



Research article

Lead content in automotive paints purchased at formal and informal outlets in Kenya

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ARTICLE INFO

Keywords:

Automotive lead-based paints
Lead exposure
Spray painting activities
Sanding
Informal sector

ABSTRACT

Lead (Pb) is added to automotive paints to prevent corrosion on metallic surfaces, for decorative colours, and for reflective properties to heighten visibility, and enhanced drying time, and durability. However, there are substitutes for all of these applications and Pb is highly toxic to human health and the environment. Through concerted efforts, leaded gasoline was phased out and currently, the focus is on lead-based paints. Leaded automotive paint used for spray painting activities often conducted in close proximity to human habitation raises public health concerns over possible exposure. This study was therefore undertaken to assess Pb levels in automotive paints frequently used by informal spray painters. A total of thirty-two ($n = 32$) cans of automotive paints were purchased in 4 sets of red, blue, green and white colours from eight formal and informal retail shops. Lead levels in the paint samples were analyzed in triplicates using Atomic Absorption Spectrophotometry. All the automotive paints from the informal retail shops had Pb levels that ranged from 220 to 2740 ppm, and exceeded the regulatory limit of 90 ppm. The blue paint from the informal store had the highest Pb levels which were 30 times of the set limit. On the contrary, the paints from the formal stores had significantly ($p < 0.05$) lower Pb levels that ranged from 80.7 to 580 ppm than those of the informal stores. Although only one paint sample from the former retail shop had Pb levels within the limit. In general, the elevated Pb levels in automotive paints that are used in an unregulated environment are potential sources of exposure and environmental contamination. The study urgently calls for enforcement of the regulatory limits and comprehensive Pb exposure assessments in this sector.

1. Introduction

Lead (Pb) pigments are added to paints during manufacturing processes to provide colours [1,2]. The most commonly used pigments in the production of automotive paints are lead chromates, lead oxides, lead molybdates, and lead sulfate [3]. Lead naphthenate, lead acetate and lead octoate may also be added to paint as drying agents and catalysts to accelerate the polymerization process making the oil-based paints dry faster and more evenly [4]. Lead tetroxide is further added to paints to prevent corrosion and rust on metallic surfaces. Paints are applied essentially on the surfaces of automobiles for aesthetic value [3,4]. In addition, automotive paints provide ultraviolet protection and enhancement of colour that include fade, mold, heat and moisture resistance.

The automobile industry is a growing enterprise globally and the demand for auto-repair-related services such as spray painting has subsequently increased in developing countries [5–9]. The informal sector in Kenya accounted for 83.4% of total employment in 2017

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<https://doi.org/10.1016/j.heliyon.2023.e12831>

Received 9 June 2022; Received in revised form 19 December 2022; Accepted 3 January 2023

Available online 12 January 2023

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[10]. During the same year, the auto-repair sub-sector reported tremendous growth as a result of the increased number of vehicle imports. The spray painters predominantly operate on a small scale, with limited resources, in open spaces often located along roadsides with possibilities of broken-down vehicles [7,11,12]. They are also frequently found adjacent to rivers, and densely populated residential and commercial areas [8,13].

Several studies have reported that lead-based paints are extensively used in several low and middle-income countries [8,14–16]. In particular, Heng et al. and Obeng-Gyasi et al. [17,18] observed that apart from legacy Pb exposure, these countries have limited resources and infrastructure to regulate and enforce Pb exposure, resulting in significantly exposed populations. Lead is highly toxic and bio-accumulates and is also persistent in the environment with serious health outcomes [16,19]. The associated burdens of diseases due to Pb exposure have been widely studied [8,20,21]. The toxic metal has devastating effects that result in long-lasting intellectual disabilities among children [8,22,23]. An estimated economic loss of GDP per year due to childhood Pb exposure in low and middle-income countries accounts for 1.9% in Asia, 2.0% in Latin America and 4.0% in Africa [24,25].

Automotive Pb-based paints when it is still in a can is not an immediate source of Pb exposure. Lead-based painted surfaces will however over time, age, weather, wear and chip when disturbed, and are great sources of Pb exposure and environmental contamination [5,6]. Auto-repair often requires the removal of paint from metal surfaces [26]. Moreover, the spray painting processes that encompass frame straightening, welding, panel beating, manual sanding, scraping, cleaning, and re-painting release related pollutants into the environment [6,26,27]. Close observations of these activities have revealed considerable amounts of hazardous Pb particles generated through intense sanding and scraping when the surfaces are prepared for repainting or remodeling [5,6,26]. Airborne Pb particles are easily inhaled by those in the vicinity. Depending on the prevailing winds, these particles can spread to contaminate soil and household dust, presenting ongoing health risks [28,29]. Other particles get washed off by rainfall where they contaminate rivers and get to humans through various food chains.

It is worth noting that painters in this sector neither have the best technologies nor best practices to prevent Pb exposures [13,27,30,31]. The majority of informal spray painters do not use ventilated paint booths allowing paint mists to spread to the surrounding areas [7]. These mists may be held up in the breathing zone air for a long time and are easily inhaled by those in close proximity. The

