

Research Project Report

Health Risk Analysis of Lead Exposure in Selected Paint Industry Workers in Indonesia



May 2024

Acknowledgement

We thank all those who helped compile and shape this study. This report presents new data on the health risks of lead paint manufacturers in Indonesia and recommends action steps by relevant stakeholders to protect the workers and consumer community from exposure to lead paints.



Nexus3 or Nexus for Health, Environment, and Development (formerly known as BaliFokus Foundation) is an organization in Indonesia that works to safeguard the public, especially vulnerable populations, from the impact of development to health and the environment, towards a just, toxics-free, and sustainable future.
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List of abbreviations

ADD	Average Daily Dose
APCI	<i>Asosiasi Pengusaha Cat Indonesia</i> / Indonesia Paint Industry Association
BLL	Blood Lead Level
BMDP	<i>Bea Masuk Ditanggung Pemerintah</i> / Government-Borne Import Duty
EC	Estimated Concentration
ELCR	Excess Lifetime Cancer Risks
HI	Hazard Index
HQ	Hazard Quotient
PMA	<i>Penanaman Modal Asing</i> / Foreign Capital Investment
PMDN	<i>Perusahaan Manufaktur Dalam Negeri</i> / Domestic Manufacturing Company
PRTR	Pollutant Release and Transfers Registry
SNI	<i>Standar Nasional Indonesia</i> / Indonesian National Standard
UKM	<i>Usaha Kecil–Menengah</i> / Small-Medium Enterprises
VOCs	Volatile Organic Compounds

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Executive Summary

Background

Until 2021, about 77% of decorative paints manufactured and sold in Indonesia contain high lead concentrations above the global achievable safe level of 90 ppm. Lead is a toxic heavy metal and is classified as a probable human carcinogen.

This study was conducted in Indonesia from 2022 to 2023 and aimed to assess the health risks faced by paint manufacturers' workers in three factories grouped as follows:

- Industry A: lead-safe paint manufacturers (20 workers);
- Industry B: a facility that more recently eliminated lead paint (12 workers); and
- Industry C: lead paint manufacturer (20 workers).

Methodology

The research subjects were recruited from the population of all paint industry workers. They were selected based on a purposive sampling technique. The inclusion criteria were male, between 25-50 years of age, having worked in the industry for at least 2 years, and willing to sign the informed consent form. The exclusion criteria include workers residing near landfills and/or industrial areas.

Samples matrix

This study collected various samples to assess workplace exposure risks, including indoor air samples, dust lead levels, intra-venous blood, inhaled lead dust, and lead absorption from skin contact. Respondents were divided into two groups: directly exposed and indirectly exposed.

Sample analysis

Prodia Clinical Laboratory in Jakarta analyzed the blood samples using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Lead captured in low-volume sampler filters and dermal patches were taken to the National Research and Innovation Agency (*Badan Riset dan Inovasi Nasional* or BRIN) for further analysis using benchtop EDXRF (Energy Dispersive X-ray Fluorescence). Dust floor samples were analysed by an SGS laboratory in the US using a flame atomic absorption spectrometer (Flame AA), following NIOSH 9100/EPA 7082.

Key findings

Based on the workers' blood lead levels and current Indonesian health standards, the study found clear evidence of more significant risks of cancer and non-cancer health conditions for workers in Industry C. Specifically:

- 75% of Industry C's respondents have high blood lead levels greater than 5 µg/dL, compared to only 5-8% of respondents in Industry A and B, respectively.
- 55% of respondents in Industry C had blood lead levels that showed an increased non-cancer risk, and another four workers of Industry C had levels above the safety standard that would prompt regular blood level monitoring.
- 10% of Industry C workers had blood lead levels linked to a significant increase in their lifetime cancer risk, four times higher than for workers in Industry A and 2.5 times higher than for workers in Industry B.
- Workers in Industry C have an elevated lifetime risk for non-cancer health conditions related to lead exposure, almost 3.5 times higher for workers in Industry A and almost 2 times higher than those in Industry B.
- Dust lead levels in Industry C are 5 times to 410 times higher than the CDC dust lead clearance level of 10 µg/ft².
- The lead captured in dermal patch filters of Industry C's respondents is 5 to 6 times higher than that of Industry A and B respondents.
- Lead exposure via skin contact or the dermal exposure pathway was significantly higher among workers in Industry C, more than four times higher than among Industry A workers and more than five times higher than among Industry B workers.
- Some respondents in all three groups had high blood levels of arsenic, cadmium, nickel, thallium, or chromium, which had elevated lifetime risks for cancer related to the inhalation pathways.

Recommendations

For Paint Industry

Since 1919, the ILO has warned women and children about the hazardous exposure of lead. In 1921, the first lead convention was adopted and restricted the use of white lead for paintings. Eliminating lead paint is the best way to protect workers from lead exposure. Our study shows companies can protect their workers and consumers from harmful lead exposures by eliminating lead paint. For decades, alternatives to lead paint have demonstrated that they are as effective and safer than lead paint. There is no advantage to continuing the use of lead in paint.

While transitioning to lead-safe paint, companies can take steps to minimize worker exposures,¹ including providing systems so workers can:

- Use tools and equipment with dust collection systems to keep lead out of the air.
- Provide changing room for workers and adequate washing basins.
- Clean surfaces using wet methods and HEPA vacuuming instead of dry sweeping or blowers.
- Avoid shaking out, brushing off, or blowing off dusty clothing.
- Scrub hands and nails and wash faces thoroughly before eating and drinking. The use of lead-removal soap or foam should be provided, as studies show that regular soap and water may not adequately remove lead particles.

Studies have also shown that workers can bring lead contamination home from their workplace. To reduce risks, employers should have systems so workers can:

- Reformulate the paint production and replace lead-based pigments and driers with safer alternatives.
- Change the solvent-based paint to water-based paint.
- Communicate the risk of chemical exposure in the factory regularly.
- Workers should wash up at the end of the day to remove lead from their hair, nails, and exposed skin; if possible, they should also have showers at work before going home.
- Use separate working clothes, shoes/boots while at work that they do not take home.
- Store their street clothes in a clean place.
- Launder lead-contaminated clothing at work, if possible. When it is not possible, workers should be provided with plastic bags to store their soiled work clothes and advised to wash and dry work clothes separately from other clothes.
- Avoid taking home tools, materials, or anything contaminated with lead.

For the Government of Indonesia

Experts noted that occupational and non-occupational exposures to metals are most severe in low- and middle-income countries where mining, waste processing, and rapid industrial development are taking place but weak occupational and environmental safeguards.

Interventions to prevent exposure to metals should be based on the “hierarchy of controls” concept, where the most effective priority is reducing and preventing exposure at the source. The reduction measure requires the identification, evaluation, control, and, if possible, elimination of the sources of exposure. In some cases, exposure reduction is achieved by changes in industrial processes or raw materials.

¹ See more at https://lni.wa.gov/safety-health/safety-rules/rulemaking-stakeholder-information/_leaddocs/LeadRuleDraftWorkerPoster.pdf and <https://www.cdc.gov/niosh/topics/lead/workerinfo.html>

The key elements of exposure prevention are Hazard Identification and Hazard Control, as recommended by experts, as follows:

- Prohibit the use of lead-based pigments and driers for all paint manufactured in Indonesia.
- Apply Extended Producer Responsibility (EPR) regulation and oblige paint manufacturers to take back lead-paint cans from consumers, classifying them as hazardous waste.
- Adopt and make a mandatory regulation with a protective lead content standard for all paints below 90 ppm based on SNI 8011:2022.
- Hazard Identification is an essential factor in the prevention process. It includes recognizing potential sources and routes of exposure and identifying the full range of health effects, including those in children's early development.
- Evaluation involves regular workplace environment, biological aspects, and workers' health monitoring.
- Hazard Control involves reducing environmental exposure at the workplace using better or best available technologies, best environmental practices, and safer alternatives. The control measures also include administrative controls, biomonitoring of at-risk workers, and applying personal protective equipment.
- Eliminating exposure at its source or primary prevention is the most effective and cost-effective prevention measure.



Health Risk Analysis of Lead Exposure in Selected Paint Industry Workers in Indonesia

Background

Lead-based paint is still widely produced and used in many low- and middle-income developing countries due to its low price in the market [1]. However, this is not always the case. It is also due to inertia, i.e., manufacturers will do how they did it if there is no reason to change. Lead is added to the paint manufacturing process as pigments, and drying agents are the primary reasons for adding lead [2].

WHO has designated lead as one of the ten chemicals of public health concern [3]. It is considered a potent poison that affects multiple body systems, even in low doses [4, 5]. Evidence shows that there is no safe level of exposure to lead [6, 7].

