estimates of Lynn and Vanhanen (2002) that are more localized in perspective, providing average IQ scores for SSA and Nigeria as 70 and 67, respectively. The present study also departs from the Pruss-Ustun et al. (2004) assessment in the following way. Instead of extracting the fraction of lead-induced MMR from an overall MMR rate in Nigeria, an estimation of the IQ drop due exclusively to lead exposure was assessed on the basis of the range of measured BLLs and the IQ decrements attributed to those ranges in the clinical literature. To estimate the burden attributable to MMR, we adopted the approach used in a Dutch Burden of Disease Study where a severity weight of 0.06 was assigned for deficits in IQ between 1 - 4 points (Stouthard et al., 1997).

The proportion of disease cases attributable to Pb exposure to an environmental risk factor (Attributable Faction) was based on Miettenen's approach (1974):

$$AF_j = \frac{P(RR_j - 1)}{P(RR_j - 1) + 1}$$

where: $AF_j =$ the fraction of burden from some cause $j$ (lead exposure); $RR_j =$ the relative risk of disease for cause j in the exposed to unexposed group; $P$ = Prevalence of exposure.

The attributable fraction was used to derive an estimate of the Lead Attributable Burden (LABD) for low, medium, and high Pb exposures given Relative Risks (or Odds Ratios) for each cause of death and disability related to the exposure, levels of exposure (pre

**Table 2**. Summary of blood lead levels in children, ages 1-6, Otukpo.

| Sex | n | Mean [BPb] | Range | SD | % > 10 ug/dL |
|---|---|---|---|---|---|
| Female | 138 | 8.9 | (2.1,23.8) | 4.2 | 32.5 |
| Male | 168 | 9.8 | (2.2,31.8) | 4.8 | 35.0 |
| Total | 306 | 9.4 | (2.1,31.8) | 4.2 | 34.3 |

valence), and burden of disease due to each cause of death and disability in a given population:

$$AB = AF_j B_j$$

where: $AB$ = Attributable Burden for a risk factor; $AF_j$ = Fraction of Burden from cause j
$B_j$ = population level burden of cause j

#### Economic cost of lead exposure

The U.S. EPA estimated the cost of a lead abatement program to be approximately 500 million dollars per year in 1985 (USEPA 1985). Estimates for the cost of a lead additive (Tetraethyl lead (TEL), $0.002/liter), refinery overhaul ($0.006/liter), and non-lead additive (Methy tert butyl ether (MTBE), $0.01/liter) were derived from Thomas and Kwong (2000). The average cost of gasoline in Nigeria was estimated to be approximately $.16/liter (Obioh et al., 2005). The annual consumption of domestic and imported gasoline in Nigeria is 24,260 and 93,550 barrels per day, respectively (US DoE, 2000). Thus, the total consumption of leaded gasoline in Nigeria is 117,810 barrels per day (Table 1). Schwartz (1993) estimated that $17.2 billion dollars per year would be saved by a 1 μ g/dL reduction in blood levels per year across the U.S. population. We used a similar approach to estimate the economic cost of lead exposure in Nigeria, but with modifications that capture issues specific to Nigeria and time differentials, including adjustments according to the consumer price index (CPI), and gross national income in purchasing power parity (GNI-PPP) of 2.3% for the study period (Population Reference Bureau, 2006).

## RESULTS AND DISCUSSION

### Blood lead levels

Blood lead levels measured in children of Otukpo are summarized in Table 2. The mean for all children was 9.4 μg/dL (SD = 4.2, n = 306). The mean value for males (55% of the sample; Table 3) was not significantly higher than for females. The highest BLL measured was 31.8 μg/dL, which is below the U.S. standard of 45 μg/dL for lead poisoning treatment with chelation therapy. The proportion of children having BLL above the USEPA action level of 10 μg/dL is more than one third.