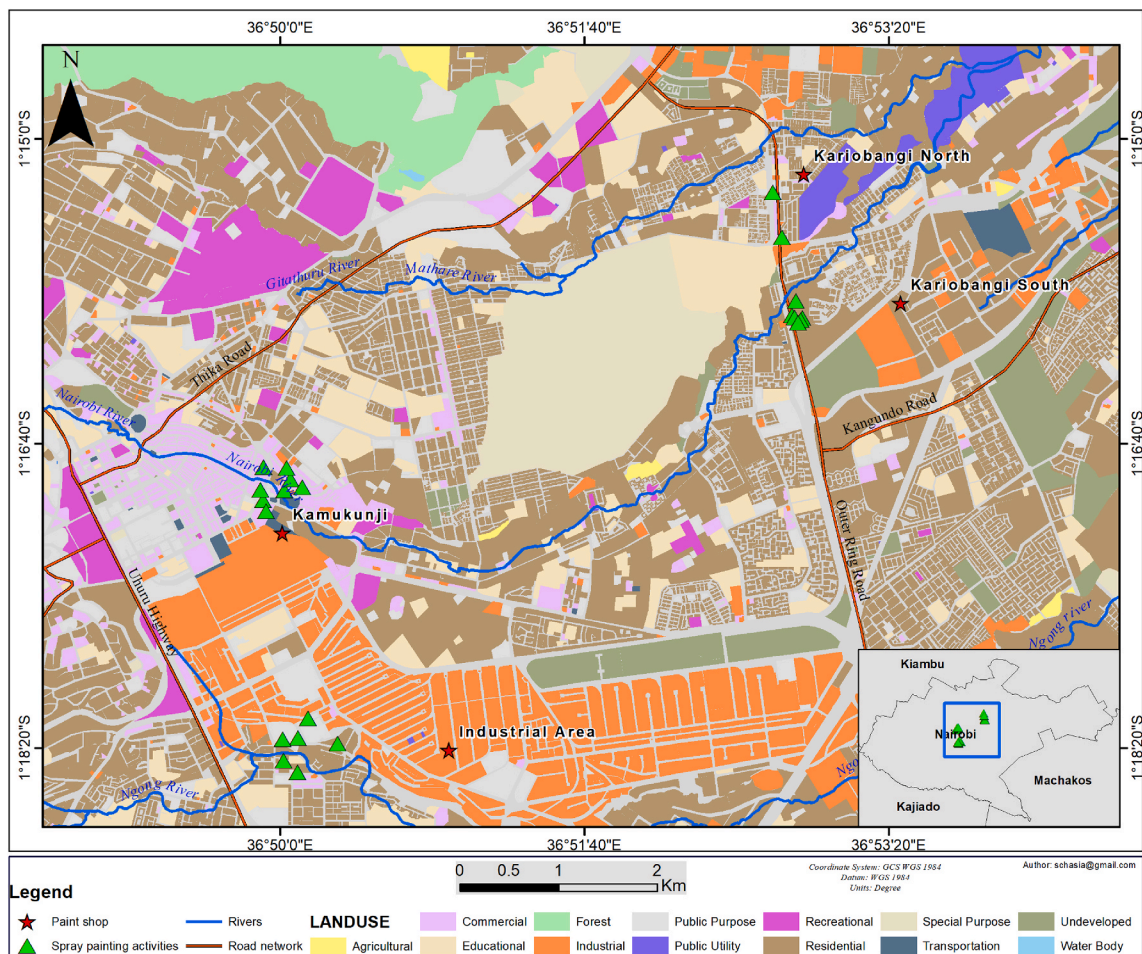


Fig. 1. Selected retail shops for automotive paints with respect to close observation of spray painting activities.

painters and nearby communities are hence susceptible to elevated levels of toxic substances containing Pb in the form of mists [32]. Toxicity levels are highly influenced by the duration of exposure. Vitayavirasuk et al. [9] considered Pb as a systematic toxicant and low levels of exposure-induced organ damage in paint artists. Indeed, to a greater extent, the continued manufacture and use of leaded automotive paints in an unregulated environment are raising public health concerns over possible exposures and environmental contaminations [26,33,34].

Lead in paints was identified as one of the major emerging policy issues of concern after the global phase-out of leaded fuel [2,15]. Nonetheless, some countries have restrictions on the use of specific Pb compounds in pigments, driers and anti-corrosive agents in paints [2,15]. For instance, Australia has several Pb compounds that have been phased out for use in paints with a few exemptions [3]. Restrictions on the use of specific Pb compounds are however difficult and costly to control and enforce when compared to the regulatory limits of total Pb content in paints. It is for this reason that some countries have established a regulatory limit of 90 parts per million (ppm) but mainly for residential paints [16]. Other countries with regulatory limits of 600 and 1000 ppm are revising them to 90 ppm and still, others do not have these limits.

In 2018, the East Africa Standards for Paints and Allied Products Technical Committee revised all the paint product standards requirements, including that of automotive paint to include the 90 ppm limit of total Pb content across the region [35]. The paint products that comply with the requirements of the standard including the 90 ppm total Pb maximum have a national standardization mark. Although implementation and enforcement of the paint standard is still a challenge in some sectors. Basically, compliance with the 90 ppm limit is easily achievable when paint manufacturers are not intentionally adding leaded materials during the production processes [2,15]. Furthermore, there are readily available non-hazardous substitutes for all lead-based paints. This study, therefore, assessed Pb contents in automotive paints and compared them with the regulatory limits.

2. Method and materials

The study was carried out between 2018 and 2019 involving a total of thirty-two ($n = 32$) cans of automotive paint samples. The paints were purchased from eight randomly selected retail shops located within a 1 km radius of automotive spray painting activities. These paints were subsequently analyzed for Pb levels using Atomic Absorption Spectrometry.

2.1. Description of the study area

The study covered both formal and informal stores that sold automotive paints directly to spray painters around Nairobi County. In this study, the formal (licensed) and informal (unlicensed) paint manufacturers had stores that sold automotive paints, the stores were then considered formal and informal retail shops, respectively. The retail shops were randomly selected on the basis of their locations adjacent to the clustered spray painting activities (Fig. 1).

The paints were retailed in small quantities at a cost-effective price and as a result, the shops were popular with small-scale spray painters. The painters were generally operating in clusters in an open space, and in most cases, in close proximity to densely populated residential areas including sensitive locations such as schools, rivers, and hospitals (Fig. 1). In addition, land use was unregulated and hence ineffective in safeguarding the environment from related contaminations. Overall, the unstructured nature of these operations was an impediment to enforcing relevant regulations [7,27]. The spray painting activities were consequently causing harm to the environment and human health. For instance, significant Pb levels have been reported in the Nairobi River around the spray painting activities [36].

The randomly selected formal retail shops in Nairobi were mainly located in the Industrial Area (IA) and Kariobangi North (KN). They sold automotive paints that were branded and had clear labeling and markings that included the batch numbers, net content (mL), date of manufacture and expiry. In this setting, the minimum paint sold was 250 mL at the lowest price of 3 USD. On the other hand, the informal retail shops were located in Kamukunji (K) and Kariobangi South (KS) in the informal settlements. These shops had limited information on the labels of automotive paints that they were retailing. In nearly all cases, the net content of paints that were dispensed in a 100 mL can was not indicated. Although a 100 mL container was selling at 1 USD which was the lowest price observed across all the informal retail shops. Moreover, the cans with the lowest price had no standardization mark, manufacturer's name, batch numbers and dates of manufacture. Additionally, there were no technical barriers that prohibited the sale of paints with added lead components to the consumers.

