

The role of the South African Medical Research Council in reducing lead exposure and preventing lead poisoning in South Africa

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Even at low levels in blood, lead has been associated with reduced IQ scores, behavioural problems, learning impediments, aggression and violent behaviour. Since the 1980s, the South African Medical Research Council (SAMRC) has been investigating the sources of exposure to lead in South Africa (SA), the groups at highest risk of lead poisoning and a selection of the myriad associated health and social consequences. SAMRC research evidence contributed to the phasing out of leaded petrol, restrictions on lead in paint and other interventions. Subsequently, childhood blood lead levels in SA declined significantly. More recent studies have revealed elevated risks of lead exposure in subsistence fishing and mining communities, users of arms and ammunition, those ingesting certain traditional medicines, and users of certain ceramicware and artisanal cooking pots. Lead-related cognitive damage costs the SA economy ~USD17.7 (ZAR261.3) billion annually, justifying further SAMRC investment in lead exposure research in the country.

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Lead is a toxic metal that is abundant in the earth's crust. It has been mined and used for millennia in ancient cultures, and awareness of the toxicity of lead dates back at least 2 000 years.^[1,2] However, a finer understanding of the depth and scale of the harmful effects of lead has been achieved over the past century in particular, alongside technical innovations (for example, in the measurement of lead concentrations at lower levels in blood) and increasingly sophisticated epidemiological and toxicological studies. It is now known that lead exposure is highest in the youngest and poorest groups in any society^[3] and detrimentally affects virtually all human organs and systems. Even at very low concentrations in blood, lead has been associated with reductions in IQ scores,^[4] behavioural abnormalities,^[5] poor school performance^[6] and hearing loss.^[7] More recently, lead exposure in early life has been associated with aggressive and violent behaviour during adolescence and early adulthood,^[8-10] and at higher concentrations with anaemia,^[11] hypertension,^[12] cardiac disease^[13] and reduced fertility,^[14] and, at very high concentrations, with coma and death.^[15]

Despite its known toxicity, lead continues to be widely used in contemporary society, including in paint, firearms, ammunition, fishing sinkers, traditional medicines, toys, ceramicware, cabling, cosmetics, protective gear, artisanal products such as cookware, and electronic products such as computers and mobile telephones.^[16] While there have been incidents of serious, mass-based lead poisoning over the past decade,^[15,17] most people are exposed to low levels of lead on a chronic basis. With increasing appreciation of the harmful health effects of lead at low concentrations in blood, countries have responded with a range of protective interventions, including the introduction, or reduction, of blood lead action levels for children. In the USA for example, blood lead action or reference levels have been reduced from 25 µg/dL in the 1980s, through 10 µg/dL, to the current

level of 5 µg/dL.^[18] There is, however, widespread consensus around the absence of a threshold of safety for lead; no matter how low its level in blood, lead is harmful to health.^[18]

Since the 1980s, the South African Medical Research Council (SAMRC) has invested in a long-term programme of research to characterise lead exposure in South Africa (SA), identify key risk factors and examine the health and social impacts in the population. In this paper, we outline the key findings of SAMRC research on lead exposure, how the research has been translated into protective actions, and the sources of public exposure to lead that remain on the unfinished action agenda to ensure higher levels of protection in SA against lead exposure, especially for the youngest and poorest in the country.

Sources, settings and groups at risk of exposure to lead in SA

Lead in petrol

One of the first comprehensive epidemiological investigations of lead exposure in SA was undertaken by the SAMRC in Cape Town in the 1980s.^[19-21] It was conducted at a time when SA used amongst the highest levels of lead in petrol (0.836 g/L) anywhere in the world.^[22] Involving the measurement of lead in air, dust, soil and blood samples from 200 first-grade school children, the study showed alarmingly high, and widespread, lead exposure, with 90 - 100% of children having blood lead levels ≥ 10 µg/dL. Higher levels of lead exposure were found at schools designated during the apartheid era for coloured (mean 18 µg/dL; 13% ≥ 25 µg/dL) compared with white children (mean 12 µg/dL; 0% ≥ 25 µg/dL). Lead exposure was significantly elevated near heavily trafficked roads, and homes that were dusty, in disrepair or overcrowded, as well as low parental education and income, were associated with elevated blood lead levels.^[21]

By 2002, 8 years after the end of apartheid and the abolition of segregationist policies, SAMRC studies showed that blood lead distributions continued to vary by suburb.^[23] For example, the mean blood lead level in children attending schools in Woodstock equaled 6.9 µg/dL, while in the less heavily trafficked suburb of Hout Bay it was 4.8 µg/dL. At the level of school, mean blood lead concentrations ranged from 3.3 µg/dL (Hout Bay) to 8.1 µg/dL (Woodstock). Unpublished data from a survey undertaken in 2007 show similarly wide-ranging differences in mean blood lead concentration across schools in Johannesburg, from 3.0 µg/dL at a school in Soweto to 11.8 µg/dL at a school in the inner-city suburb of Bertrams (A Mathee, personal communication). Subsequent studies showed significantly elevated levels of lead in residential garden soil in Bertrams,^[24] indicating a possible pathway of exposure to lead among children in that suburb.

