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Review article

# Lead-based paint remains a major public health concern: A critical review of global production, trade, use, exposure, health risk, and implications

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ABSTRACT

Human exposure to lead (Pb) is a growing global public health concern. Elevated blood lead is thought to cause the mental retardation of > 0.6 million children globally each year, and has recently been attributed to ~18% of all-cause mortality in the US. Due to the severe health risk, the international community, led by the United Nations Environment Programme (UNEP) and the World Health Organization (WHO), is actively supporting the global phase-out of lead-based paint by 2020. However, there are many significant hurdles on the way to achieving this goal. In light of the importance of the lead-based paint issue, and the urgency of achieving the 2020 phase-out goal, this review provides critical insights from the existing scientific literature on lead-based paint, and offers a comprehensive perspective on the overall issue. The global production and international trade of lead-based paints across Asia, Africa, Latin America, and Europe are critically discussed – revealing that lead-based paints are still widely used in many low and middle-income developing countries, and that the production and trade of lead-based paint is still wide-spread globally. In India, as well as many south-east Asian, African, Latin American and European countries, lead concentrations in paints often exceed 10,000 mg/kg. This will certainly pose a serious global threat to public health from surfaces painted with these products for many decades to come. The sources and pathways of exposure are further described to shed light on the associated health risk and socioeconomic costs. Finally, the review offers an overview of the potential intervention and abatement strategies for lead-based paints. In particular, it was found that there is a general lack of consensus on the definition of lead based paint; and, strengthening regulatory oversight, public awareness, and industry acceptance are vital in combating the global issue of lead based paint.

## 1. Introduction

According to the World Health Organization (WHO), lead exposure accounted for nearly half a million deaths in 2016, and over 9 million disability-adjusted life years (DALYs) (WHO, 2017); 82% of these lead related deaths occur in low and middle-income developing countries (Landrigan et al., 2018). Lead is an abundant contaminant in the environment (Hou et al., 2017b), and thus a global public health concern. However, only very recently has the remarkably large relative contribution of environmental lead exposure to mortality been quantified. Lanphear et al. (2018) undertook a population-based cohort study, involving 14,289 adults in the US. In this study, the attributable fraction of blood lead level (BLL) for all-cause mortality was revealed to be a remarkable 18%, equating to an estimated 412,000 deaths per year, thus making lead exposure comparable to tobacco smoke exposure as a cause of mortality. Lanphear et al., also found that an increase in BLL from 1.0 to 6.7 μg/dL, which represented the 10th and 90th percentile BLL of the study population, was associated with a hazard ratio of 1.37 (95% CI 1.17–1.60). Although acute lead poisoning is not a thought to be major contributor to child mortality globally, children with elevated BLLs may suffer from impaired neurological development (WHO, 2010). Childhood lead exposure is thought responsible for mild to

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moderate mental retardation of > 0.6 million children each year globally (Fewtrell et al., 2004). The toxic effect of lead exposure on IQ is thought irreversible, persisting for a lifetime (Gilbert and Weiss, 2006).

Experience in the US shows that, historically, there were three major sources of lead exposure to children, which were (i) airborne lead from leaded gasoline, (ii) chips and dust of deteriorated lead-based paint in the home, and (iii) lead in soil due to both geogenic and anthropogenic sources (Committee on Environmental Health, 2005). After the US ban of leaded gasoline, the primary source of children's lead poisoning has become lead-based paint and lead contaminated soil (Lofgren et al., 2000). With an estimated 70% of cases of elevated BLL have an immediate lead paint source (Renner, 2010). Drinking water may also be regarded as a potential lead exposure source in certain areas with a plumbosolvent water supply (Elwood et al., 1984). For instance, in the US, elevated child BLLs have been previously linked to elevated lead in drinking water in North Carolina (Triantafyllidou et al., 2007), Maine (Triantafyllidou et al., 2007), Washington DC (Edwards et al., 2009a), and Flint, Michigan (Hanna-Attisha et al., 2016). In the UK, the main sources of lead in drinking water have been attributed to lead service pipes and household plumbing, where solubility depends on water acidity, temperature and residence time (Harries et al., 2013). Therefore, although lead in paint and dust are considered the focus to reducing children's exposure to lead, lead in water should not be overlooked (Renner, 2010).

Lead has been incorporated into mass-market consumer products such as lead-based paint for more than a century. Paint manufactures have historically added lead to paint because of its highly protective properties that make paints more durable (Gilbert and Weiss, 2006), and improves paint adherence to substrates/surfaces (Lin et al., 2009), or to enhance colours (Greenway and Gerstenberger, 2010). For example, lead (II)carbonate ($PbCO_3$) and lead chromate (PbCrO4) have been used as white and yellow color pigments, respectively. Lead carbonate can also aid the neutralization of acidic decomposition products that derive from some oils in paint, this helps paint coatings to stay tough yet flexible, and crack-resistant for longer (Crow, 2007). It is now well-established from a myriad of scientific reports and studies that there are detrimental health effects and the associated socioeconomic costs of lead-based paint being available, a UNEP published in 2017 report noted that only about one third of the 193 countries investigated regulate the use of lead in paint (UNEP, 2017a).