The International Agency for Research on Cancer (IARC) identified lead as a human carcinogen [8-10]. Evidence from countless studies over decades of research has linked high levels of lead in blood to an increased incidence of cancer - especially lung and brain cancers - and several other non-cancer health conditions [11-19].

Benson et al. [20] highlighted inhalation as a primary route of metal exposure for occupational and, to a lesser extent, environmental exposure. Metals have a high potential for producing toxic effects in the respiratory tract. Nemery (1990) has reviewed the toxicity of metals to the human respiratory tract [21] as the primary risk to people associated with occupational exposures to metals during mining, refining, smelting, and end-use operations such as electroplating, machining, and welding.

Studies indicated that occupational exposure to many metals results in a variety of acute and chronic lung diseases, including chemical pneumonitis, chronic obstructive lung disease, immune-mediated diseases, fume fever, and cancer [22, 23]. Figure 1 shows the multiple pathways of exposure to lead paint.

Due to its toxicity, lead exposure affects hormonal synthesis and regulations in both genders [5, 24]. In men, exposure to lead may affect libido and semen quality, such as declining sperm count, motility, viability, integrity, elevation in morphological abnormalities, and sperm DNA integrity [25].

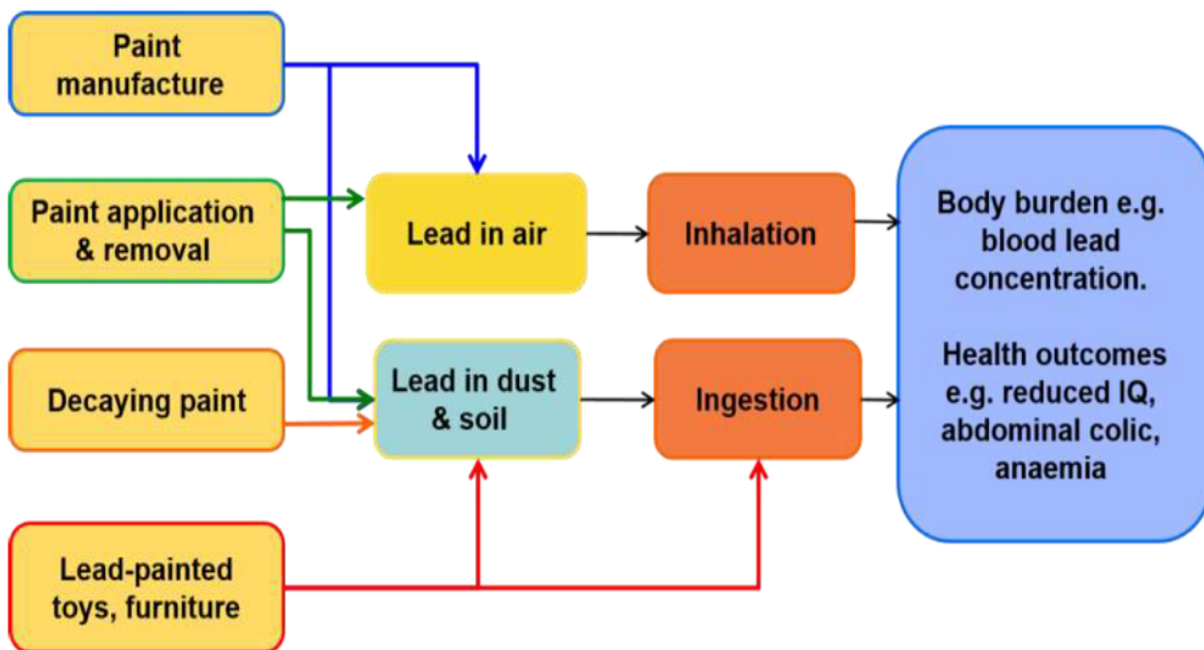


Fig. 1. Multiple pathways of exposure to lead from paint.
Source: SAICM, GEF Project Indonesia.

Reviews of lead toxicity in the male reproductive system also suggest that hormonal disruption might occur at lower levels of blood lead [26, 27]. These alterations led to reduced fertility potential and chances of miscarriages and preterm birth, among others, in their partner.

Lead exposure, which is stored in the body, also affects female reproduction by impairing menstruation, reducing fertility potential, delaying conception time, altering hormonal production and circulation, and affecting pregnancy and its outcome, among others [28, 29].

It is well understood that no known level of exposure is without harmful effects. Lead mimics calcium and iron in the body, affecting multiple body systems. Lead also accumulates in bone, and its long-term effects include reduced IQ, anti-social behaviour, and cardiovascular and renal disease [30-33]. Children under six are most sensitive to lead's effects [34-36]. Low lead concentrations in their blood can cause hearing and learning problems, anemia, behaviour problems, slowed growth, a lower intelligence quotient, and hyperactivity [36-38].

Lead causes a significant burden of diseases, which reflected in 1.06 million deaths from long-term effects, 24.4 million disability-adjusted life years (DALYs) lost, attributed to 63.2% of the global burden of idiopathic developmental intellectual disability, and 10.3% of hypertensive disease [39].

In 2013, Attina et al. calculated the economic losses due to lead exposure as a major contributor to children's intellectual disability in low- and middle-income countries (LMICs), which was equal to \$977 billion (between \$728.6 and \$1162.5 billion) or 1.20% of the world's gross domestic product (GDP) in 2011 [40].

Further, these figures increased significantly in 2019 - 729 million IQ points lost (95.3% of the total global IQ loss) and 5,004,000 (90.2% of total) cardiovascular disease deaths due to lead exposure occurred in LMICs.

IQ loss in LMICs was nearly 80% higher than the previous estimate. The global cost of lead exposure was US\$6.0 trillion (range 2.6–9.0), which was equivalent to 6.9% (3.1–10.4) of the world's GDP [41].

A 2018 study done in the US predicted that eradicating lead paint hazards from older homes of children from low-income families would provide \$3.5 billion in future benefits, or approximately \$1.39 per dollar invested, and protect more than 311,000 children [42].

About \$2.8 billion of the benefits would accrue to roughly 244,000 of the 4 million children in the 2018 cohort study. The other \$670 million benefits would accrue from protecting approximately 67,000 additional children born into those homes over the next ten years. The total benefits include \$630 million in federal and \$320 million in state and local health and education savings and increased revenue. Controlling lead paint hazards in the US would cost \$2.5 billion for the 2018 cohort study.

Due to the high risk of exposure to workers' health and the public, especially children, and its persistence for long periods of time in the environment, the safe achievable level for Pb used in paint is 90 ppm (dry weight) based on current best available technology [11, 43-45].

The latest Nexus3 and IPEN study (2021) results show that 77% of paint samples (n=120) contained lead above 90 ppm and 39% above 10,000 ppm [46]. However, lead-based paint is still widely produced and sold, especially for primary colors. However, the National Standard SNI-8011:2022 set the dry weight standard to 90 ppm, replacing the 2014 standard of 600 ppm.

Besides heavy metals, other types of chemical compounds, such as chromium, are also used in the paint production process as pigments, extenders, binders, additives, and solvents and pose risks through inhalation and dermal contact [47].

Studies highlighting occupational risk and VOCs found that paint manufacturing workers are potentially exposed to various hazardous chemicals to produce paints at different levels [2, 48, 49]. However, the effect of exposure on an individual may differ depending on their health condition and roles at the workplace [50, 51].

Cr(0), Cr(III), and Cr(VI) are sold and applied commercially and are present in the environment. Cr(0) is mainly metallic as a component of iron-based alloys such as stainless steel [52]. Studies show that occupational exposure to Chromium (VI) can cause lung cancer and nose and nasal sinus cancer in humans [9, 53]. Cr(VI) is also suspected to cause stomach cancer and laryngeal cancer in humans [54]. Cr(VI) is found and used in the chromate, chromate pigment production and chromium plating industries. IARC classified Cr(VI) as a Class 1 carcinogen, a proven cause of cancer in humans [53].

The CDC calls the reference level the "Blood Lead Reference Value" or BLRV, which was updated to 3.5 µg/dL in 2021. Reference values for other heavy metals may be different [55].

The CDC's BLRV is neither a "safe" level nor a threshold level of concern. Its use is to identify high-risk childhood populations and geographic areas most in need of primary prevention [56].

In 2012, when it was first established, the CDC's BLRV was set at a BLL of 5 µg/dL. In 2021, the CDC reduced its BLRV to 3.5 µg/dL to reflect a reduction in childhood BLLs in the United States, mainly due to reduced use of lead in household and commercial applications.