Demonstrating the role of housing conditions and socioeconomic status in the distribution of lead exposure, blood lead concentrations in 2002 continued to vary significantly by apartheid-era population groups, with coloured, black African and white children in the study having mean blood lead concentrations of 7.0, 6.0 and 3.5 µg/dL, respectively.^[23] As petrol lead levels were incrementally reduced over the 1980s and 1990s, culminating in exclusive use of unleaded petrol in SA from 2006, subsequent SAMRC epidemiological studies demonstrated correspondingly lower blood lead levels in first-grade school children across the country. In Johannesburg for example, mean blood lead levels in first-grade children declined from 11.9 to 8.1 µg/dL between 1995 and 2007, and from

13.2 to 4.6 µg/dL in the rural village of Pella between 1986 and 2007 (Fig. 1).^[25]

Lead in paint

The incidental identification in a 2002 Johannesburg blood lead survey of a 7-year-old girl with a blood lead level of 44.4 µg/dL (relative to a sample ($n=383$) mean of 9.4 µg/dL), sparked a series of investigations into lead paint hazards in SA. A home visit revealed that the girl had a severe pica habit and was frequently ingesting paint at both home and school. The paint applied to the walls of her home and school had lead concentrations up to 3 940 µg/g and 2 601 µg/g, respectively (relative to the current, internationally accepted guideline level of 90 µg/g).^[26] Subsequent investigations showed that lead paint had been applied to 20% of dwellings across the City of Johannesburg,^[27] that 96% of children's play parks had playground equipment coated with lead paint,^[28] that paint with highly elevated lead concentrations (up to 145 000 µg/g) had been applied to children's toys and educational equipment (including painted wooden building blocks, airplanes, carts and pencil crayons purchased from toy stores, craft shops, stationery stores and flea/craft markets),^[29] and that highly elevated lead concentrations (up to 189 000 µg/g) could be found in enamel paint available to the general public at retail stores, usually without any content label or warning of the hazardous contents.^[29]

Lead poisoning in subsistence fishing communities

A study of lead exposure in 160 grade 1, 2 and 3 children living in subsistence fishing communities in the remote coastal villages of Elands Bay and Struisbaai revealed blood

lead levels ranging from 2.2 to 22.4 µg/dL, with the mean level equaling 7.4 µg/dL. Around 74% of children had blood lead levels ≥ 5 µg/dL and 16% had blood lead levels ≥ 10 µg/dL.^[30] Questionnaire data showed that in 18% of dwellings, someone crafted fishing sinkers from molten lead. Two households had a member who had swallowed a lead fishing sinker and only 20% of respondents were aware that lead was harmful to health.^[30]

Lead poisoning from Ayurvedic medicines

Ayurvedic medicines have been gaining in popularity around the world in recent years, but have also been associated with incidents of lead poisoning. In 2012 in Durban, SA, a lead poisoning outbreak among adolescents was associated with the consumption of an Ayurvedic medicine for the treatment of skin conditions. In 2014, 8 individuals (out of 12 affected) were traced and interviewed. Their blood lead levels had initially ranged from 34 to 116 µg/dL, and in 2014 from 13 to 34 µg/dL. The implicated Ayurvedic capsules had a lead content of 125 235 µg/g. Participants suffered a wide range of non-specific ill-health symptoms, and there was a significant delay in the diagnosis of lead poisoning, indicating low levels of awareness of the ongoing risk of lead exposure and poisoning in the general public, as well as the medical fraternity.^[31]

Childhood exposure to lead in mining communities

The town of Aggeneys, located in the far north-western part of SA, was developed to support the operation of a lead mine. The SAMRC has undertaken blood lead surveys in Aggeneys, as well as in a control town, Pella, in 1991, 2002 and 2008. Despite higher socioeconomic status (usually a protective factor), blood lead levels in Aggeneys children were significantly elevated relative to their Pella counterparts. The mean blood lead level in Aggeneys was 16 µg/dL compared with 13 µg/dL in Pella (1991). In Aggeneys and Pella, 98% and 85% of children had blood lead levels ≥ 10 µg/dL, respectively. Blood lead levels were associated with low paternal educational status and paternal personal hygiene practices at the end of workdays. Among children with blood lead levels >18 µg/dL, 35% had failed a year at school, compared with 10% in children with lower blood lead levels ($p=0.033$).^[32]