Figure 1 shows a comparison of BLL distribution among children residing in Otukpo with previous reports of blood lead levels for children in the more urbanized city of Kaduna and other distantly located cities (Nriagu et al.,

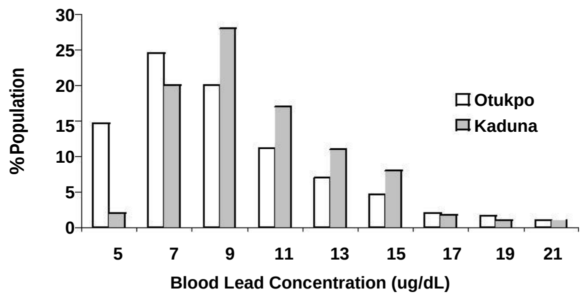


**Figure 1.** Blood lead levels measured in Nigerian children.

**Table 3.** Summary of demographic characteristics in children, ages 1 - 6, Otukpo.

| Characteristics | Percentage | |
|---|---|---|
| **Gender** | | |
| Male | 54.9 | |
| Female | 45.1 | |
| **Age of Child** | | |
| 1 Year | 19.9 | |
| 2 Years | 18.3 | |
| 3 Years | 15.0 | |
| 4 Years | 13.7 | |
| 5 Years | 15.4 | |
| 6 Years | 17.6 | |
| **Born in Otukpo** | | |
| Child | 87.9 | |
| Mother | 42.8 | |
| Father | 34.6 | |
| Average Household Size | 6.8 People | |
| Maternal Literacy | 64.7 | |
| **Education Level** | **Mother** | **Father** |
| 0-4 Years | 61.5 | 55.6 |
| 5-8 Years | 17.9 | 21.6 |
| 9-12 Years | 18.2 | 15.0 |
| >12 Years | 2.3 | 7.8 |
| **Occupation** | **Mother** | **Father** |
| Self-Employed | 54.6 | 30.9 |
| Professional | 10.1 | 15.4 |
| Factory Worker | 1.0 | 4.9 |
| Homemaker | 14.1 | 0.0 |
| Farmer | 13.4 | 27.8 |
| Other | 13.1 | 18.6 |
| **Years Child has Lived in Current Residence** | | |
| 1 Year | 28.1 | |
| 2 Years | 20.9 | |
| 3 Years | 15.0 | |
| 4 Years | 12.4 | |
| 5 Years | 10.1 | |

**Table 3.** Contd.

| | |
|---|---|
| 6 Years | 12.1 |
| **Type of Housing** | |
| Detached | 21.2 |
| Attached | 62.4 |
| Apartment | 15.4 |
| Other | 1.0 |
| **Housing Construction Material** | |
| Brick/Block | 98.0 |
| Wood | 0.7 |
| Other | 0.7 |
| Unknown | 0.7 |
| **Source of Drinking Water** | |
| Pipes | 29.7 |
| Public Faucet | 1.6 |
| Well | 61.8 |
| Barrels | 2.3 |
| Bottled | 1.6 |
| Combination | 3.0 |
| **Time Spent Away From Home by Child** | |
| 0 Hours | 84.3 |
| 1 Hour | 0.3 |
| 2 Hours | 0.7 |
| 3 Hours | 2.9 |
| 4 Hours | 2.6 |
| >4 Hours | 9.4 |
| Children That Wash Hands | 40.8 |
| Mothers that Cook/Store Food/Water in Clay Pots | 36.0 |

1997; Adeniyi and Anetor, 1999) . The population of Kaduna is approximately 1.5 million people in 2002. The mean BLL in Kaduna children ages 1 - 6 years old is 10.6 µg $dL^{-1}$ (± 3.8); with total atmospheric emissions of Pb in the region being 150 tons annually, and 97% of that exposure coming from leaded gasoline (Nriagu et al., 1996; Obioh et al., 1988).

Table 3 shows a summary of the Socio-Demographic data that was collected through the epidemiological survey. Almost 90% of the children were born in Otukpo, but less than half of the parents were indigenous. The average household size was approximately 7 individuals and most lived in attached compound houses constructed of cement bricks with groundwater wells being the source of drinking water. Mean BLL was significantly associated with household size, maternal literacy, parental occupation, home floor type, time spent outside the home, residential proximity to a ceramics shop, and by parental employment in a print shop ($p<.05$), but not with age, parental education, housing construction type or detachment status, drinking water, and frequency of hand-to-