2.2. Sampling

Four sets of cans of automotive paints consisting of red, blue, green and white colours of 250 mL and 100 mL were purchased from each of the eight randomly selected formal and informal retail shops, respectively. The choice of the colours was also in the context of the shades of colours that were frequently used by several spray painters in the area. The paints were purchased from the selected retail shops and included the Formal Industrial Area shop-1 and 2, coded as FIA 1 and FIA 2 Formal Kariobangi North shop-1 and 2, coded as FKN 1 and FKN 2, the Informal Kariobangi South shop-1 and 2, coded as IKS 1 and IKS 2 and finally the Informal Kamukunji shop-1 and 2, coded as IK 1 and IK 2, illustrated in Fig. S1 (Supplementary material).

2.3. Laboratory sample preparation

A total of thirty-two ($n = 32$) coded automotive paint samples in cans were then transferred to the Analytical Laboratory of the

Table 1
Optimized AAS conditions for analysis of lead in automotive paints.

Operating Conditions for Pb analysis	Wavelength (nm)	Lamp current (mA)	Measurement time (s)	Fuel	Slit width/bandwidth (nm)	Flow rate (L/min)	Sensitivity (ppm)	The detection limit (ppm)	Linear Equation	R2
Parameters	283.3	5	1.0	Air-Acetylene	0.7	2.0	0.1100	0.0200	$y = 0.0012x + 0.0039$	0.995

Mines and Geological Department in the Ministry of Mining in Nairobi. The preparation of samples for Pb analysis was carried out in accordance with ISO 6503 (1984) and the [37]. All the operations were carried out in a fume cupboard. Each of the samples in cans was thoroughly mixed for homogenization. Thereafter 0.5000 g of the wet paint samples in triplicates (making a total of 96 samples), were placed in each of the 500 mL conical flasks using plastic droppers. The samples were heated gently on a hot plate for 5 min at a temperature of 200 °C to remove all volatile solvents. The dried paint samples were then digested with 5 mL sulphuric acid, 96% v/v and heated for 15 min to decompose and carbonize the organic substances until white fumes evolved. The samples were then allowed to cool for 10 min. This was followed by further additions of four 5 mL hydrogen peroxide 30% v/v allowing the reaction to subside after each addition. It was again heated for about 10 min and then allowed to cool for 5 min.

Two of 5 mL portions of the hydrogen peroxide solution were again added while heating for 5 min and allowing to cool for 5 min. Finally, a 5 mL portion of hydrogen peroxide solution was added and heated to decompose the remaining hydrogen peroxide. The contents were further heated until copious white fumes evolved and the solution evaporated to dryness. They were then removed from the hotplate and allowed to cool. The samples were then extracted by addition of 50 mL Ethylenediaminetetraacetic acid (EDTA), the disodium salt of 37 g per liter solution; 10 mL of the ammonia solution 25% v/v and 50 mL distilled, and deionized water. This was then boiled gently for 15 min. The sample extracts were left to cool at room temperature and filtered using Whatman No. 42 filter paper into a 100 mL volumetric flask and topped up to the mark using distilled and deionized water for AAS analysis. The blanks were prepared using the same procedure but without the sample.

2.4. Analysis of lead levels

Atomic Absorption Spectroscopy (AAS) Shimadzu ASC 7000 (auto-sampler) equipped with appropriate mono-elementary hollow cathode lamp for Pb and a deuterium (D₂) arc—background corrector was used for quantification of total Pb. A series of standards of 2, 4, 8, 10, and 20 parts per million (ppm) for Pb calibration curves were freshly prepared by serial dilution in 0.01 M nitric acid (1% (v/v) from 1000 ppm commercial stock for the AAS. The levels of Pb in digested paint and blank samples were assayed using AAS at optimized operational conditions (Table 1). The concentration was then obtained directly from the standard calibration curves after correction of the absorbance using appropriate reagent blanks. The samples were diluted in cases where their absorbance was higher than that of the standard solution, All the automotive paint samples were measured in triplicates and the mean values were expressed in parts per million (ppm).

2.5. Quality control and assurance

In view of the importance of quality assurance and control of analytical procedures, precautions were taken to avoid external contamination of samples to ascertain the reliability and accuracy of the results. The reagents and chemicals that were used throughout the analytical procedure were of high-purity analytical grade (Merck). The deionized and distilled water was used throughout the analysis. The glassware was washed thoroughly and left overnight in dilute (2%) nitric acid to remove any trace amounts of metals that could have been adsorbed on the glassware, and then rinsed with deionized and distilled water. The linearity of the standard calibration curve was also evaluated by checking the linear regression coefficient (R²) values. The values were within the acceptable range (Table 1). For every ten samples that were analyzed a standard solution was aspirated to check the instrument drift.

The Inter-laboratory comparisons were also carried out by randomly subjecting 10 selected samples to similar analytical procedures at the Analytical Laboratory at the Mines and Geological Department under the Ministry of Mining and the Department of Chemistry of the University of Nairobi. The Pearson correlation coefficient at P = 0.05 gave a positive correlation coefficient of r = 0.950. Furthermore, the analyzed samples were randomly spiked with the addition of varying amounts of Pb in the standard solutions. Spike recovery values were between 90 and 110% which was within the expected AAS performance. The validity of the method was further ascertained by cross-method checks and replication analysis. The averages of all analyzed samples in triplicates were considered when the relative standard deviation (RSD) values were less than 5%, indicating a high precision.

It should also be noted that there were no known Pb-based blue pigments among the raw materials that were commonly used for the production of paints. The possibility of chemical interferences of Pb signals as a result of high concentrations of coloured transitional metals such as copper (wavelength: 324.2 nm and slit width: 0.5 nm) and iron (wavelength: 248.5 nm and slit width: 0.2 nm) was ruled out by using the AAS to analyze the respective metals in the blue and green paints. Nevertheless, their concentrations were much lower than 10,000 mg/L, suggesting that there were no such interferences in regard to Pb signals.

2.6. Data analysis

The coded raw data of Pb levels in parts per million (ppm) of four sets of colours of automotive paints from eight formal and informal retail shops were subjected to appropriate statistical analysis. The Pb concentrations were analyzed in triplicate ($n = 3$) and expressed as arithmetic means with a standard deviation (\pm sd). Descriptive analyses were applied to all variables. The Shapiro-Wilk test in R was used to determine the distribution normality of the data for comparison of lead (Pb) levels in automotive paints purchased from informal and formal retail shops. The data was not normally distributed and therefore the nonparametric tests were applied. Wilcoxon rank sums tests were used to compare Pb levels in automotive paints purchased from formal and informal retail shops, whereas the Kruskal-Wallis rank sum test was used to relate Pb levels in various colours of automotive paints. All the tests were done at the 5% significance level.

