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Leaded Paint in Cambodia—Pilot-scale Assessment

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Background. Lead is a heavy metal that is well known to pose a threat to human health. Although the sale and use of lead paint has been banned in much of the developed world, lead is still commonly used in enamel paints in the developing world, including Cambodia. As Cambodia's economy grows, this may increase the purchase and use of lead-based paints, thus potentially exposing more of the population to the toxic effects of lead.
Objective. This study was performed to evaluate the concentration of lead in enamel paints in Cambodia using a method that is quick, effective, and cost-efficient.
Methods. A handheld X-ray fluorescence analyzer was used to evaluate 21 samples of enamel paint, including 8 replicates that were randomly purchased from three shops in Phnom Penh, Cambodia to evaluate the level of metals. All of the paint samples in the current study were manufactured in Thailand.
Discussion. Ninety percent of the enamel paints sampled in Cambodia exceeded the voluntary standard of 100 µg/g lead of the producing country, Thailand. The mean and median levels for lead were 11,833 µg/g, and 4,961 µg/g, respectively.
Conclusion. Based on our pilot-scale assessment, high levels of lead appear to be common in enamel paints in Cambodia, and a fuller assessment of the situation is warranted. Import and production of such toxic products should be avoided and appropriate labeling and public warnings should be provided.
Competing Interests. The authors declare no competing financial interests.
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Introduction

Countries began banning lead in paint in 1909, and in 1922 the League of Nations banned lead-based paint.[1] Although the toxicity of lead, especially to children, was well documented, the USA did not ban lead in paint until 1977.[2-4] The delay partly reflected promotion by producers of such paints. Because some paint manufacturers promoted "the use of lead-based interior paints for decades after they were recognized as potentially harmful" in 2014, a judge in California ruled that these companies establish a $1.15 billion fund to remove lead-based paint from homes in California.[5,6] However, the sale of paints with lead continues in much of the less developed world.[7-11] As prosperity increases, people often update their homes with colorful paints and sales of such paint is common in the developing world. For example, Indonesia's paint market grew 13% from 2011 to 2012, after a previous average annual growth of 8% between 2006 and 2011.[12] Although Cambodia is one of the least developed countries with a gross domestic product (GDP) per capita in 2013 of $1,006.80 US, from 2002 to 2012 Cambodia's economic growth rate averaged 7.47%.[13] Cambodia could soon follow worldwide trends in the use of colorful enamel paints, which may contain lead.

Although prior to this study it was expected that Cambodia was importing or producing paints as has been documented throughout this region, there have been no data on this issue. Cambodian laboratories are still poorly developed and the analysis of lead in paint requires a simple method with minimal operating costs. The most appropriate method for this analysis is X-ray fluorescence (XRF). The use of handheld XRF analysis for lead-based paints was conducted as early as 1975 by the Chicago Board of Health in response to the growing concern of lead poisoning, particularly in children.[14] Subsequently, the United States Environmental Protection Agency (USEPA) and the US Department of Housing and Urban Development integrated handheld XRF protocols for testing lead-based paints into their monitoring programs.[15] It is important to note that more powerful X-ray sources such as radioisotopes are needed to detect lead under layers of new paint. Analyses of this type have found that lead-containing paints remain very common in some places. In a survey

from 1998–2000 in the US, "38 million housing units had lead-based paint, down from the 1990 estimate of 64 million. Twenty-four million had significant lead-based paint hazards".[16] More than half of XRF measurements indicated a lead level of 1.0 mg/cm$_2$ or greater.[16] Moreover, 14% of the houses observed in the Little India district in Singapore had lead levels equal to 1.0 mg/cm^2 or greater, while 63% of the surfaces tested in Singapore's Chinatown were greater than or equal to 1.0 mg/cm^2.[17] The purpose of this study was to evaluate the presence of lead in enamel paints in Cambodia using a handheld XRF analyzer.

Abbreviations

$Cr_2Mo_2O_{11}Pb_2$	Lead chromate molybdate	*RPD*	Relative percent difference
GDP	Gross domestic product	*SUNY*	State University of New York
$PbCrO_4$	Lead chromate	*USEPA*	United States Environmental Protection Agency
$PbSO_4$	Lead sulfate	*XRF*	X-ray fluorescence
QA/QC	Quality assurance/ quality control		

Methods

In 2011, 21 paints, including eight replicates, were randomly purchased from three shops in Phnom Penh, Cambodia to evaluate the level of metals. The labels indicated all paints were produced by U-90 in Thailand. A secondary goal was to purchase different paint colors in order to determine if lead concentration was equally distributed among paint colors. A Niton XL3t handheld XRF unit (Thermo Fisher Scientific, Waltham, MA) was used in this study. Before the analysis, each paint sample was manually shaken for 30 seconds to homogenize the metal content. Then, an Eppendorf pipette was used to transfer 1 ml of the sample onto a Mylar film.[18] The sample was immediately shot with the handheld XRF XL3t for 30 seconds in plastics mode at the University of Health Sciences in Phnom Penh. In previous analyses of face creams, plastics mode produced satisfactory results.[18] The paint was not dried; we wanted a method that could be used quickly to evaluate products at sites of importation or where the public could get an analysis of paint in real time.