**Table 4.** Deaths (x1000) and DALYs (x1000) from all Pb-linked diseases for males and females, ages 0-14.

| Pb-Disease Category | Deaths, 0-14 | | DALYs, 0-14 | |
|---|---|---|---|---|
| | male | female | male | female |
| Genito-Urinary Disease | 16 | 13 | 710 | 541 |
| Prematurity* | 384 | 384 | 2,295 | 2,295 |
| Dental Caries | 0 | 0 | 129 | 127 |
| Nervous System Cancers | 7 | 6 | 270 | 210 |
| Congenital Anomalies | 32 | 33 | 2,455 | 2,628 |
| Hypertension** | 2 | 2 | 66 | 69 |
| Cerebrovascular Disease | 9 | 9 | 313 | 298 |
| Pb-Mild Mental Retardation (MMR) | 0 | 0 | 2,463 | 2,414 |
| Low Birth Weight*** | 262 | 234 | 9,827 | 8,873 |
| Sub-Saharan Africa (SSA) | 712 | 681 | 18,528 | 17,455 |
| SSA, M & F | 1,393 | | 35,983 | |
| Nigeria | 121 | 116 | 3,150 | 2,967 |
| Nigeria, M & F | 237 | | 6,117 | |

*DALYs calculated using DISMOD with incidence rates from (Antilla et al., 1995).
**DALY data from Type I Diabetes, ***Low Birth Weight is the largest category within Perinatal Conditions

**Table 5.** Pb-linked burden of disease percentages ($BD_{Pb}$%).

| | Deaths | | DALYs | |
|---|---|---|---|---|
| | male | female | male | female |
| PbBD% of SSA | 2.42 | 2.75 | 1.82 | 2.04 |
| PbBD% of SSA, 0-14 | 4.57 | 5.31 | 2.97 | 3.34 |
| PbBD% of SSA, 0-14, m/f | 4.90 | | 3.14 | |
| PbBD% of Nigeria | 14.25 | 16.18 | 10.71 | 11.99 |
| PbBD% of Nigeria, 0-14 | 26.86 | 31.25 | 17.48 | 19.67 |
| PbBD% of Nigeria, 0-14, m/f | 29.06 | | 18.58 | |

mouth behavior (Ogunseitan and Smith, submitted).

## Lead-associated burden of disease estimates

Table 4 shows the results for overall Deaths and DALYs by gender for children, ages 0-14, of Sub-Saharan Africa (SSA) and Nigeria. Table 5 shows the results by gender for lead-linked disease burden for children in Nigeria. The data are shown as a percentage of SSA burden, SSA childhood burden, Nigerian burden, and Nigerian childhood burden. Table 6 shows the medium estimate for DALYs of all nine disease burden categories by gender for children, ages 0-14, for both SSA and Nigeria. Also, the ORs that were found in the literature are shown. The three exposure categories are classified as low exposure (5-8 μg/dL), medium exposure (9- 15 μg/dL), and high exposure (>16 μg/dL). There is no OR for lead-attributed mild mental retardation ($MMR_{Pb}$) required, because by definition, 100% of $MMR_{Pb}$ is due to lead exposure. Table 7 shows the medium estimate of both the attributable risk and attributable burden for lead exposure across all three exposure categories for children, ages 0 - 14, in SSA and Nigeria. Also, the Pb-attributed burden of disease ($BD_{Pb}$) is shown as a percentage of the total Nigerian BD, and the total Nigerian childhood BD. Nigerian childhood BLLs of 5 - 8 μg/dL account for approximately 2.18% of the total Nigerian childhood burden, BLLs of 9 - 15 μg/dL account for 7.50%, and BLLs >16 μg/dL account for 5.07%. Combined all lead exposure accounts for approximately 14.74% of the total Nigerian childhood disease burden.

## Health costs of lead (Pb) exposure

The estimates of childhood health costs of lead exposure are outlined in Table 8. The total costs are presented in millions of dollars. While all of the sub-categories (medical, compensatory education, lost earnings, IMR, and neonatal care) show significant health costs of Pb expos-

**Table 6**. Dalys and odds ratios for 9 Pb-linked diseases (Medium estimate).

| Pb-Disease Category | DALYs, 0-14 | | | OR @ 3 PbB Levels* | | |
|---|---|---|---|---|---|---|
| | male | female | total | 5-8 | 9-15 | >16 |
| Genito-Urinary Disease | 710 | 541 | 1251 | 1.0 | 1.9 | 3.8[1] |
| Prematurity | 2295 | 2295 | 4590 | 2.2 | 4.3 | 8.6[2,3] |
| Dental Caries | 129 | 127 | 256 | 6.8 | 9.6[4] | 13.5[4] |
| Nervous System Cancers | 270 | 210 | 480 | 2 | 5.5[5] | 11.0[5] |
| Congenital Anomalies | 2455 | 2628 | 5083 | 1.0 | 1.6 | 3.2[6] |
| Hypertension | 66 | 69 | 135 | 1.0 | 1.5[7] | 3 |
| Cerebrovascular Disease | 313 | 298 | 611 | 2.2[8] | 4.5[8] | 6.8[8] |
| Pb-Mild Mental Retardation | 2463 | 2414 | 4877 | N/A | N/A | N/A |
| Low Birth Weight | 9827 | 8873 | 18700 | 1.2 | 2.4 | 4.7[9] |
| Total SSA | 18528 | 17455 | 35983 | | | |
| Total Nigeria | 3150 | 2967 | 6117 | | | |