3. Results and discussion

Table 2 is the summarized descriptive data of lead (Pb) levels in parts per million (ppm) in automotive paints purchased from informal and formal retail shops. The corresponding Fig. 2 compares the mean Pb levels (ppm) of various colours of automotive paints and regulatory limits of 90, 600 and 1000 ppm that are in existence in different countries across the world [15,16,35].

The automotive paints from the informal retail shops had high Pb levels in the range of 220–2740 ppm when compared to that of the formal retail shops, which ranged from 80.7 to 580 ppm based on the descriptive statistics (Table 2). From inferential analysis, using the Wilcoxon rank sum test, it was established that there was a significant difference between Pb levels from the formal and informal retail shops (p -value = $6.435e-12 < 0.05$).

Fig. 2, indicates that the mean Pb levels in all (100%) automotive paint samples from the informal stores exceeded the most protective regulatory limit of 90 ppm total Pb in paint [15,16,35]. In addition, about 63% and 38% of these paints had mean Pb levels above the existing regulatory limits of 600 ppm and 1000 ppm, respectively in other countries, suggesting that these paints cannot be sold in those countries [16,25]. On the contrary, the paints from the formal retail shops had significantly lower Pb levels (p -value = $3.217e-12 < 0.05$), even though there was only one sample from the first retail shop in Industrial Area (FIA 1) that had levels that fell within the 90 ppm limit. Nonetheless, all the automotive paint samples that retailed in the formal stores had mean Pb levels that were within the acceptable limit of 600 ppm, implying that the paints can be sold freely in those countries [15,16]. Ultimately, the high Pb values that exceeded the 90 ppm limit in the automotive paints from both informal and formal retail shops could be attributed to the additions of the correspondingly high amount of Pb pigments and driers during paint production [3,16].

It should be noted that several paint manufacturers are only producing lead-free paint, with a total Pb content of less than 90 ppm and many automotive manufacturers are exclusively using these products. This is achievable by carefully avoiding the use of leaded materials or pigments during manufacturing processes. From these observations, it is apparent that all the automotive paints sampled, from both informal and formal retail shops had intentionally varying content of added leaded compounds with exception of one paint sample (FIA 1). This means that virtually all automotive paint manufacturers represented in our survey were adding leaded compounds during production processes. The study is in agreement with that of [34,38] that observed high levels of Pb in the air of the work environment that correlated with blood lead levels (BLLs) among workers in production areas of paint manufacturing.

The informal retail stores had a significantly higher Pb level (p -value = $1 > 0.05$) than their counterparts. In descending order, it follows that IK 2 had the highest overall mean Pb levels, followed by IKS 2 and IK 1. Among the informal retail shops, Kariobangi South shop-1 (IKS 1) had a relatively low mean Pb level of 312 ± 74.3 ppm with comparable median values (Kruskal-Wallis chi-squared = 5.0807, $df = 3$, p -value = $0.166 > 0.05$) with that of the formal retail shops (FKN 2). This implies that some of the informal stores are capable of formulating and retailing automotive paints with comparable Pb content as those of the formal stores. It is hence imperative that such stores may require technical support in the area of standardization of their paint products and serve as models for the elimination of Pb paints within the informal sector. In addition, it is worth noting that in almost all cases, the formal retail shops in the Industrial Area (FIA) had fairly low overall mean Pb levels compared to those of Kariobangi North (FKN). This could be attributed to the latter using a substantial amount of leaded compounds in form of pigments, drying agents, or anti-corrosive agents in the production processes.

Among the paint colours (Fig. 2), the blue paint purchased from the first informal retail in Kamukunji (IK 1) had the highest mean Pb values of 2688 ± 20 ppm, which was about 30 times greater than the 90 ppm of the regulatory limit. The second retail shop in the same location had equally high mean Pb levels of 2651 ± 77 ppm in the blue paint. The paints were also marketed as “economical fast drying auto-paint”. In contrast, the blue paint retailing at the same price from IKS I had the lowest mean Pb level of 221 ± 1.4 ppm. Interestingly, the blue paint procured from the first formal retail shop in the Industrial Area (FIA 1) had no added leaded compounds. Yet, the same quality of blue paint from the second shop on the same site had relatively high mean Pb values of 151 ± 5.0 ppm. Furthermore, the blue paints from FKN 1 and FKN 2 had somewhat high mean Pb levels of 169 ± 14 ppm and 277 ± 4.3 ppm, respectively. Similar trends of differing values of Pb levels in the same paint colours were observed across all the automotive paint samples. From these observations, it is plausible that cost may not be the influencing factor for retailing or manufacturing lead-based automotive paints. Several studies have further reported that paint products sold under the same brand, with the same cost and colour had varied Pb levels across different countries [2,15,25].

On the high spectra, almost all automotive paints from IK 2 and the blue paint from IK 1, as well as the red and white paints from IKS 2, had the highest Pb levels that exceeded the regulatory limit of 1000 ppm [16]. The IK retail shops were marketing their paint products as “economical fast drying auto-paints” that provide long-lasting durability and high resistance to weathering. Lead-based compounds when added to paints usually improve the quality of speed drying to increase durability, retain a fresh appearance and

resist moisture. The most commonly used Pb-driers are lead octoate and lead naphthenate [39]. The anti-corrosive Pb compounds such as lead tetroxide are also added to paints to inhibit rust or corrosion on metal surfaces. The Pb driers are most likely responsible for the elevated Pb levels in the blue paints from IK shops since there are no known lead-based blue pigments. In addition, the possibility of chemical interferences of Pb signals due to high concentrations of other coloured ions such as copper and iron in the paint samples were ruled out through the AAS analysis.

Basically, from Fig. 2, the automotive paints in the informal stores had the highest mean Pb levels of 1490 ± 1364 ppm in blue colour, followed by 1267 ± 909 ppm in white, 1026 ± 999 ppm in green and lastly 1017 ± 745 ppm in red. The high standard deviation values from the mean Pb levels for various paint colours was observed across the informal retail shops. This could strongly suggest that varying proportions of leaded pigments, anti-corrosive agents or driers were added to paints during the manufacturing processes. It is also possible that these paints may have originated from different manufacturers that used different formulations. The green paint purchased from all the formal retail shops had Pb concentrations ranging from 327 ± 6.6 to 555 ± 36.1 ppm and were consistently higher than the other coloured paints in the same shops. The addition of varying amounts of Pb compounds to a great extent contributed to the Pb values of more than 90 ppm, notwithstanding the location of these retail shops.