For quality assurance/quality control (QA/QC) purposes, duplicate analyses were done for yellow, green, and red paints from three different stores. In addition, a side-by-side

Samples	N	Min.	Max.	Mean	SD	SE
Yellow	5	705	33,150	22,322	10,171	406
Red	5	15,350	43,970	24,949	10,586	459
Green	5	1,753	4,961	3,215	1,277	75
Black	1	(–)	(–)	516	(–)	22
Grey	1	(–)	(–)	ND	(–)	ND
Brown	1	(–)	(–)	334	(–)	22
Blue	1	(–)	(–)	82	(–)	13
White	2	560	1,088	824	373	35

Table 1 — XRF Measurement of Lead in Paints
Note: Values presented as µg/g. ND–not detectable; SD–standard deviation; SE–standard error; (-)–Value not available due to limited sample size
The means for single samples are analyzer-generated means, whereas the means of replicate samples are traditional statistical means.

Country	Number of Samples	Mean (µg/g)	% ± 90 µg/g
China	64	15,070	333
Ecuador	10	31,960	60
Egypt	20	26,660	65
India	72	29,660	82
Indonesia	11	14,770	73
Malaysia	72	24,510	50
Nigeria	25	15,750	96
Peru	10	11,550	80
Seychelles	28	24,880	61
Singapore	41	7,000	37
Thailand	18	19,410	89

Table 2 — Lead Content in Paints by Country[12]

comparison was done using an XRF xLi unit in the Department of Earth Sciences, Buffalo State, State University of New York (SUNY), with the XL3t unit and a sediment standard, Canadian Certified Reference Materials Project (CCRMP) Till-4. The Buffalo State, SUNY XRF analyzer was calibrated more extensively than was possible in Cambodia and provided a greater level of QA/QC analysis.[19]

Results

The paint data are summarized in Table 1. For all samples collectively, around ninety percent (90.5%) of the paints had higher lead than the guideline of 90 µg/g.[20] Table 1 also shows that there may be some differences in lead levels depending on the color of the paint. The red, yellow and green paint results were entered into a chi-square test (the other colors were not statistically analyzed because of the limited sample size) and it was found that there was a significant difference between the colored paints ($P < 0.05$), with green paint having significantly lower lead levels. Qualitatively, black, grey, brown, blue, and white paints also seemed to have lower lead levels as compared to the red and yellow paints. Differences in lead levels across paint colors is not surprising, as the most common lead pigments include lead chromate ($PbCrO_4$), lead chromate molybdate ($Cr_2Mo_2O_{11}Pb_2$) and lead sulfate ($PbSO_4$), with mixtures of lead chromate and lead sulfate being used to produce different shades of reds and yellows.[12] However, it is not possible to estimate lead by color, and a larger sample might have produced different results.

For comparison purposes, results for other countries are shown in Table 2, and a survey by color for other countries is shown in Table 3.[12] The trend towards higher levels of lead in red and yellow as compared to other paint colors seems to be consistent across countries (*Table 3*), and the lead levels reported in the present study are generally in the higher range of those reported for other countries (*Table 2*).

A relative percent difference (RPD) was calculated for the duplicate samples and the mean RPD was 40%. While this value is higher than might be hoped, it is within the accepted maximum range for soils of 30–50%.[21] Side-by-side comparisons of the two XRF units and the sediment standard are shown in Table 4. At these levels, the lead was underestimated by 50% and this may mean the numbers we report in this paper are conservative.

In this study of U-90 enamel paints, mercury was not detected (< 20 µg/g). Other metals were detected, but relative to lead, were not significant (i.e. mean ± standard deviation: arsenic 737 ± 650 µg/g, chromium 3410 ± 3150 µg/g, titanium 14600 ± 20700 µg/g).

Country	Yellow	Red	Green	White	Blue	Grey	Brown	Black
Cambodia								
Mean	22,322	24,949	3,215	824	82	ND	334	516
Median	26,724	18,506	2,823		—	ND	—	—
SD	10,171	10,586	1,277	373	—	ND	—	—
N	5	5	5	2	1	1	1	1
Nigeria[29]								
Mean	42,271	23,744	15,976	3,035	3,457	—	—	—
Median	40,515	24,457	12,216	4,110	3,615	—	—	—
SD	5,393	15,877	9,410	1,864	1,729	—	—	—
N	4	4	3	5	5	—	—	—
Taipei[30]								
Mean	64,400	17,830	33,130	1,115	3,427	—	—	—
Median	34,235	5,369	24,124	4.5	725	—	—	—
SD	—	—	—	—	—	—	—	—
N	5	5	5	5	5	—	—	—
China[31]								
Mean	—	—	—	—	—	—	—	—
Median	17,600	752	8,950	21	139	100	—	218
SD	—	—	—	—	—	—	—	—
N	9	16	5	8	5	2	—	7
India[32]								
Mean	90,000	6,539	21,250	992	5,600	—	—	3,619
Median	—	—	—	—	—	—	—	—
SD	—	—	—	—	—	—	—	—
N	16	31	16	24	28	—	—	21
Malaysia[33]								
Mean	149,000	—	24,200	—	—	—	—	—
Median	—	—	—	—	—	—	—	—
SD	—	—	—	—	—	—	—	—
N	1	—	1	—	—	—	—	—