Between 1991 and 2002, the mean blood lead level in Aggeneys children declined significantly, from 15.9 to 7.8 µg/dL, but changed little thereafter (by 2008 the mean

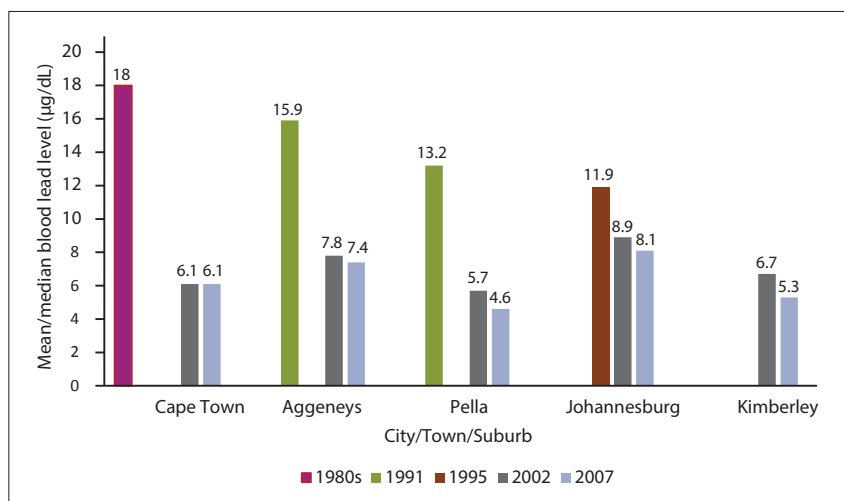


Fig. 1. Mean/median blood lead levels by place and time in South Africa.

blood lead level was 7.4 µg/dL). In Pella, on the other hand, there was a statistically significant decline in mean blood lead levels between each study: 13.2 µg/dL, 5.7 µg/dL and 4.6 µg/dL in 1991, 2002 and 2008, respectively (Fig. 1). It is possible that the declines observed in both Aggeneys and Pella between 1991 and 2002 were due to the introduction of unleaded petrol in 1996. Between 2002 and 2008 the impact of lower levels of lead in petrol may have been overwhelmed by lead exposure associated with lead mining in Aggeneys, compared with Pella. By 2008 more than double the proportion of children in Aggeneys (73%) relative to Pella (30%) had blood lead levels ≥ 5 µg/dL.^[25,32]

Exposure to lead prior to birth

Geophagia is the intentional ingestion of soil and is widely practised in sub-Saharan Africa, especially among pregnant women. While strongly held beliefs about the nutritional benefits of geophagia exist, ingestion of soil has been shown to interfere with the bioavailability of micronutrients (leading to micronutrient deficiencies), and may result in geohelminthic infections, anaemia, hypokalaemia and intestinal obstruction or perforation.^[33-35] Geophagic behaviour may also increase exposure to metal contaminants in the soil, including arsenic and lead.^[36] During 2010 the SAMRC undertook a cross-sectional survey to determine the prevalence of geophagia in pregnant women attending antenatal clinics at the Rahima Moosa Mother and Child Hospital in Johannesburg. Overall, 60/307 women (20%) reported practicing geophagia during their pregnancy; geophagia was most prevalent in international migrant women (19/60 or 32%) relative to women born in SA (41/247 or 17%). Blood lead concentrations were elevated in women who practiced geophagia, but the relationship lost statistical significance after taking account of potential confounding factors. The authors recommended further research on the source and toxic metal content of the soils consumed, as well as the relationship between geophagia and fetal lead exposure in studies with greater statistical power.^[37]

Lead exposure in users of arms and ammunition

Following global scrutiny of lead exposure in shooting ranges,^[38] the SAMRC conducted a survey of the blood lead levels in users of firearm shooting ranges (one outdoor and three indoor), relative to users of archery ranges in Gauteng Province. A total of 118 (87 shooters and 31 archers) were included in the analysis. Shooters had significantly higher blood lead levels compared with archers, with 36/85 (42.4%) of shooters v. 2/34 (5.9%) of archers found to have a blood lead level ≥ 10 µg/dL ($p < 0.001$). At shooting ranges the lowest median blood lead (7.3 µg/dL) was found at the outdoor range, while median blood lead levels at the indoor sites ranged from 9.1 to 16.1 µg/dL. Inadequate infrastructure, poor ventilation, poor housekeeping practices, poor personal hygiene practices and low levels of awareness of lead hazards were amongst the risk factors identified.^[39]

Studies of the health and social effects of lead exposure

Through a partnership between two SAMRC research units the relationships between blood lead levels at birth and during adolescence, and outcomes such as the age of onset of puberty, behavioural maladjustment, aggression and violence were examined. Data from the Birth to Twenty (Bt20) Cohort, which commenced in 1990, were analysed and included babies born in Soweto, Johannesburg.