Study locations and methodology

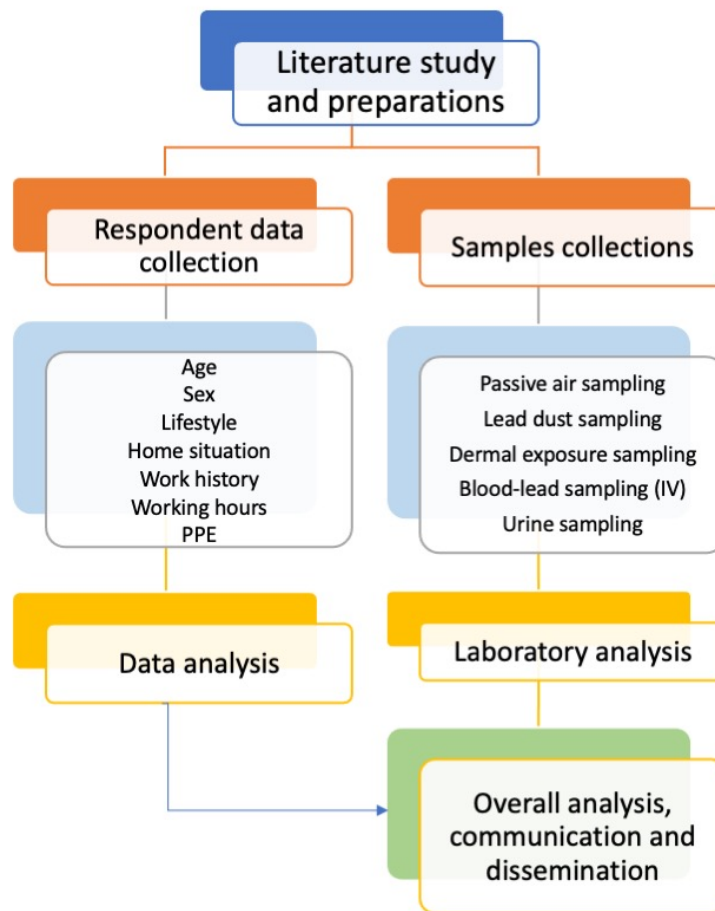


Fig. 2. Study flow and research methodology.

The study flow and steps follow the diagram shown in Figure 2. The research subjects were recruited from the population of all paint industry workers. They were selected based on a purposive sampling technique. The inclusion criteria were male, 25 – 50 years old, having worked in the industry for at least 2 years, and willing to sign the informed consent form. The exclusion criteria include workers residing near landfills and/or industrial areas.

The Padjadjaran University Research Ethic Commission reviewed and approved the methods involving human research subjects through document number 1066/UN6.KEP/EC/2022.

The OriginPro 2015 statistics analysis tool was used in this study.

Figure 3 shows Indonesia on the global map, and Figure 4 shows the locations of three factories in this study.



Fig. 3. Indonesia in the globe map. Credit: [Wikimedia Commons](#)



Fig. 4. Study locations: Industry A in Central Java Province, Industry B in West Java Province, and Industry C in East Java Province.




Locations	Sample size (n) = 52 respondents	Remarks
 Industry A	20 workers	Lead-safe paint producer
 Industry B	12 workers	Formerly lead paint producer; changed to lead-safe paint and moved to a new factory
 Industry C	20 workers	Lead paint producer

Fig. 5. Sampling sites and sample sizes.

Figure 5 describes the number of respondents from three factories, and Figure 6 describes the sampling plan based on exposure pathways. Urine samples were excluded due to resource limitations.

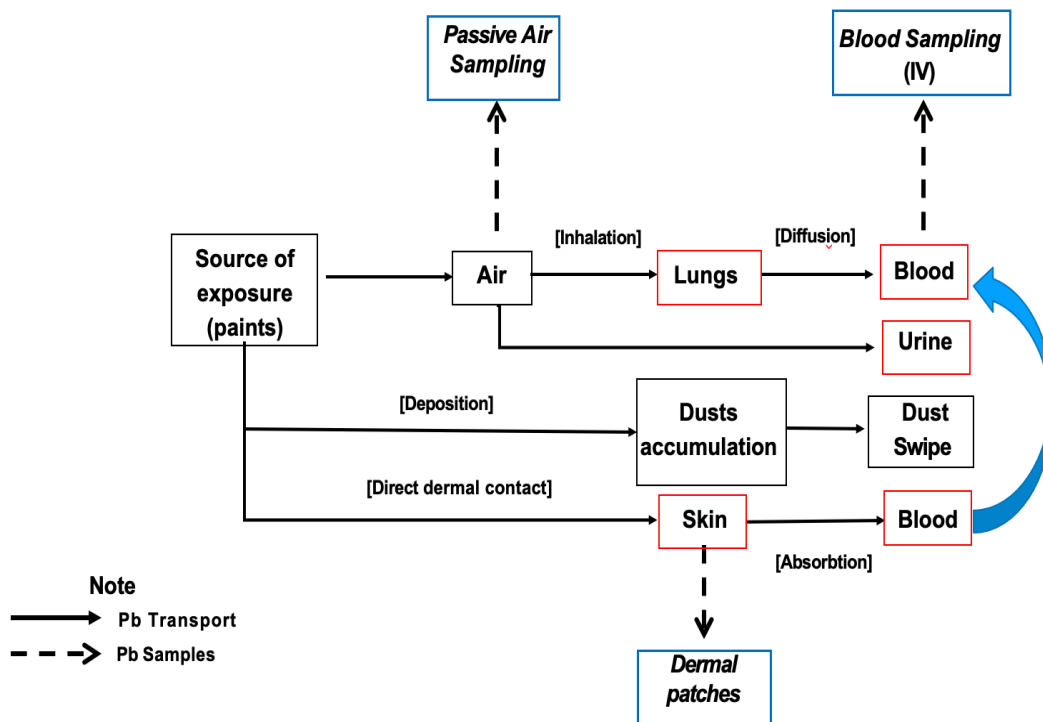


Fig. 6. Sampling plan based on exposure pathway: personal passive air sampler, indoor air samples, blood samples (intra-venous), dermal patches, urine samples, and dust wipes.

Recruitment criteria and sample size

The research was conducted in three paint companies in Indonesia with three different conditions. The population used as subjects in this research were all workers of the paint production factories, whether directly involved in the production process or not. In this study, we recruited volunteers among workers using the following inclusion and exclusion criteria:

Inclusion criteria:

- Female and male workers use lead-based and non-lead-based pigments in paint production factories.
- Females and males work in areas that are potentially directly exposed to lead (e.g., production/process areas, mixing, and transporting raw materials and products).
- Workers, both males and females, work in areas that are indirectly exposed to paint materials (e.g., administration, etc.).
- Workers, females, and males, aged between 25 to 50 years.
- Female and male workers have worked in the factory for over two years.
- Willing to sign informed consent.

Exclusion criteria:

- Lives near a landfill or rubbish dump and/or around an industrial complex.

Based on WHO guidance [57], the ideal sample size for this study with a 95% confidence level and a $\pm 5\%$ margin of error is 209 respondents. However, due to low interest from the workers in three factories, the research team recruited only 53 respondents. Later, one volunteer dropped out, making the total number of respondents 52. Therefore, with 52 respondents, this study has an 80% confidence level with a $\pm 5\%$ margin of error.

For this study, respondents were categorized into two groups: directly exposed and indirectly exposed. A directly exposed group consists of those directly exposed to lead in production-related departments, such as raw materials handlers, mixing, pigment mixers, maintenance staff, packing and labelling staff, etc.

In contrast, indirectly exposed groups are those indirectly exposed to lead and raw materials, such as security guards or administrative staff.

Further, the WHO guidance [58] advised that the appropriate sample size for health research is 30 to 500 respondents. In this research, 35 workers were respondents from the directly exposed group and 17 from the indirectly exposed group.

Table 1 summarized the number of respondents and Table 2 the number of respondents and their groupings.

Table 1. The sample size of this study and the proportion of the population from three paint factories

Industry	Number of workers	Respondents (volunteers)	% of population of three factories
A	150	20	13.3
B	220	12	5.5
C	87	20	23.0
TOTAL	457	52	11.4

Table 2. Respondents groups from three industries.

Grouping	Section	Industry A	Industry B	Industry C	Total	Total per group
Directly exposed group	Grinding	1	0	0	1	35
	Premix		0	4	4	
	Color matching/ tinting	3	0	4	7	
	Filling	1	5	6	12	
	Filter, filling, packing	7	0	0	7	
	PPIC (Production Planning & Inventory Control)	2	0	0	2	
	QC (Quality Control)	1	0	1	2	
Indirectly exposed group	General Affair	1	0	0	1	17
	Logistics (products warehouse)	4	2	4	10	
	Maintenance	0	3	0	3	
	Cement production	0	1	0	1	
	Latex production	0	1	0	1	
	Sales engineers	0	0	1	1	
	Total	20	12	20	52	52

Biomarkers sampling

For this study, we collected blood samples from workers from three paint manufacturing facilities, grouped as follows:

- Industry A: a lead-safe paint manufacturer (20 workers)
- Industry B: a new lead-safe paint manufacturer (12 workers)
- Industry C: a lead paint manufacturer (20 workers total)

Inhaled air sampling

To isolate the source of air inhaled by respondents, we used a personal air sampler for every respondent for four hours to measure the inhaled lead and other metals during working hours.