Table 3 — Lead in Paint by Color, International Examples
Analysis not done for a particular color represented by —; ND–not detected; SD–standard deviation, N–number of samples. All values presented as µg/g.

	Certified CCRMP-TILL4		XRF XL3t 900		XRF XLi	
Element	Ref. Value	Sigma (δ)	Value	Sigma (δ)	Value	Sigma (δ)
Cu	230	±13	217	±16	235	±15
Fe	32,000	±39	31,009	±234	31,230	±245
Pb	56	±4.2	24	±6	32	±10
Zn	71	±13	48	±8.1	55	±6.1
As	97	±5.2	101	±6.2	105	±7.2

Table 4 — Validation Check Between Two XRF Analyzers and Reference Material
All values are in µg/g; ND–not detected

Discussion

Due to concerns over lead toxicity, leaded gasoline for cars is now only available in 4–6 countries with modest use, but unfortunately, leaded paints are found in more than 40 countries, many with extensive use.[22,5] In addition to the effects on human health, the economic costs to countries polluted with lead is significant.[23,24] Cambodia is like much of the developing world in that lead-based enamel paints appear to be common. More extensive evaluations are recommended. Although Thailand was the only source of paints analyzed in this study, paints are also imported from other countries and are manufactured within Cambodia as well. Thailand now has a voluntary standard of 100 µg/g of lead, which was exceeded in 90% of the samples analyzed in our study.[10] Given the apparent widespread availability of paints with lead throughout the developing world (*Tables 2 and 3*), it is important for countries like Cambodia to develop a monitoring program to assess new imports as well as domestic production. Unfortunately, it is unlikely that anything will be done about old paint stocks that remain on the shelves of paint stores in developing countries. There is a need for more international pressure on the producers of these paints. Both the Global Alliance to End Lead Paint and the American Public Health Association have called for the elimination of lead paint.[25,26]

Handheld XRF analyzers with X-ray tubes are useful for detecting lead in fresh paint and with minor developments should be effective in the developing world. Within the paints we processed, those with lead beyond the Thai guideline would still have been detected without shaking the sample. This is important for customs agents. More accurate results require shaking immediately before subsampling. Unfortunately, when we did our study, reference materials for fresh paint were not readily available. Current paint standards are for dried paint. Our intent was to develop a method to quickly measure paints in markets to avoid their being sold in the first place. Drying paint takes time, which is not optimal for rapid inspection. Again, the measurement of dried paint on house walls cannot be done with a simple handheld XRF powered with an X-ray tube. Analysis of dried paint on walls is done with more powerful XRF analyzers with radioisotope sources of X-rays, and because of the greater safety concerns, usually require more rigorous training and licensing. Verification with a calibrated XRF analyzer as used in this study is one option, but ideally, inexpensive standards would be available. The matrix of samples has a very substantial effect on XRF analysis and validation is difficult for simple laboratories. Government laboratories in poor countries typically have minimal support for operating their laboratories. Because of the emphasis on remediation of lead-containing paint in houses in the developed world, most standards supplied by XRF producers are for old paint.

In Cambodia, the metal content of older dried paints in houses and paints on products like toys and garments should be explored through further studies. In a set of 38 toys in Phnom Penh, 12,313 and 20,479 µg/g of mercury was found in paint on two of the toy tops.[27] Full discussion of this issue is beyond the scope

of this paper, but it is important to note that high concentrations of mercury are also found in some paints. Moreover, there are concerns that mercury is being used in paints on clothing in garment factories in Cambodia. Mercury was banned in American paints in 1990.[28] Mercury is likely much less common than lead in paints, but mercury warrants concern and for this reason it would be advantageous to use an instrument that could quickly detect multiple metals. Lead-based paints appear to be the biggest concern, but all toxic metals in paints should be restricted globally, not just in developed countries.

Conclusion

Our pilot-scale assessment indicated high levels of lead appear to be common in enamel paints in Cambodia, and a fuller assessment of the situation is warranted. Import and production of such toxic products should be avoided and appropriate labeling and public warnings should be provided. Ideally, a government office or NGO would provide access to analysis of lead in paint to the public.

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