*BLLs are presented in ug/dL. Not all the Odds ratios were available for all three blood lead levels in every disease category. Estimates were used in those cases. [1](Antilla et al., 1995) [2](Asien et al., 2000); [3](Khera et al., 1980); [4](Gemmel et al., 2002); [5](Landrigan et al., 1976) [6](Kristensen et al., 1993) [7](Factor-Litvak et al., 1996) [8](Gomaa et al., 2002) [9](Kristensen et al., 1993).

**Table 7**. Attributable risks and attributable Burden for 9 Pb-linked diseases (Medium estimate)

| | AR for PbB Levels | | | *AB for PbB Levels | | |
|---|---|---|---|---|---|---|
| Pb-Disease Category | 5-8 | 9-15 | >16 | 5-8 | 9-15 | >16 |
| Genito-Urinary Disease | 0.0 | 33.5 | 21.9 | 0 | 419 | 274 |
| Prematurity | 29.0 | 64.9 | 43.2 | 1,330 | 2,978 | 1,982 |
| Dental Caries | 6.8 | 9.6 | 13.5 | 17 | 25 | 35 |
| Nervous System Cancers | 25.4 | 71.6 | 50.0 | 122 | 344 | 240 |
| Congenital Anomalies | 0.0 | 25.1 | 18.0 | 0 | 1,278 | 917 |
| Hypertension | 0.0 | 21.9 | 16.7 | 0 | 30 | 23 |
| Cerebrovascular Disease | 29.0 | 66.2 | 36.7 | 177 | 405 | 224 |
| Pb-Mild Mental Retardation | 100.0 | 100.0 | 100.0 | 1,609 | 1,609 | 1,609 |
| Low Birth Weight | 6.4 | 43.9 | 27.0 | 1,191 | 8,218 | 5,050 |
| Total SSA | | | | 4,446 | 15,306 | 10,353 |
| Total Nigeria | | | | 756 | 2,602 | 1,760 |
| % Nigeria BOD Attributable to Pb | | | | 1.40 | 4.80 | 3.25 |
| % Nigeria BOD, Attributable to Pb (0-14) | | | | 2.18 | 7.50 | 5.07 |

*Attributable Burden is presented in DALYs (x1000)

ure, lost earnings and increased IMR appear to have the largest impact on overall cost. The total childhood health cost was estimated to be $10.3 billion ($238 million GNI-PPP adjusted), or 29.8 billion naira annually for a 1 μg/dL increase in BLL. Considering that the average BLL in Nigerian children is approximately 10 μg/dL, the cost of lead exposure could be ten times higher than what is reported here. Thus, if Nigeria is able to decrease national BLL average by 5 μg/dL, the country could gain more than $ 1 billion in savings annually from childhood health costs.

Table 9 shows the results for the adult health costs of lead exposure. The total health costs are presented in millions of dollars. Mortality costs of hypertension–related deaths provide the driving force behind the bulk of the adult health costs, accounting for $6.6 billion out of $7 billion (94%) estimated for total adult health costs. Table 10 shows the estimates for the total health cost annually for the entire population. It also provides the annual per capita health cost of lead exposure, the annual health cost as a percentage of GNI-PPP, and the annual health cost as a percentage of the average per capita health ex-