Dermal exposure sampling

Lead and other heavy metals exposure through the skin or dermal pathways are also measured in every respondent.

Indoor air sampling

We collected indoor air samples using a low-volume air sampler (LVAS) for three to eight hours in several corners of the selected rooms in every location.

Dust lead sampling

In this study, researchers also collected dust samples in several corners of several selected rooms in every industry.

Laboratory Analysis

All biomarker samples were analyzed in an independent clinical laboratory in Jakarta, Prodia, using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analytical technique to measure elements at trace levels in biological fluids.

Filters used in dermal absorption and indoor air sampling using low-volume air samples were analyzed at the BRIN laboratory (*Badan Riset dan Inovasi Nasional* or National Agency for Research and Innovation) using EDXRF Epsilon.

Dust wipes were sent to the SGS Lab in Carson, California, USA, and lead dust was analyzed using Flame AAS Method 7082.

Sample Collection Methods

Ethical clearance for this study was obtained from the Research Ethic Committee of Padjadjaran University No. 1066/UN6.KEP/EC/2022 on 26 October 2022.

1. Biomarkers: blood samples and analysis

Data was collected through interviews and questionnaires to obtain general information on workers' characteristics and habits and other information such as working time and period. To determine the BLL, the medical personnel of Prodia Clinical Laboratory took blood samples from the respondents using an intravenous (IV) blood collection method to provide a more accurate quantification of body burden.

The Prodia Clinical Laboratory analyzed the blood samples. The blood lead levels were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) [59]. Then, the haematological parameter, haemoglobin, was counted using a haematology analyzer [60].

Figure 7 shows the Intravenous (IV) blood sampling, and Figure 8 shows the blood analysis method.



Fig. 7. Blood sampling conducted by a clinician from Prodia Clinical Laboratory.

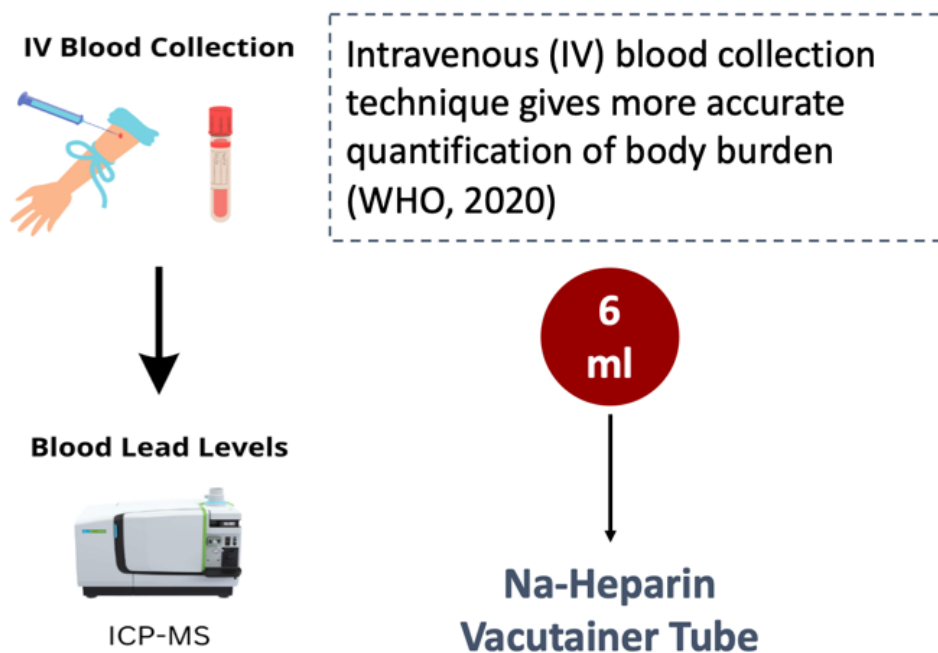


Fig. 8. Intravenous (IV) blood collection technique and analysis using ICP-MS.

2. Dermal patches

Dermal lead exposure sampling was carried out using a Mixed Cellulose Ester (MCE) filter with a diameter of 47 mm and a pore size of 0.8 μm . The filter is attached to the open skin surface (head, neck, right arm, and left arm). After 4 hours, each MCE filter was stored in a petri dish sealed using parafilm. Sample and transportation were stored in silica gel boxes and placed at room temperature. The location of the filter patch attachment for measuring Pb exposure via the dermal route on several exposed parts of the respondent's body, forehead, wrists and ankles [61].

Figure 9 shows the application of dermal patches in the respondent's body, and Figure 10 shows EDXRF used to analyze the patches. Both figures are taken with consent from the respondents



Fig. 9. Dermal patches applied in wristband, forehead and chest or neck.

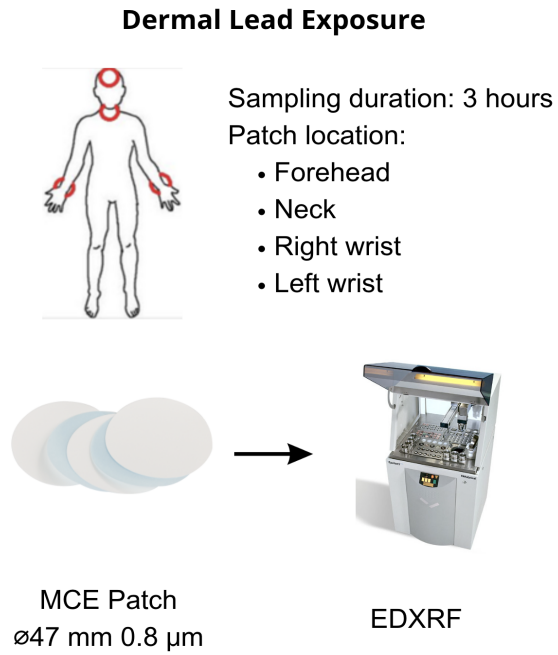


Fig. 10. Filter from dermal patches was analyzed in the lab using EDXRF.

3. Personal air sampler

Personal air sampling was carried out to determine the concentration of heavy metal exposure in the inhalation route of paint industry workers during working hours. The sampling was conducted using purposive passive air sampling in the respondents' breathing zone to meet the criteria based on NIOSH 7300 Issue 2 [62].

Sampling was done using a personal sampler pump with a filter, mixed cellulose ester (MCE), Ø25 mm and a pore size of 0.8 µm. The type of personal sampling pump used in this research is HFS-513A.

The personal sampling pump draws air into the worker's breathing zone, where heavy metals are retained in the MCE filter. The filter in the cassette is clipped to the worker's collar or breathing area.

Figure 11 shows how the personal sampler pump and flow rate were set. Figure 12 shows how the personal sampler pump is installed at the back of the respondent's waist, and Figure 13 shows the nozzle to measure air inhaled by the respondent.



Personal Sampler Pump
 Flowrate: 2-2.5 LPM
 Duration: 2-3 hours

Fig. 11. Personal sampler pump used in this study.



Fig. 12. The personal sampler pump hooked at the back of the waist of a respondent.



Fig. 13. The air inhaled by respondent was sucked through the nozzle in front of the chest.

4. Indoor air samples

Indoor air sampling to measure lead in the room was conducted using a low-volume air sampler (LVAS) for a minimum of 2 hours at a speed of 2.5 litres per minute for 3 hours in selected corners of the room. The sampling followed NIOSH 7082 with a hydrophobic Polytetrafluoroethylene (PTFE) membrane filter Ø47 mm and a pore size of 0.45 µm.

After the sampling, the cassette with the filter was taken to the National Research and Innovation Agency (*Badan Riset dan Inovasi Nasional* or BRIN) for further analysis using benchtop EDXRF (Energy Dispersive X-ray Fluorescence). Figure 14 shows how the indoor air samples were collected, and Figure 15 shows the filter used in the LVAS in the selected rooms.



Fig. 14. Indoor air samples being collected in an area of a study location.



Fig. 15. Low Volume Air Sampler with filter was used to collect samples of lead concentrations indoor air concentrations

5. Dust sampling (floor)

Dust sampling from the floor was conducted to measure lead dust in the room, following the guidance provided by USEPA. In several factory corners, dust samples were collected using a lead dust sampling wipe for professional use (ASTME 1792). Wipe samples were analysed by an SGS laboratory in the US using a flame atomic absorption spectrometer (Flame AA), following NIOSH 9100/EPA 7082.