Lead-based paints are still widely manufactured and used in many developing countries (Kessler, 2014; Kumar, 2009). For instance, in China - the largest paint producer and consumer of paints globally (Wu et al., 2017) –paints are often available in the market with elevated lead levels, despite enacting a mandatory limit on lead in paint since 1986 (Section 2.2), and despite India's voluntary standard for lead content in paints, lead-based paints are still widely available (Section 2.3). Although most developed countries, and some developing countries now regulate lead concentration in paints used for building interiors and toys, paints for industrial usage (e.g. anti-corrosive paints) are still often unregulated. These paints pose a risk to human health and the environment if they later enter the consumer market, (IPEN, 2017a) for instance in home-related products such as toys, or in deteriorated paint chips, dusts, and soils, which are often observed as a consequence of lead-based paint use. Further to this, paint production and consumption have been steadily growing in developing countries, and many countries lack legally binding controls for lead-based paint (Kessler, 2014; Kumar, 2009). In these countries, average lead concentrations are often in the range of tens of thousands of mg/kg in household and decorative paints (Section 2), while internationally the typical regulatory thresholds are 90–600 mg/kg, with 90 mg/kg being considered as protective.

In the past several years, the lead-based paint issue has drawn the attention of international organizations and non-governmental organizations (NGOs) (IPEN, 2017a). The International Conference on Chemicals Management (ICCM) at its second session (ICCM-2, Geneva, 11–15 May 2009) endorsed the United Nations Environment Programme (UNEP) and World Health Organization (WHO) to establish the Global Alliance to Eliminate Lead Paint (GAELP), with the task to globally eliminate lead in paint by 2020. As of September 2017, out of the 193 member states of the UN, 67 had verified legally binding limits on lead in paint (UNEP, 2017b); and as of early 2016, 53 countries had established the further requirements for paint can labelling, and 17 countries had requirements for paints to be tested and certified for lead content to enforce their leagally binding limits (UNEP, 2016). Despite the international effort toward establishing regulatory controls, there remain many hurdles for achieving the GAELP's goal of eliminating lead-based paint globally by 2020. Unless addressed, these hurdles, coupled with a loss of political will among developed nations to provide the technical assistance to back such plans in developing countries (Tan and Li, 2017), may lead to disappointment.

In light of the risk to human health and the environment posed by the use of lead-based paints, and the urgency for achieving the 2020 phase-out goal, we believe that it is important to review the existing scientific literature regarding lead-based paint, and to provide a comprehensive perspective on the overall issue. Therefore, this review article provides critical insights into: 1) the global production, trade, and use of paints; 2) the effectiveness of regulatory controls across Asia, Africa, Latin America, and Europe; 3) the various sources and exposure pathways pertaining to lead-based paint; 4) the recent health risk management strategies developed to address lead exposure and the associated socioeconomic costs; and 5) the implications and recommendations regarding environmental management of lead-based paint.

## 2. Production, trade and use

### 2.1. Production and international trade

According to the European Union (EU) Directive 2004/42/CE on paints and varnishes and vehicle refinishing products, paint is defined as a product which provides “a film with decorative, protective or other functional effect on a surface”, and, in the context of the directive, a “film” is “a continuous layer resulting from the application of one or more coats to a substrate” (European Parliament, 2004). Paint includes both oil and water based products. Market analysis often mixes the terms “paints” with “paints and coating” or “coatings” (Valk, 2014), herein we use the term “paint” collectively. Global paint consumption was estimated to be 36.1 million tons in 2006 (Betne et al., 2011). As Fig. 1 shows, in recent years, the production of paint has significantly increased in developing countries, while a decrease in developed countries is seen. The major producers of paints manufactured 21.5

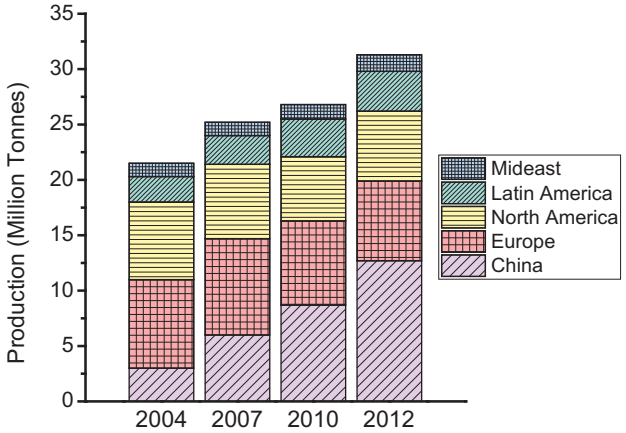


**Fig. 1.** Global production of paints – years 2004 to 2012, Data source IHS Chemical - Country Statistics: (Valk, 2014).