The frequently used pigments in the manufacture of these coloured paints are lead chromate molybdate sulfate [3]. They are unevenly blended phase crystals that contain lead chromate (yellow), lead sulfate (white), and lead molybdate (orange) in varying proportions to produce diverse shades of colours [40]. Furthermore, there is lead chrome green [PbCrO₄: KFe(Fe(CN)₆)] that is added to give a green pigment. These pigments are opaque and are easily pulverized into fine particles producing high-gloss automotive paints with varying Pb values [3]. The paints are also durable and resistant to ultraviolet light. Lead (II) oxide also known as red lead is generally used as a pigment in the manufacture of automotive paints and can result in a high concentration of Pb in red paints [40]. Leaded compounds for example lead tetroxide are further added to paint to inhibit rust or corrosion [1,40]. This clearly explains the high variations in the Pb levels that were observed across different shades of colours of automotive paints in this study.

Paint formulation encompasses a large number of components. It is obvious that there are several safer substitutes for Pb pigments derived from combinations of organic and inorganic to natural sources, including iron oxides that provide quite a range of reds, yellows, purples, browns and blacks. This implies that there is no single lead-free alternative for exact replacements of all the technical properties of lead-based paint. The white paint with leaded compounds can easily be replaced with titanium oxide and barium-zinc-sulfur combinations and their durability is enhanced by the addition of silicon or aluminium oxides. Replacement of Pb driers to a larger extent does not require complex reformulations, zirconium and calcium provide good substitutes for these driers. The main challenge is usually to formulate quality paints with accurate and precise colours for repainting. This is especially difficult in the informal paint manufacturing industry that has limited resources in regard to research and development coupled with the use of old technology in the formulation of new paints. This probably explains why most automotive paints from the informal stores with an exception of one shop (IKS 1) had elevated Pb levels when compared to those from the formal retail shops. It now appears that the increased Pb exposure and environmental contamination is attributed to continued deep reliance on Pb-based paints for several decades [41,42].

In 2018, the Kenyan government gave a directive pursuant to the Traffic (Amendment) Bill of [43] that all school vehicles should be painted yellow using unleaded paints. This was to enhance safety through standardization of colours of school vehicles and yellow colour is associated with clear visibility. The directive further gave the specification code for both the quality and colour of the paint [35]. It was also requisite that the painting should be done by a qualified painter. Despite the clear specifications of the colour code, the vehicles are painted with diverse shades of yellow colours ranging from light yellow to deep orange. It is most probable that some painters or paint manufacturers find it challenging to come up with a standard yellow colour. There are also many derivatives of yellow paint on the market [4,40]. Studies have further reported unusually high Pb levels in bright yellow and orange paints for residential use ranging from 5000 to 20,000 ppm [25,44]. This has been a clear indication of intentionally added lead compounds during paint manufacturing [4,25,44]. However, the retail shops that were surveyed in this study did not have yellow paint colour in small quantities.

This study has evidently shown that Pb levels in automotive paints were high and differed across the retailing shops and were not necessarily influenced by the price. The high Pb levels observed in this study implied that unprotected users could directly get exposed. Lead is one of the elements that is a cumulative and neurotoxicant with no known biological function [45]. It is a key public health concern as it negatively affects virtually all the biological systems within the human body and has devastating consequences on human health [46]. Health authorities have also acknowledged that there is no safe level of Pb exposure that impacts pregnancy and neurological foetal development (WHO. 2019).

Several authors have revealed elevated blood lead levels (BLLs) that persist in many low and middle-income countries [8,14,44]. In

Table 2
Lead levels (ppm) in the automotive paints from informal and formal retail shops.

Sampled sites	Formal retail shops				Informal retail shops				
	Coded retail shops	FIA1 (n = 12)	FIA2 (n = 12)	FKN1 (n = 12)	FKN2 (n = 12)	IK1 (n = 12)	IK2 (n = 12)	IKS1 (n = 12)	IKS2 (n = 12)
Mean (SD)		172 (103)	227 (69.6)	287 (97.2)	376 (112)	1230 (877)	1900 (757)	312 (74.3)	1360 (934)
Median Range (Min, Max)		137 (180.7, 338)	201 (145, 336)	269 (157, 420)	333 (274, 580)	780 (691, 2710)	2050 (853, 2740)	314 (220, 443)	1290 (391, 2460)

n = Number of samples; SD = Standard Deviation; Range (Min = minimum and Max = maximum) in a parenthesis.

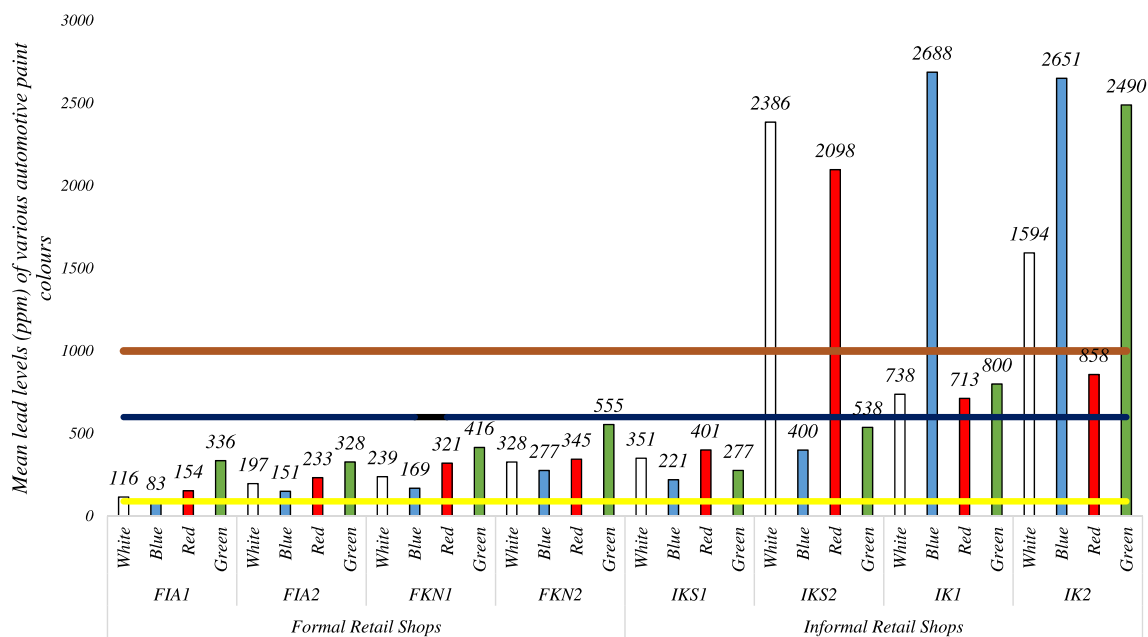


Fig. 2. Mean lead levels (ppm) of various automotive paint colours purchased from formal and informal retail shops.