The SGS laboratory used a certified vendor, Inorganic Ventures, to set the standard for all lead analyses. This vendor provides SGS with the highest quality standard. The reference level of floors' lead dust is 10 micrograms per square foot ($\mu\text{g}/\text{ft}^2$) [63].

Figure 16 shows how lead dust sampling was taken. Figure 17 shows the dust wipes used in this study.



Fig. 16. Lead dust sampling on the floors in some corners of selected rooms.



Fig. 17. Lead dust sampling wipe used in this study.

Health Risk Assessment

WHO [64] defined human health risk assessment as a process to estimate the risk to a given target organism, system or (sub)population, including identifying attendant uncertainties following exposure to a particular agent. The assessment considers the inherent characteristics of the agent of concern as well as the characteristics of the specific target system.

The risk assessment process begins with problem formulation and includes four further steps: (a) hazard identification, (b) hazard characterization, (c) exposure assessment, and (d) risk characterization. Figure 18 shows this study's schematic diagram of health risk assessment focusing on lead.

Health Risk Assessment

Chemical of concern: **Lead**

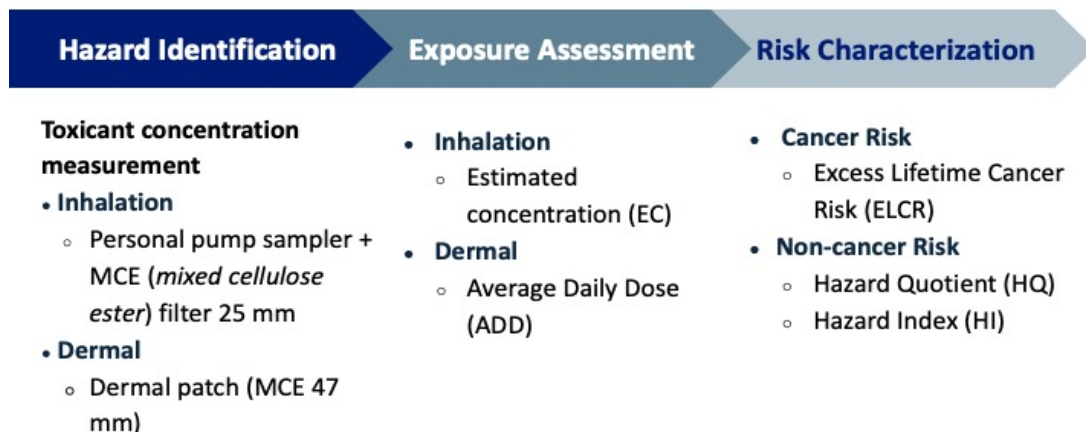


Fig. 18. Schematic diagram of health risk assessment in this study.

The study identified potential lead hazards from inhalation and dermal exposures. After obtaining laboratory analysis results, researchers assessed the exposure by calculating the estimated concentration (EC) through the inhalation pathway and the Average Daily Dose (ADD) through dermal absorption.

Finally, the risk characterization was formulated as cancer risk in the form of Excess Lifetime Cancer Risks (ELCR) and non-cancer risk in the form of Hazard Quotient (HQ) and Hazard Index (HI). ELCR means the estimated probability that an individual's exposure to a substance could result in cancer.

For more than 200 years, lead has been among the most applicable inorganic pigments in paint production. Lead is used in many forms, including carbonate, oxide, oxychloride, sulphate, acetate, borate, and chromate. Zinc chromate, zinc oxide, chromium oxide, barium chromate, and cadmium sulphide are also used as inorganic pigments. Lead chromates and oxides are the most common pigments [65, 66].

Figure 19 shows the IARC monograph on the hazard classification of carcinogens. IARC classified lead inorganic compounds as 2A and lead metallic as 2B [67]. Figure 20 shows the carcinogenic effects of lead, and Figure 21 shows the carcinogenic effects of arsenic [68].

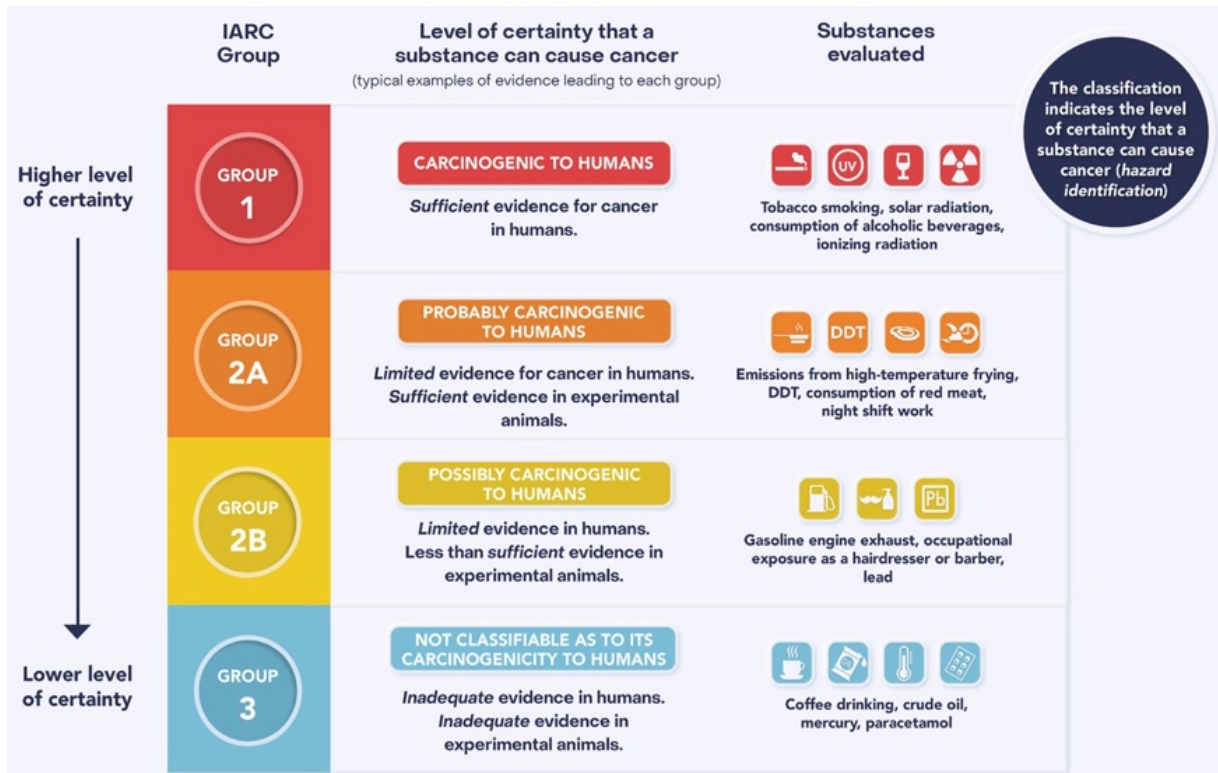


Fig. 19. IARC monograph of hazards classification for carcinogens



Fig. 20. Carcinogenic effect of Lead.

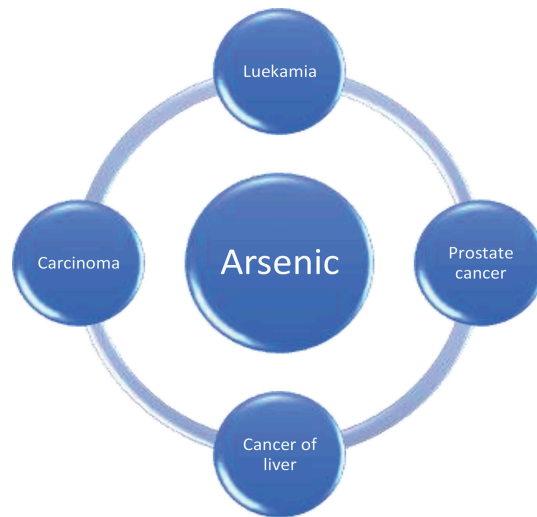


Fig. 21. Carcinogenic effect of Arsenic.

The CDC calls lead the "Blood Lead Reference Value" or BLRV. It was updated to 3.5 µg/dL in 2021, especially as a reference for children. Reference values for other heavy metals may be different [55].

The CDC's BLRV is neither a "safe" level nor a threshold level of concern. Its use is to identify high-risk childhood populations and geographic areas most in need of primary prevention [56]. In 2012, when it was first established, the CDC's BLRV was set at a BLL of 5 µg/dL. In 2021, the CDC reduced its BLRV to 3.5 µg/dL to reflect a reduction in childhood BLLs in the United States, mainly because of reduced use of lead in household/commercial applications.