Lead exposure and delays in onset of puberty

The average age of menarche in 712 adolescent females in the Bt20 cohort was 12.7 years, and at 13 years, 4% and 7% had reached Tanner

stage 5 for pubic hair and breast development, respectively. The mean blood lead level for the sample at 13 years of age was 4.9 µg/dL, and 49% had blood lead levels ≥ 5.0 µg/dL. Analyses showed that higher blood lead levels were associated with significant delays in the onset of puberty.^[40] Earlier, at nine years of age, blood lead levels ≥ 5 µg/dL was associated with slower progression of pubic hair and breast development. In males, elevated blood lead levels at birth were associated with slower tempo of pubic hair development.^[41]

Lead exposure and the emergence of aggressive and violent behaviour

Bt20 data were also used to examine the relationships between blood lead levels during adolescence and aggression or violent behaviour. Using 32 items representing rule-breaking and aggressive behavioural characteristics from the Youth Self Report (YSR) it was shown that blood lead levels at 13 years of age were significantly elevated in boys (6.0 µg/dL) relative to girls (4.5 µg/dL), and associated with aggressive behavior (attacking people).^[42] By the time the cohort reached 14 years of age, elevated blood lead levels at 13 years were positively associated with direct aggression in males.^[43] At the age of 15 - 16 years, blood lead levels ranging from 5.0 to 10.0 µg/dL at 13 years of age were associated with physical violence, while blood lead levels ≥ 10 µg/dL were associated physical violence and fighting. Males were more likely than females to be involved in violence using a weapon ($p = 0.01$), physical violence ($p < 0.0001$), and robbing others ($p < 0.05$).^[44]

Discussion

Since the 1980s, the SAMRC has played a singular and fundamental role in revealing who, where and how the SA population has been, or still is, exposed to lead. The earliest studies conducted revealed pervasive contamination of living and learning environments from very high levels of lead added to petrol in SA, especially in urban areas.^[19-21,23] Selected results from these studies were included in a submission to the SA Cabinet seeking approval for the phase-out of leaded petrol in the country, which was eventually implemented in 2006, alongside significant reductions in childhood blood lead levels.

A series of SAMRC studies revealed widespread use of lead in paint applied to dwellings, schools, children's playground equipment and toys^[27-29] in SA. The evidence generated was successfully used by the SAMRC to lobby for formal regulation of the lead content of paint, rather than rely on the ineffective voluntary industry agreement in place at the time. Such regulations were promulgated in 2009, and are currently being revised and strengthened by reducing the maximum permissible lead concentration in paint from 600 to 90 parts per million, and extending its applicability from household paints, to all paints, pigments, glazes and other coatings intended for use in commercial and industrial sectors. In this regard the National Department of Health, the Department of Environment, Forestry and Fisheries and the Department of Planning, Monitoring and Evaluation are playing steering roles. The updated lead paint regulations will play a pivotal role in protecting current and future generations against lead hazards at home and school, as well as in painted playground and educational equipment, furniture and toys.

Other measures adopted by various sectors as a result of SAMRC lead and health studies include regular training and awareness programmes at pre-school institutions in Johannesburg and elsewhere, restrictions on the use of lead paint by various provincial and local government departments, investment in lead monitoring equipment at local and provincial tiers of government and joint lead hazard awareness campaigns by the National Department of Health (NDoH), the Department of Agriculture, Forestry and Fisheries, the SA Police Service (SAPS), the National

Department of Labour (NDoL), the University of Johannesburg and the University of the Witwatersrand.

Notwithstanding the achievements to date, lead exposure remains a high priority environmental and public health concern in SA, with numerous lead sources and potentially vulnerable groups remaining unattended to, for example, communities living around formal sector lead-related industries and sites of e-waste disposal, subsistence fishing communities and users of arms and ammunition. Moving forward, the SAMRC needs to investigate and lobby for protective actions in relevant formal sector activities, including ceramicware and pottery. However, the biggest, and arguably most daunting, lead exposure reduction challenge ahead is the myriad sources of lead in the informal sector, including cottage industries (home-based micro income generation activities). A study of five neighbourhoods in Johannesburg showed that the proportion of households operating at least one cottage industry potentially associated with lead, ranged from 6.7 to 37.1%.^[45] The use of lead in cottage industries holds the potential for insidious exposure to high levels of lead amongst all household members, as well as broader contamination of the neighbourhood environment. By way of example, the SAMRC lead research team has recently begun investigation of exposure to aluminium, arsenic and lead from the smelting of waste aluminium (for example, from irons, toasters and vehicle wreckage) to craft cooking pots.^[46] Preliminary analyses indicate cause for concern in relation to the leaching of metals into foods prepared in such cookware, and research in this regard is now being scaled up.