Note: The horizontal lines indicate the legal limits of 90 (Yellow), 600 (Black) and 1000 (Brown) ppm of lead in paints set by different countries [16]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

addition, the substantial occupational and environmental Pb exposure that occurs in these countries is solely unregulated and is coupled with limited monitoring capacities [6,8,17] and [19]. This is especially true when considering the unregulated production of paints and spray-painting activities often conducted in close proximity to densely populated areas [8,18]. Equipment that is normally used for spray painting includes; spray guns, high volume low pressure sprayers and rotary bell spray. Spray guns are cheaper and affordable to informal workers [7]. The low-resourced painters usually use spray guns that have compressed air with very low paint deposition capacity and this is the utmost avenue for great exposure as a result of paint overspray [27,47]. The exposure levels are further built up by surface preparation prior to re-painting which is typically characterized by intense sanding and scraping of old paintwork [6,26].

The spray painters also operate in an environment with limited knowledge of occupational safety and health. In Ethiopia for example, a high proportion of workers who were engaged in manual vehicle painting activities had the BLLs of greater than 20 $\mu\text{g}/\text{dL}$ [5]. The job remuneration and experiences for this cadre are profoundly evaluated in terms of manual scraping and sanding of the surfaces of old paints. This usually progresses from the painting of small patches to the entire surface. Ahmad et al. [6] established the highest mean Pb levels of 78.0 $\mu\text{g}/\text{dL}$ in blood, 24.0 mg/kg in hair and 29.6 mg/kg in nails of spray painters when compared to the other auto-technician. According to Ref. [26]; the sanding and painting operations in an auto repair shop in the United States resulted in increased BLLs. These authors were in agreement that the situation in the developing countries could be worse due to the increased maintenance of older vehicles for a longer period in an unregulated environment coupled with limited engineering controls, inadequate work practice and use of inappropriate PPEs. This study is supported by several authors documenting elevated BLLs in auto-repair and paint sprayer workers.

The residues produced from these activities can effectively contaminate and spread in the environment [28]. Soils, air, water and food crops have suffered an amalgamation of similar contamination across the food chain that can build up slowly over time presenting a long-lasting negative impact [9]. Remediation of such sites is complex and costly. These activities continue to heavily contribute to the extensive exposure and contamination of rivers, residential, agricultural, and commercial sites [8]. Especially since land-use zoning that separates the hazardous areas has proved to be ineffective. Of great concern is therefore the health outcome of communities living adjacent to the unregulated spray painting activities that use lead-based automotive paints. From a health point of view quality of life and economic empowerment for these communities are diminished with severe implications on sustainable development goals [8,25]. Certainly, any strategy that prevents Pb exposure and environmental contamination will result in increased economic development [24].

4. Conclusion and future perspective

Lead in paint was identified as one of the key emerging policy issues during the second International Conference on Chemicals Management in 2009 which called for the elimination of all applications of lead paint. The Global Alliance to Eliminate Lead Paint was successively launched in 2011 aimed at the global phase-out of lead in paint by the year 2020. Although, this deadline has not been

met. Several countries, including those in East Africa, established a regulatory limit of 90 ppm. Other countries are currently establishing or revising their legal limits of 600 ppm and 1000 ppm–90 ppm in order to protect human health and the environment. The 90 ppm limit if enforced could ensure that no paint manufacturers add lead compounds during the production processes.

Given that there is no safe level of Pb exposure, the manufacturers should not use any raw materials that contain Pb but use alternatives that have the least hazardous properties. Similarly, spray painters should use unleaded automotive paints. There is therefore an urgent need to enforce the most protective regulatory limit of 90 ppm total Pb, which will reduce exposures to auto repair workers and the environment. The strategies and efforts to eliminate Pb in paint are however faced with a number of challenges dominated by differing production landscapes. Formal paint manufacturers are more likely to adopt the established regulatory limits. Apparently, they have resources for training in research and development to shift to unleaded paints. Their paints are further branded and hence implementation and enforcement of the stipulated limit are feasible. On the other hand, their counterparts who also run retail shops have limited resources and suppliers of raw materials have a less commercial interest in such small markets. They indeed lack incentives to shift to unleaded materials, creating uneven competition and a challenge in the implementation and enforcement of the 90 ppm limit. This sector is in urgent need of a comprehensive assessment of Pb exposure levels and support in the mapping of the supply chain to procure safe substitute ingredients. Intervention to ensure the availability of safer and less hazardous inputs and consumer network is critical. Without efforts to ban the production and import of lead pigments and driers, automotive paints will remain a major source of Pb exposure and environmental contamination.

Acknowledgements

The authors thank the Department of Chemistry, Faculty of Science and Technology of the University of Nairobi for the research facility and technical support. We also acknowledge the Analytical Laboratory in the Department of Chemistry of the University of Nairobi, Analytical Laboratory in Mines and Geological Department and the Materials Testing Research Division Laboratory for their research facilities and technical support. We thank the retail shops that participated in the study. The authors are also grateful to Perry Gottesfeld, the Director of Occupational Knowledge for his contribution to the revision of the manuscript.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.heliyon.2023.e12831>.