Exposure Assessments

Inhalation Intake: Estimated Concentration (EC)

- The magnitude of the contaminant's concentration entering the portal of entry.
- The amount of inhaled lead exposure is adjusted with the exposure frequency and duration.

The Estimated Concentration (EC) was calculated using this formula:

$$EC = \frac{CA \times ET \times EF \times ED}{AT}$$

Where:

EC (µg/m³) = estimated concentration

CA (µg/m³) = inhaled lead external exposure

ET (hour/day) = exposure time (working hour per day)

EF (day/year) = exposure frequency (working days in a year)

ED (year) = exposure duration (working period)

AT (hour) = averaging time (70 years for carcinogenic effect and ED converted into hours for non-carcinogenic effect)

Dermal Intake: Average Daily Dose (ADD)

- The magnitude of the contaminants enters the portal of entry and is absorbed into the body.
- The amount of dermal lead exposure adjusted with the exposure frequency, duration, and workers' body mass.

The Average Daily Dose (ADD) was calculated using this formula:

$$ADD = \frac{DA_{day} \times ED \times EF \times SA \times ABS}{BW \times AT}$$

Where:

ADD (mg/kg-day) = average daily dose

DA_{day} (mg/cm²-day) = dermal absorbed lead external concentration

SA (cm²) = exposed skin area

ABS = inorganics metal absorption factor = 1%

BW (kg) = workers' body mass

Risk Characterization

Cancer Risk Calculations

- Through inhalation

$$ELCR = EC \times IUR$$

- Through dermal

$$ELCR = ADD \times CSF$$

Where:

ELCR = Excess Lifetime Cancer Risk

IUR = Inhalation Unit Risk = 1.2×10^{-5} m³/μg [69]

CSF = Cancer Slope Factor = 0.085 kg/mg-day [69]

Interpretation of results:

- Generally, the acceptable ECLR for a regulatory range is between 1×10^{-6} and 1×10^{-4} .
- ELCR value of 1×10^{-6} is interpreted as 1 case per 1 million population. $ELCR \leq 10^{-6}$ is categorized as negligible risk [70].

Non-cancer Risk calculations

- Through inhalation

$$HQ = \frac{EC}{RfC \times CF}$$

- Through dermal

$$HQ = \frac{ADD}{RfD}$$

Where:

HQ = Hazard Quotient

RfC = Inhalation Reference Concentration = 1.5×10^{-4} mg/m³ [69]

RfD = Dermal Reference Dose = 2.86×10^{-5} (mg/kg-day) [69]

Interpretation of results:

- $HQ \leq 1 \rightarrow$ no expected adverse non-carcinogenic health effects [71].
- $HQ > 1 \rightarrow$ potentially causing adverse non-carcinogenic health effects [71].

Statistical analysis and limitations

In statistics, normality tests are used to determine whether a data set is well-modelled by a normal distribution and to compute the likelihood that a random variable underlying the data set is normally distributed.

The statistical normality test assessed whether the data generated in a study comes from a normal distribution. A normal distribution is a symmetric distribution around a mean value. Most of the data is centered around the mean value, with a small portion on either side. Normality tests are essential because many statistical analyses assume the data comes from a normal distribution.

One commonly used normality test is the Shapiro-Wilk test [72]. This test analyses the null hypothesis that the data sample comes from a normal distribution. In this test, the null hypothesis states that the data sample is taken from a normally distributed population. Suppose the Shapiro-Wilk test's p-value is more significant than the specified significance level (usually 0.05); in this case, our null hypothesis will be rejected, which means we have sufficient evidence to conclude that the data sample is normally distributed.

However, if the p-value is less than the specified significance level, we can reject the null hypothesis and assume that the data sample is not normally distributed [73].

Table 3 shows the normality test results using the Shapiro-Wilk Normality test.

Table 3. Normality Test (Shapiro-Wilk Normality Test)

Classification	Data	Degree of Freedom (DF)	Statistic	p-value	Decision at level (5%)
Indirectly Exposed	Pb in blood	14	0.95562	0.65076	Can't reject normality
	Pb in dermal patch	14	0.81481	0.00765	Reject normality
	Pb in inhaled air	14	0.92707	0.27748	Can't reject normality
	Working experience	14	0.93483	0.35605	Can't reject normality
	Age	14	0.91888	0.21187	Can't reject normality
Directly Exposed	Pb in blood	38	0.9161	0.0075	Reject normality
	Pb in dermal patch	38	0.36749	1,27E-06	Reject normality
	Pb in inhaled air	38	0.93939	0.04004	Reject normality
	Working experience	38	0.83351	5,44E+00	Reject normality
	Age	38	0.92247	0.0117	Reject normality

We identified that most of the data in this study have an abnormal distribution. Therefore, non-parametric tests are recommended for further statistical measurement parameters.

Several methods can be used to test the strengths or weaknesses of correlations between normally distributed and non-normally distributed data [74]. Pearson's r correlation method is usually used for normally distributed data, and Spearman's rho correlation method is usually used for non-normally distributed data. Meanwhile, Kendall is also used for data that is not normally distributed, but it has the advantage that if there are outliers, the data will not match the results of the Kendall correlation analysis.

Table 4 shows the correlations between different parameters using several correlation methods. Due to the small sample size, the correlation coefficients show weak to mild correlations between parameters.

Table 4. Data Distribution and Correlation Value by Pearson, Spearman, and Kendall

Classi- fication	Data	Data distribution	Correlation (r)		
			Pearson	Spearman	Kendall
Directly Exposed	Pb in blood vs in dermal	●	0.35846	0.34429	0.23615
	Pb in blood vs in inhaled air	●	0.01073	0.12052	0.09091
	Pb in dermal vs in inhaled air	●	-0.13323	-0.00744	-0.01708
	Pb in blood vs working experience(s)	●	0.08851	0.24952	0.17065
	Pb in blood vs age	●	0.01199	0.10083	0.04886
	Cr in dermal vs in inhaled air	●	0.0499	0.06587	0.04487
	Ni in dermal vs in inhaled air	●	-0.02901	0.10221	0.06125
Indirectly Exposed	Pb in blood vs in dermal	◐	0.46178	0.32563	0.1547
	Pb in blood vs in inhaled air	◑	0.22821	0.37707	0.20112
	Pb in dermal vs in inhaled air	◐	0.41864	0.47305	0.3757
	Pb in blood vs working experience(s)	◑	0.48738	0.41317	0.33757
	Pb in blood vs age	◑	-0.33782	-0.43147	-0.25454
	Cr in dermal vs in inhaled air	●	-0.11921	0.01987	0.02235
	Ni in dermal vs in inhaled air	●	0.80404	0.25275	0.18681

Notes

● = Both data are not normally distributed

◐ = One of the data is not normally distributed

◑ = Both data are normally distributed

Blue text = mild to strong correlations

The correlation value is described in 0 and 1. Zero means no correlation, whereas 1 means a complete or perfect correlation. The (+) or (-) signs in front of the r value show the direction of the correlation. A negative r means that the variables are inversely related. The correlation's strength increases from 0 to +1 and 0 to -1 [75].

Results

Based on the workers' blood lead levels and current Indonesian health standards, **the study found clear evidence of more significant risks of cancer and non-cancer health conditions for workers in Industry C. Specifically:**

- **Almost 70%** of 52 respondents have blood lead levels that exceed the CDC standard of 5 µg/dL, mainly in Industry C (75% of Industry C's respondents). In Industries A and B, only 5-8% of respondents have high blood lead levels greater than 5 µg/dL.
- **75% of 20 respondents in Industry C had high blood lead levels, compared to 13.3% combined in Industry A and B. Meanwhile, 55% of respondents in Industry C had blood lead levels that showed** an increased non-cancer risk, and another four workers of Industry C had levels above the safety standard that would prompt regular blood level monitoring.
- **Dust lead levels in Industry C are 5 times to 410 times higher than the CDC dust lead clearance level** of 10 µg/ft².
- **The lead captured in dermal patch filters of Industry C's respondents is 5 to 6 times higher** than that of Industry A and B respondents.
- **The average concentration of lead indoor air in Industries A and C is twofold and threefold of the CDC reference standard, respectively.**
- Although Industry A has not used lead pigment since the beginning, the **lead in indoor air** potentially came from **impurities** in paint materials.
- **10% of 20 workers in the leaded paint facility had blood lead levels linked to a significant increase in their lifetime cancer risk.** None of the workers in the long-time or more recent lead-safe facilities showed a significantly increased cancer risk.
- **Workers in Industry C have an elevated lifetime risk for cancer-related lead exposure.** The lifetime cancer risk, on average, for workers in Industry C is four times higher than for workers in Industry A and 2.5 times higher than for workers in Industry B.
- **Workers in Industry C have an elevated lifetime risk for non-cancer health conditions related to lead exposure.** On average, this risk is almost 3.5 times higher than for workers in Industry A and almost 2 times higher than for workers in Industry B.
- **Lead exposure via skin contact (dermal exposure) was significantly higher among workers in Industry C.** On average, the cancer-related daily dose from dermal exposure for workers in Industry C was more than four times higher than for Industry A workers and **more than five times higher** than for Industry B workers.