Recommendations

It is our view, and we have lobbied for, to confront the ongoing public health risk of lead exposure in SA through an integrated and sustained programme of action, rather than the current, piecemeal approach. In a cohesive and concerted lead exposure reduction effort, the following would be high-priority actions:

- establishment of an Office of Lead Poisoning Prevention Programme within the NDoH, to coordinate lead exposure and reduction efforts nation-wide
- promulgation of blood lead standards for children and adults
- conducting blood lead screening and surveillance programmes in high-risk settings and groups
- strengthening systems for notification of cases of lead poisoning
- developing standard processes for responding to and documenting cases of lead poisoning
- implementing comprehensive, visible and sustained lead hazard awareness programmes (directed at the general public as well as the health, educational and social development fraternities)
- investing in research to identify and prioritise remaining sources of lead exposure
- implementing measures to eliminate sources of lead in affected areas.

The establishment of inter-sectoral partnerships between the NDoH and key non-health sectors in the interests of effective prevention of lead exposure and poisoning, would be an important, and cost-effective, element of any lead poisoning prevention strategy for SA. Among the actions that may be taken up through inter-sectoral partnerships, would be:

- planning departments could play a powerful, preventive role through preventing the location of new human settlements in close proximity to sources of lead, such as mining or smelting operations and relevant industries or infrastructure
- working with the NDoL to introduce more protective lead screening and interventions for workers, including the reduction

of blood lead action levels for workers to levels in closer alignment with international trends

- assisting the SAPS and the Department of Defence, as well as other users of firearms and ammunition, to increase the robustness of blood lead surveillance and protections in these groups
- working with the trade and industry sector to investigate the emerging risks of lead exposure from e-waste
- working with the Department of Small Business Development, local government and other stakeholders, to assess risks of lead exposure from the operation of cottage industries, including subsistence fishing and artisanal pot making, and develop appropriate exposure reduction measures.

The cost of lead exposure reduction efforts may be high, but the cost of inaction is higher. Studies by the SAMRC Burden of Disease Unit conservatively estimated that cardiovascular mortality and disability-adjusted life years (DALYs) in adults aged 30 years and older, as well as mild mental disability (DALYs) in children under 5 years of age from lead exposure, were associated with 1 428 (0.3%) of all deaths in SA in 2000.^[47] From a study undertaken by Attina and Trasande^[48] (2013) to determine the cost of lead exposure in developing countries, it emerged that Africa is one of the regions in which the public health and social costs of lead exposure are particularly high. SA was determined to be second only to Egypt in bearing an exceptionally high economic burden from the loss of IQ points associated with environmental lead exposure. Annually, the SA economy is conservatively estimated to lose around USD17.7 (ZAR262) billion from lead-related loss of IQ points in children. The analyses did not take account of losses associated with lead-related ill-health outcomes such as cardiac disease and violent or criminal behaviour.^[48] Health economics studies undertaken in the USA show that investments in lead exposure prevention are cost-efficient, yielding public health and societal benefits that significantly outweigh the costs. For each dollar invested in lead paint hazard control, for example, a return of USD17 - USD221 (ZAR251 - ZAR3 262) was yielded, which significantly exceeds the return of between USD5.30 (ZAR78) and USD16.50 (ZAR244) from every dollar spent on immunisations.^[49]

Lead poisoning has been described as a 'silent poison' with clinical health effects such as reductions in IQ scores, hearing loss, anaemia and increases in violence and aggression not being readily discernible; a blood lead test is usually required to detect lead poisoning. Through the ongoing SAMRC research programme on lead poisoning, a compelling body of evidence of lead exposure and harms has been generated. The essential next step is the translation of the research generated into a concerted and integrated lead exposure reduction programme in SA. The most vulnerable groups – young children and the poor – will be the chief beneficiaries, with benefits for communities and the national economy reaped through improved learning ability and advanced educational achievement, lowered violence (two major socio-political challenges in SA), and other economic benefits. Action to prevent lead exposure makes national health, social, educational and economic sense; inaction is indefensible.

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