References

- [1] J.H. Bieleman, in: *Additives for Coatings*, Wiley-VCH, Weinheim, New York, USA, 2000, pp. 1–202.
- [2] GAELP (Global Alliance to Eliminate Lead Paint), Retrieved from: <http://www.unep.org/hazardoussubstances/LeadCadmium/PrioritiesforAction/GAELP/GAELPObjectives/tabid/6331/Default.aspx>, 2011.
- [3] DEEA (Department of the Environment and Energy Australia), Lead in paints. <http://www.environment.gov.au/protection/chemicals-management/lead/lead-in-auto-paints>, 2017.
- [4] E. Gliozzo, C. Ionescu, *Pigments—lead-based whites, reds, yellows and oranges and their alteration phases*, *Archaeol. Anthropol. Sci.* 14 (1) (2022) 1–66.
- [5] Y. Adela, A. Ambelu, D.A. Tessema, Occupational lead exposure among automotive garage workers—a case study for Jimma town, Ethiopia, *J. Occup. Med. Toxicol.* 7 (2012) 15, <https://doi.org/10.1186/1745-6673-7-15>.
- [6] I. Ahmad, B. Khan, S. Khan, M.T. Khan, A.P. Schwab, Assessment of lead exposure among automobile technicians in Khyber Pakhtunkhwa, Pakistan, *Sci. Total Environ.* 633 (2018), <https://doi.org/10.1016/j.scitotenv.2018.03.160>, 293–29.
- [7] A.O. Odongo, W.N. Moturi, A.M. Obonyo, Influence of task-based airborne lead exposures on blood lead levels: a case study of informal automobile repair artisans in Nakuru town, Kenya *Environ. Geochem. Health* 42 (7) (2020) 1893–1903, <https://doi.org/10.1007/s10653-019-00464-7>. Epub 2019.
- [8] WHO (World Health Organization), Lead exposure in African children contemporary sources and concerns. World Health Organization, Regional Office for Africa ISBN: 978-0-86970-787-6 ©WHO Regional Office for Africa, 2015, <https://apps.who.int/iris/bitstream/handle/10665/200168/9780869707876.pdf;jsessionid=1DC724A077FEE22AAC523237855B0E5?sequence=1>, 2015.
- [9] B. Vitayavirasuk, S. Junhom, P. Tantis-baerane, Exposure to lead, cadmium and chromium among spray painters in automobile body repair shops, *J. Occup. Health* 47 (2005) 518–522. <https://pubmed.ncbi.nlm.nih.gov/16369115/#:~:text=doi%3A%2010.1539/joh.47.518>.
- [10] Kenya National Bureau of Statistics (KNBS), Kenya Economic Survey 2017, Government Printer, Nairobi, 2018. <https://a.captchaless.top/robot4/?c=03e4531e-5a15-4e86-844f-2ad60c13eee2&a=190852#>.
- [11] J.J. Ashraph, R. Kinyua, F. Mugambi, A. Kalebi, Health effects of lead exposure among Jua Kali (informal sector) workers in Mombasa, Kenya: a case study of the Express Jua Kali workers, *Int. J. Med. Med. Sci.* 5 (1) (2013) 24–29, <https://doi.org/10.5897/IJMMMS12.126>. Available online at: <http://www.academicjournals.org/IJMMMS>.
- [12] A. Saliu, O. Adebayo, O. Kofoworola, O. Babatunde, A. Ismail, Comparative assessment of blood lead levels of automobile technicians in organized and roadside garages in Lagos, Nigeria, *J. Environ. Public Health* (2015), <https://doi.org/10.1155/2015/976563>.
- [13] S. Tamilselvi, S. Balraj, Assess the knowledge and problem faced by the spray painters working in small scale auto garages in Sriperumbudhur, *Int. J. Adv. Res. Community Health Nurs.* 2 (2) (2020), 89–9, <http://www.communitynursing.net/>.
- [14] B. Ericson, H. Hui, E. Nash, G. Ferraro, J. Sinitsky, M.P. Taylor, Blood lead levels in low-income and middle-income countries: a systematic review, *Lancet Planet. Health* 5 (3) (2021) 145–153, [https://doi.org/10.1016/S2542-5196\(20\)30278-3](https://doi.org/10.1016/S2542-5196(20)30278-3).
- [15] D.O. O'Connor, D. Deyi Hou, J. Ye, J. Yunhui Zhang, Y. Sik, Y. Song, F. Coulon, T. Peng, L. Li Tian, Lead-based paint remains a major public health concern: a critical review of global production, trade, use, exposure, health risk, and implications, *Environ. Int.* 121 (2018) 85–101, <https://doi.org/10.1016/j.envint.2018.08.052>.
- [16] UNEP (United National Environment Programme), Update on the global status of legal limits on lead in paint, Available from: <https://www.unenvironment.org/resources/report/2019-update-global-status-legal-limits-lead-paint>, 2019.
- [17] Y.Y. Heng, I. Asad, B. Coleman, L. Menard, S. Benki-Nugent, H.F. Were, J. Catherine, J.C. Karr, S.M. Megan S McHenry, Heavy metals and neurodevelopment of children in low and middle-income countries: a systematic review, *PLoS One* 17 (3) (2022), e0265536, <https://doi.org/10.1371/journal.pone.0265536>.
- [18] E. Obeng-Gyasi, Sources of lead exposure in various countries, *Rev. Environ. Health* 34 (1) (2019) 25–34, <https://doi.org/10.1515/reveh-2018-0037>.