**Table 8**. Childhood health costs of lead exposure.

| Children | Variable | $(M) | GNI-PPP Adjusted | Million Naira |
|---|---|---|---|---|
| **Medical Costs** | Average blood lead concentration | 9.8 ug/dL | | |
| | Number of children requiring chelation therapy | 160,909 | | |
| | Cost of chelation therapy | 1,920 | | |
| | **Total Medical Costs** | 309 | 7 | 888 |
| **Compensatory Education** | Number of children who receive education | 162,231 | | |
| | Cost of education | 4,902 | | |
| | **Total Compensatory Education Cost** | 795 | 18 | 2,286 |
| **Earnings** | Number children, age 6 | 3,515,600 | | |
| | Increase in earnings of a 1 ug/dL reduction in BLL | 1,920 | | |
| | **Total Earnings Lost** | 6,750 | 155 | 19,406 |
| **Infant Mortality** | IMR | 75/1000 | | |
| | 1 ug/dL reduced maternal blood – IMR | 74.9/1000 | | |
| | Value of statistical life | 4,429,840 | | |
| | Number of live births in Nigeria, 2002 | 5,192,000 | | |
| | Number of reduced deaths | 519 | | |
| | **Total IMR Cost** | 2,299.09 | 52.88 | 6,609.88 |
| **Neonatal Care** | # of NICU admissions | 1,752,300 | | |
| | Reduced NICU admissions | 1,749,960 | | |
| | Number of fewer NICU admissions | 2,340 | | |
| | Cost of NICU | 86,661 | | |
| | **Total Neonatal Cost** | 202.79 | 4.66 | 583.01 |
| | **Total Childhood Cost** | 10,356.03 | 238.19 | 29,773.58 |

expenditure. All of these health cost figures are for a 1 μg/dL change in BLL. The total health cost is presented as a low, medium, and high value. The low value was calculated by subtracting the cost of compensatory education and NICU from the total. It is hypothesized that Nigeria could have significantly less compensatory education than the United States for children who are academically challenged. Likewise, the frequency of children admitted into NICU in Nigeria could be much lower than the US. Based upon these assumptions, the low estimate for the health costs due to lead exposure is estimated to be approximately $377 million. The high value for health costs due to lead exposure was taken from Landrigan et al. (2002) who estimated that the health costs due to lead exposure for the cohort of children born in 2000 is approximately $43.4 billion (USD, 1997). This estimate was adjusted using both the Consumer Price Index (CPI) and the GNI-PPP ratio between the US and Nigeria (2.3%). The resultant health cost estimate after allowing for these adjustments is approximately $1.15 billion.

**Cost of lead abatement**

Table 11 illustrates the cost of a lead abatement program in Nigeria. The cost is a combination of four subcategories: the cost the refinery upgrades, the cost of a non- lead additive, the cost of unleaded gasoline, and the cost of TEL. These sub-category costs are presented in $/Liter. To calculate the overall cost of the abatement program, the cost of TEL is subtracted from the summed costs of refinery upgrades, non-lead additive, and unleaded gasoline. Using the national gasoline consumption provided by the Department of Energy (DOE), the medium overall estimated cost of a lead abatement program for Nigeria is approximately $194 million for the first year. This is approximately 48.5% of the health cost of a 1 μg/dL increase in BLL per year μg/dL.

The low estimate, using the low estimate cost of $0.01 /L reported by the Organization for Economic Development (OCED) for lead phase out is $76 million per year (11). The high estimate, using the high estimate cost of

**Table 9.** Adult health costs of lead exposure.

| Adults | Variable | $(M) | GNI-PPP Adjusted | Million Naira |
|---|---|---|---|---|
| **Medical costs** | | | | |
| **Hypertension** | Number of cases of hypertension | 288,712 | | |
| | Annual medical costs | 812 | | |
| | **Total Medical Cost** | 234.43 | 5.39 | 674.00 |
| **Heart attacks** | Number of cases of heart attacks | 1,454 | | |
| | Medical costs | 33,960 | | |
| | Total Medical Cost | 49.38 | 1.14 | 141.96 |
| **Strokes** | Number of cases of stroke | 591 | | |
| | Annual medical costs | 26,574 | | |
| | **Total Medical Cost** | 15.71 | 0.36 | 45.15 |
| **Lost wages** | | | | |
| **Hypertension** | Number of cases of hypertension | 288,712 | | |
| | Annual lost earnings | 115.0 | | |
| | **Total Earnings Lost** | 33.20 | 0.76 | 95.46 |
| **Heart Attacks** | Number of cases of heart attacks | 1,454 | | |
| | Annual lost earnings | 31,000 | | |
| | **Total Earnings Lost** | 45.07 | 1.04 | 129.59 |
| **Strokes** | Number of cases of stroke | 591 | | |
| | Annual lost earnings | 17,716 | | |
| | **Total Earnings Lost** | 10.47 | 0.24 | 30.10 |
| **Mortality** | Number of deaths | 1,500 | | |
| | Value of statistical life | 4,429,840 | | |
| | Total Mortality Cost | 6,644.76 | 152.83 | 19,103.69 |
| **Total Adult Cost** | | 7,033.02 | 161.76 | 20,219.94 |