Additionally, other heavy metal concentrations in blood, such as arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), and thallium (Tl), were also observed. Respondents of paint factories that produce lead-safe paints had high levels of heavy metals above the blood lead reference value set by the CDC.

- **77% of the respondents in this study had arsenic blood concentrations above the CDC blood reference value of 1 µg/dL. In Industries A and B, 90% and 100% of respondents had high blood arsenic concentrations that exceeded the reference value, respectively.**
- **71% of respondents had cadmium blood levels above the 5 µg/L reference standard. 95% of Industry A and 75% of Industry B respondents had cadmium blood concentrations above 5 µg/L.**
- **87% of respondents had nickel blood concentrations above the CDC reference value of 1.0 µg/L. In Industry A and C, 100% of respondents had Nickel-blood levels above the 1.0 µg/L reference value.**
- **All workers in three companies had elevated lifetime risks for cancer related to Chromium exposure through the inhalation pathways. IARC classified chromium (in the form of Cr(VI)) as a Class 1 carcinogen, a proven cause of cancer in humans. Cr(VI) was found and used in chromate, chromate pigment, and chromium plating industries [76].**

Respondents' Profile

Table 5. Respondent's profile and variables in the study

Variables	n	%	Mean ± SD	Min	Max
Blood Lead Levels (BLLs) (µg/dL)					
Below reference level	35	67%	4.22 ± 1.60	1.40	8.10
Exceeded reference level	17	33%			
Respondents' Age (year)					
25-35	35	67%	33.27 ± 5.40	26	50
36-45	16	31%			
46-56	1	2%			
Length of work (year)					
<5 years	6	12%	9.60 ± 4.80	2.5	29
6-10 years	25	48%			
11-15 years	18	35%			
>16 years	3	6%			
Body Mass Index (BMI)					
Overweight/Pre-obese (BMI 25.0–29.9)	1	2%	43.87 ± 7.88	29.82	58.33
Obese (Class I) (BMI 30.0–34.9)	5	10%			
Obese (Class II) (BMI 35.0 – 39.9)	9	17%			
Obese (Class III) (BMI ≥ 40.0)	37	71%			

Table 6. Respondent's profile and variables in the study

Communicated risks		
Regularly informed	17	33%
Never been informed	3	6%
Informed but not regular	32	62%
Smoking habit		
Smokers	25	48%
Non-smokers	27	52%
Health issues		
No health issues	39	75%
Anemia	4	8%
Liver	3	6%
Lungs	2	4%
Heart	1	2%
Allergy	1	2%
Kidney	1	2%
Cholesterol	1	2%

Blood lead levels and other heavy metals levels in blood

In this study, we used the US-CDC/ATSDR reference standard for all heavy metals in blood. The Indonesian references for all heavy metals were taken from Prodia clinical laboratory results, as shown in Table 7.

Table 7. Comparison of references for heavy metals reference levels in blood

References	As-Blood	Cd-Blood (µg/L)	Pb-Blood (ug/dL)	Hg-Blood (µg/L)	Ni-Plasma (µg/L)	Tl-Blood (µg/L)
US CDC	<10µg/L	<1.0	<5	<10	<1	<2
Indonesia's lab (Prodia)	<12µg/L	<4.9	<9	<9	<5.9	<1

Table 8 compares blood arsenic levels in all study locations (in $\mu\text{g/L}$), and Figure 22 shows blood arsenic levels in respondents from three industry groups in $\mu\text{g/dL}$ (n=52).

The results show that 90% and 100% of respondents from Industry A and Industry B, respectively, have blood arsenic concentrations that exceed the reference level of $10 \mu\text{g/L}$. 77% of respondents in all sites have blood arsenic levels above $10 \mu\text{g/L}$.

Table 8. Comparison of Blood Arsenic Levels in all study locations (in $\mu\text{g/L}$)

As in Blood	A	B	C	All
>10 $\mu\text{g/L}$	90%	100%	55%	77%
<10 $\mu\text{g/L}$	10%	0%	45%	23%
Min	0.80	1.50	0.05	0.05
Max	2.50	4.70	5.70	5.70
Mean	1.58	2.41	1.67	1.80
Standard Deviation	0.45	1.03	1.61	1.17

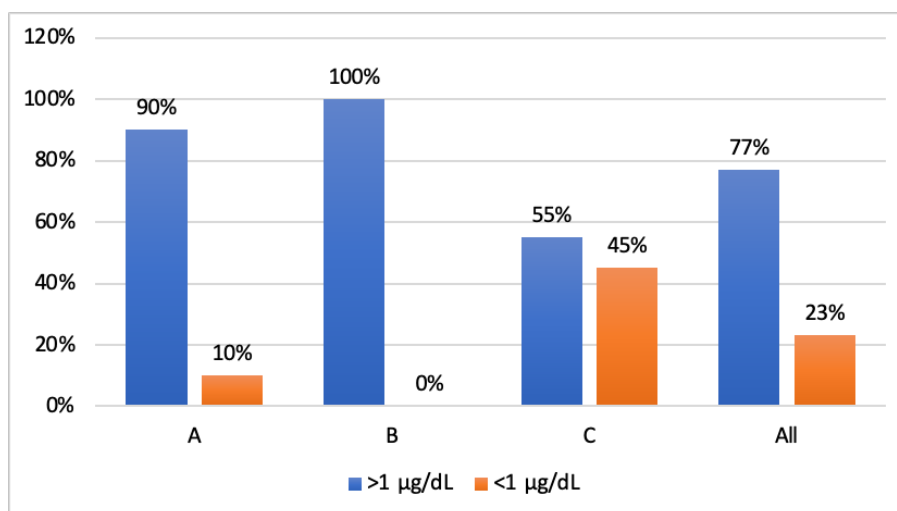


Fig. 22. Blood arsenic levels in respondents from three industry groups (in $\mu\text{g/dL}$).

Table 9 compares blood cadmium levels in this study (in $\mu\text{g/L}$), and Figure 23 shows the bar charts comparing blood cadmium in all sites. Results show that 95% of Industry A respondents and 75% of respondents in Industry B have blood cadmium above the reference value of $5\mu\text{g/L}$. In total, 63% of all respondents have high cadmium concentrations in their blood.

Table 9. Comparison of Blood-Cadmium Levels in all study locations (in $\mu\text{g/L}$)

Cd-Blood	A	B	C	All
>5 $\mu\text{g/L}$	95%	75%	45%	63%
<5 $\mu\text{g/L}$	5%	25%	55%	37%
Min	4.00	2.00	2.00	2.00
Max	39.00	44.00	25.00	44.00
Mean	12.25	21.17	6.60	12.13
Standard Deviation	9.67	15.53	5.88	11.44

The Occupational Safety and Health Administration, US Department of Labor considers a whole blood level of $5\mu\text{g/L}$ of cadmium or higher hazardous [77].

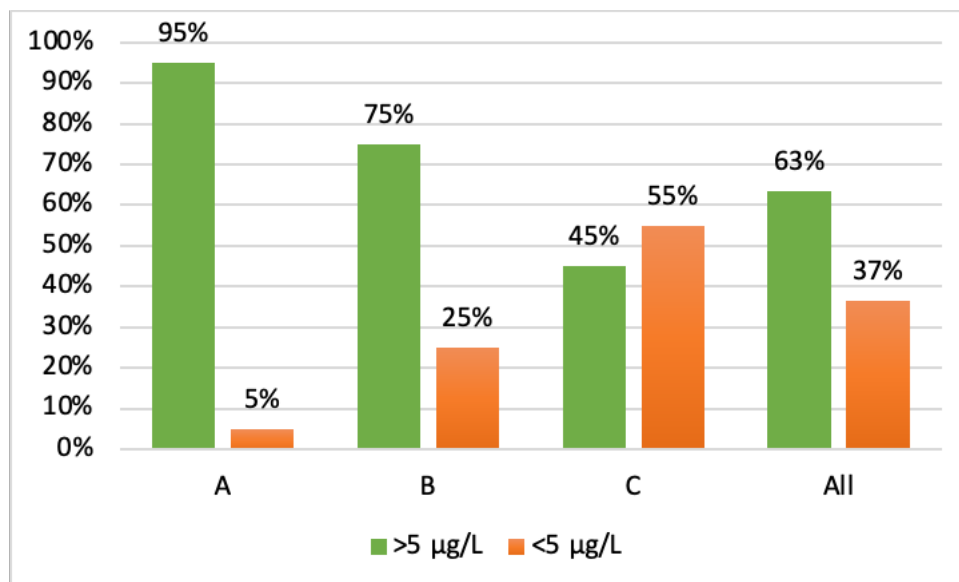


Fig. 23. Blood cadmium levels in respondents from three industry groups (in $\mu\text{g/L}$).