- [19] WHO (World Health Organization), Lead Poisoning and Health. <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>, 2019.
- [20] P. Ahlawat, V. Shukla, Biological monitoring of lead and cadmium in blood, hair and nail of autoworkers, *Int. J. Basic Appl. Biol.* 3 (2016) 142–145.
- [21] F. Gil, A.F. Hernández, C. Márquez, P. Femia, P. Olmedo, O. López-Guarnido, A. Pla, Biomonitorization of cadmium, chromium, manganese, nickel and lead in whole blood, urine, axillary hair and saliva in an occupationally exposed population, *Sci. Total Environ.* 409 (2011) 1172–1180, <https://doi.org/10.1016/j.scitotenv.2010.11.033>.
- [22] J.O. Nriagu, M.L. Blankson, K. Kwamena Ocran, Childhood lead poisoning in Africa: a growing public health problem the, *Sci. Total Environ.* 181 (2) (1996) 93–100, [https://doi.org/10.1016/0048-9697\(95\)04954-1](https://doi.org/10.1016/0048-9697(95)04954-1).
- [23] R.M. Tripathi, R. Raghunath, A.V. Kumar, V.N. Sastry, S. Sadasivan, Atmospheric and children's blood Lead as indicators of vehicular traffic and other emission sources in Mumbai, India, *Sci. Total Environ.* 267 (1–3) (2001) 101–108, [https://doi.org/10.1016/S0048-9697\(00\)00770-1](https://doi.org/10.1016/S0048-9697(00)00770-1).
- [24] T.M. Attina, L. Trasande, Economic costs of childhood lead exposure in low- and middle income countries, *Environ. Health Perspect.* 121 (2013) 1097–1102. Available from: http://ehp.niehs.nih.gov/1206424/?utm_source=rss&utm_medium=rss&utm_campaign=1206424.
- [25] IPEN, Global Lead Paint Elimination by 2020. [http://refhub.elsevier.com/S0160-4120\(18\)31435-1/rt0480](http://refhub.elsevier.com/S0160-4120(18)31435-1/rt0480), 2016.
- [26] R.T. Enander, H.J. Cohen, D.M. Gunte, L.C. Brown, A.M.C. Desmaris, R. Missaghian, Lead and methylene chloride exposure among automotive repair technicians, *J. Occup. Environ. Hyg.* 1 (2004) 19–25, [https://doi.org/10.1016/0048-9697\(95\)04954-1](https://doi.org/10.1016/0048-9697(95)04954-1).
- [27] A.K. Mwatu, Health Hazards Associated with Spray Painting among Workers in Small Scale Auto Garages in Embakasi Division, Msc Thesis, School of Health Sciences, Kenyatta University, Nairobi, Kenya, 2011, <https://ir.library.ku.ac.ke/bitstream/handle/123456789/7230/Agnes%20K.%20Mwatu.pdf?sequence=1>.
- [28] O.O. Abidemi, Levels of Pb, Fe, Cd, and Co in soils of automobile workshop in Osun State, Nigeria, *J. Appl. Sci. Environ. Manag.* 15 2 (2011) 279–282, <https://doi.org/10.4314/jasem.v15i2.68510>.
- [29] U. Franck, S. Odeh, A. Wiedensohler, B. Wehner, O. Herbarth, The effect of particle size on cardiovascular disorders—the smaller the worse, *Sci. Total Environ.* 409 (2011) 4217–4221, <https://doi.org/10.1016/j.scitotenv.2011.05.049>.
- [30] D. Dibakar DeySanjeev, K. Kumar Supriyo, S. Supriyo Chakraborty, Effects on lung function among workers exposed to automobile spray painting – a cross-sectional study at Nagatilla, Silchar, Assam, *J. Evidence-Based Med. Healthcare* 4 (92) (2017) 5600–5604, <https://doi.org/10.18410/jebmh/2017/1122>.
- [31] S.T. Methre, M.S. Karandikar, A study of pulmonary functions of spray painters working in automobile garage, *IOSR J. Dent. Med. Sci.* 15 (3) (2016) 1–7, <https://doi.org/10.9790/0853-15340107>, e-ISSN: 2279-0853, p-ISSN: 2279-0861.
- [32] J. Suwansakri, N. Teerasart, V. Wiwanitkit, T. Chaiyaset, High blood lead level among garage workers in Bangkok, public concern is necessary, *Pubmed* 15 (4) (2002) 367–370, <https://doi.org/10.1023/a:1020233202035>.
- [33] S.K. Pachathundikandi, E.T. Varghese, Blood zinc protoporphyrin, serum total protein, and total cholesterol levels in automobile workshop workers in relation to lead toxicity: our experience, *Indian J. Clin. Biochem.* 21 (2006) 114–117.
- [34] F.H. Were, M.C. Moturi, P. Gottesfeld, G.A. Wafula, N.G. Kamau, P.M. Shiundu, Lead exposure and blood pressure among workers in diverse industrial plants in Kenya, *J. Occupat. Environ. Hygiene* (2014), <https://doi.org/10.1080/15459624.2014.908258>.
- [35] KEBS (Kenya Bureau of Standards), Kenya Gazettees New Paint Standards to Eliminate Lead Paints (14 February 2018), Retrieved from: <http://www.ecogreennews.com/kenya-gazettes-new-paint-standards-to-eliminate-lead-paints/>, 2018.
- [36] F.A. Masee, Investigation of Pollutants, Determination of Physico-Chemical Characteristics of the Nairobi River and Remediation of Some Toxic Heavy Metals Using Fish Bones, Msc Thesis, School of Physical Sciences, University of Nairobi, 2010, http://erepository.uonbi.ac.ke/bitstream/handle/11295/11560/Masee_Investigation%20of%20pollutants,%20determination%20of%20physico-chemical%20characteristics%20of%20the%20Nairobi%20river.pdf?isAllowed=y&sequence=3.
- [37] US. EPA, (United States, Environment Protection Agency), Standard Operating Procedures for Lead in Paints by Hot Plate or Microwave Based Acid Digestion and Atomic Absorption Spectroscopy or Inductively Coupled Plasma Emission Spectroscopy, 2001.
- [38] S.L. Huang, C.-Y. Yin, S.Y. Yap, Particle size and metals concentrations of dust from a paint manufacturing plant, *J. Hazard Mater.* 174 (1–3) (2010) 839–842, <https://doi.org/10.1016/j.jhazmat.2009.09.129>.
- [39] G. Buxbaum, *Industrial Inorganic Pigments*, John Wiley and Sons, 2008, pp. 105–206.
- [40] C. Higgitt, M. Spring, D. Saunders, Pigment-medium interactions in oil paint films containing red lead or lead-tin yellow, *Natl. Gallery Tech. Bull.* 24 (2003) 75–95. <https://cool.culturalheritage.org/waac/wn/wn27/wn27-2/wn27-204.pdf>.
- [41] J. Montes-Santiago, G. Fortuny, Van Gogh, V. Portinari, Lead poisoning in painters across three centuries, *Rev. Clínica Española* 206 (2006) 30–32, [https://doi.org/10.1016/s0014-2565\(06\)72707-2](https://doi.org/10.1016/s0014-2565(06)72707-2).
- [42] A. Mathee, H. Röllin, J. Levin, I. Naik, Lead in paint: three decades later and still a hazard for African children? *Environ. Health Perspect.* 115 (2007) 321–322, <https://doi.org/10.1289/ehp.9575>.
- [43] Traffic amendment Bill. <https://www.kenyans.co.ke/news/19793-kenyan-school-buses-be-painted-yellow>, 2016.
- [44] A. Kumar, P. Gottesfeld, Lead content in household paints in India, *Sci. Total Environ.* 407 (2008) 333–337.
- [45] WHO (World Health Organization), Lead Poisoning and Health. Archived from the Original on 18 October, Retrieved from: <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>, 2016.
- [46] WHO (World Health Organization), World Health Organization. Exposure to lead: a major public health concern. Geneva, Retrieved from; <https://www.who.int/ipcs/features/lead.pdf?ua=1>, 2010.
- [47] W. Heitbrink, R.H. Verb, Comparison of Conventional and High Volume-Low Pressure Spray-Painting Guns, 1996, <https://doi.org/10.1080/15428119691015043>. Wallace Published 1 March 1996.