**Table 10.** Total health costs of lead exposure.

| **Low Estimate** | **$M (2003)** | **GNI-PPP Adj. $M** | **†Million Naira** |
|---|---|---|---|
| Total annual health cost to Nigeria of 1 μg/dL BPb | *16,391 | 377 | 47,124 |
| Annual per capita cost | 126 | 2.90 | 362 |
| Annual cost as percentage of GNI-PPP | 0.36% | 0.36% | 0.38% |
| Annual cost as percentage of per capita health expenditures | 14% | 14% | 14% |
| **Medium Estimate** | | | |
| Total annual health cost to Nigeria of 1 μg/dL BPb | 17,389 | 400 | 49,993 |
| Annual per capita cost | 134 | 3.08 | 385 |
| Annual cost as percentage of GNI-PPP | 0.38% | 0.38% | 0.38% |
| Annual cost as percentage of per capita health expenditures | 15% | 15% | 15% |
| **High Estimate** | | | |
| Total annual health cost to Nigeria of 1 μg/dL BPb | **49,810 | 1,145 | 143,203 |
| Annual per capita cost | 383 | 8.81 | 1,102 |
| Annual cost as percentage of GNI-PPP | 1.10% | 1.10% | 0.38% |
| Annual cost as percentage of per capita health expenditures | 44% | 44% | 44% |

*Low estimate = Total health costs – cost of compensatory education and NICU. **High estimate = ($43.4 billion) (CPI, 2003), (49). †Million Naira.

**Table 11.** Cost of lead abatement in Nigeria.

| | | Cost ($/liter) | ‡Cons. (10^6 l/year) | Cost (M$/yr 1995) | Cost (M$/yr 2003) | Cost (†MN/yr, 2003) |
|---|---|---|---|---|---|---|
| **Abatement factors** | Unleaded Gasoline | 0.01 | 6,837 | 68 | 82 | 10,250 |
| | Non-Pb Additive | 0.01 | 6,837 | 68 | 82 | 10,250 |
| | Refinery Retooling | 0.006 | 6,495 | 39 | 47 | 5,875 |
| | Tetraethyl Lead (TEL) | 0.002 | 6,837 | 14 | 17 | 2,125 |
| **Gasoline source** | Domestic Gasoline | 0.16 | 6,495 | 1,039 | 271 | 33,821 |
| | Foreign Gasoline | 0.16 | 342 | 55 | 66 | 8,250 |
| | Total Gasoline | 0.16 | 6,837 | 1,094 | 1,313 | 164,148 |
| **Low estimate** | | | | | | |
| | Total annual cost of abatement | | | | *75.6 | 24,250 |
| | Pb abatement cost / Pb health cost | | | | 0.189 | 0.189 |
| | Abatement as % of health cost | | | | 18.9% | 18.9% |
| **Medium estimate** | | | | | | |
| | Total annual cost of abatement | | | | 194 | 24,250 |
| | Pb abatement cost / Pb health cost | | | | 0.485 | 0.485 |
| | Abatement as % of health cost | | | | 48.5% | 48.5% |
| **High estimate** | | | | | | |
| | Total annual cost of abatement | | | | *227 | 24,250 |
| | Pb abatement cost / Pb health cost | | | | 0.567 | 0.567 |
| | Abatement as % of health cost | | | | 56.7% | 56.7% |

*Low estimate = ($.01/L) (Liters consumed/year) (11). **High Estimate = ($.03/L) (Liters consumed/year) (11). ‡Consumption, †Million Naira.

$0.03/L reported by OECD, is $227 million per year (OECD, 1999).

In conclusion, we have shown that lead exposure remains a major health risk factor in all Nigeria communities, both rural and urban. The most important – and controllable – source of exposure is leaded automobile fuels. Arguments based on the enormous costs to society of switching to unleaded fuels are weak in the face of counterarguments based on the even more astounding health care and special educational costs associated with lead exposure. In the presence of alternative renewable fuels such as ethanol (Thomas and Kwong, 2000), the removal of lead from all fuels in Nigeria – and all countries in sub-Saharan Africa – should not be delayed a single day further.

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