Table 10 shows blood lead levels in all study locations (in $\mu\text{g}/\text{dL}$). Figure 24 shows the Blood Lead Levels (BLLs) in three locations based on exposed groups, directly and indirectly exposed groups. Respondents of Industry C have a higher average concentration of lead in their blood than those in Industry A and B. The CDC's blood lead reference value is $5 \mu\text{g}/\text{dL}$.

Table 10. Comparison of Blood-Lead Levels (BLLs) in all study locations (in $\mu\text{g}/\text{dL}$)

BLLs	A	B	C	All
$>5\mu\text{g}/\text{dL}$	5%	8%	75%	33%
$<5\mu\text{g}/\text{dL}$	95%	92%	25%	67%
Min. ($\mu\text{g}/\text{dL}$)	1.40	2.50	1.80	1.40
Max. ($\mu\text{g}/\text{dL}$)	5.30	5.80	8.10	8.10
Mean ($\mu\text{g}/\text{dL}$)	3.20	3.71	5.57	4.22
Standard Deviation	0.86	0.92	1.57	1.60

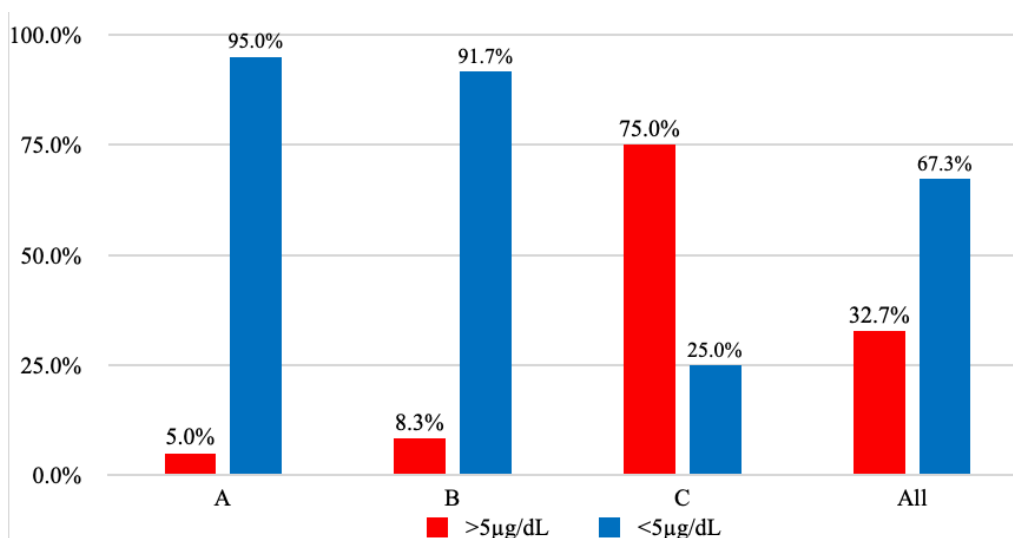


Fig. 24. Blood Lead Levels (BLLs) in respondents from three industry groups in $\mu\text{g}/\text{dL}$.

The results also show discrepancies between the blood lead levels of workers from lead-safe manufacturers and lead paint manufacturers.

Figure 25 shows that both the directly and indirectly exposed groups of Industry C have higher blood lead levels compared to Industry A and B.

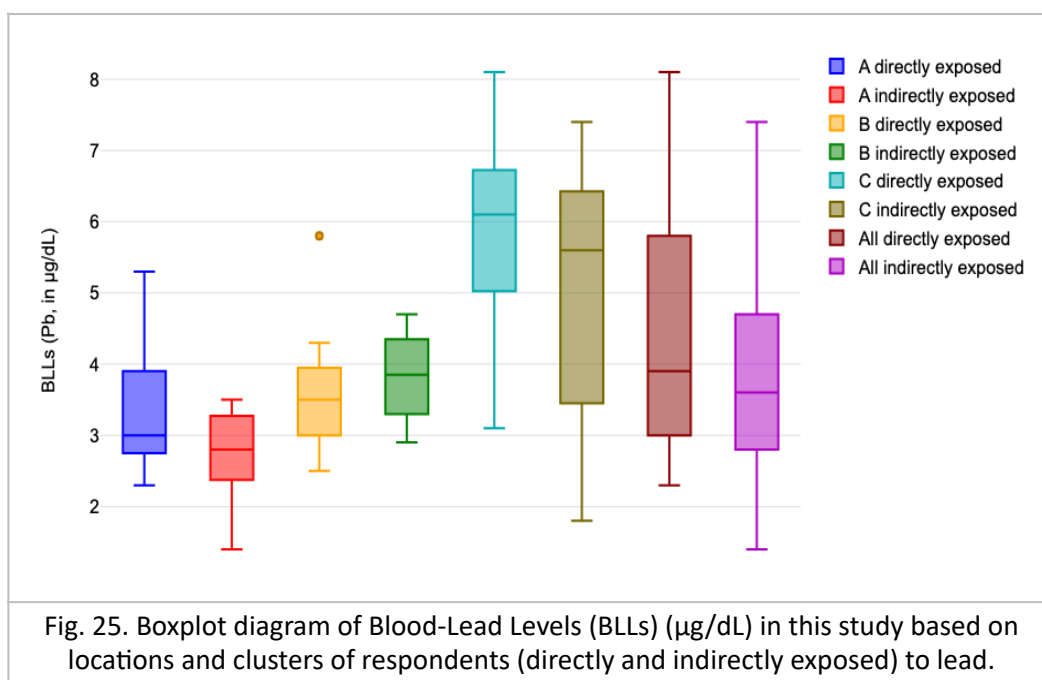
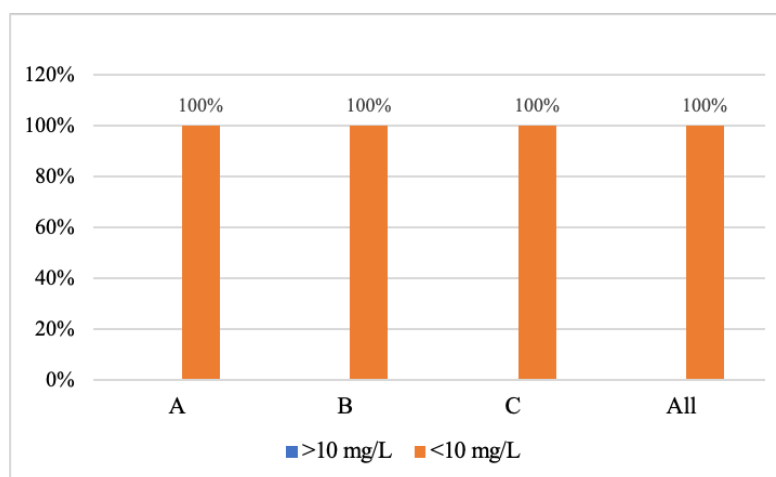


Table 11 describes blood mercury levels in this study (in mg/L), and Figure 26 compares blood mercury levels in all study locations. All respondents have blood mercury levels below the WHO reference value, which is $10 \text{ mg}/\text{L}$.

Table 11. Comparison of Blood-Mercury Levels in all study locations (in mg/L)

Hg-Blood	A	B	C	All
>10mg/L	0%	0%	0%	0%
<10mg/L	100%	100%	100%	100%
Min	1.30	2.80	3.20	1.30
Max	5.90	7.40	9.00	9.00
Mean	1.23	4.11	4.92	4.07
Standard Deviation	1.17	1.22	1.25	1.41



Blood nickel levels in all sites are presented in Table 12 (in $\mu\text{g}/\text{dL}$), and Figure 27 compares the charts of three sites. The results show that 87% of all respondents have blood nickel levels above the reference value of 1 $\mu\text{g}/\text{L}$. Industry B's respondents have the lowest percentage of blood nickel (42%), while 100% of respondents, Industry A and Industry C, have blood nickel above the reference value.

Table 12. Comparison of Blood-Nickel Levels in all study locations (in $\mu\text{g}/\text{L}$)

Ni-Blood plasma	A	B	C	All
>1.0 $\mu\text{g}/\text{L}$	100%	42%	100%	87%
<1.0 $\mu\text{g}/\text{L}$	0%	58%	0%	13%
Min	1.60	0.70	1.00	0.70
Max	1.80	2.00	1.90	2.00
Mean	1.73	1.18	1.45	1.49
Standard Deviation	0.07	0.51	0.21	0.34

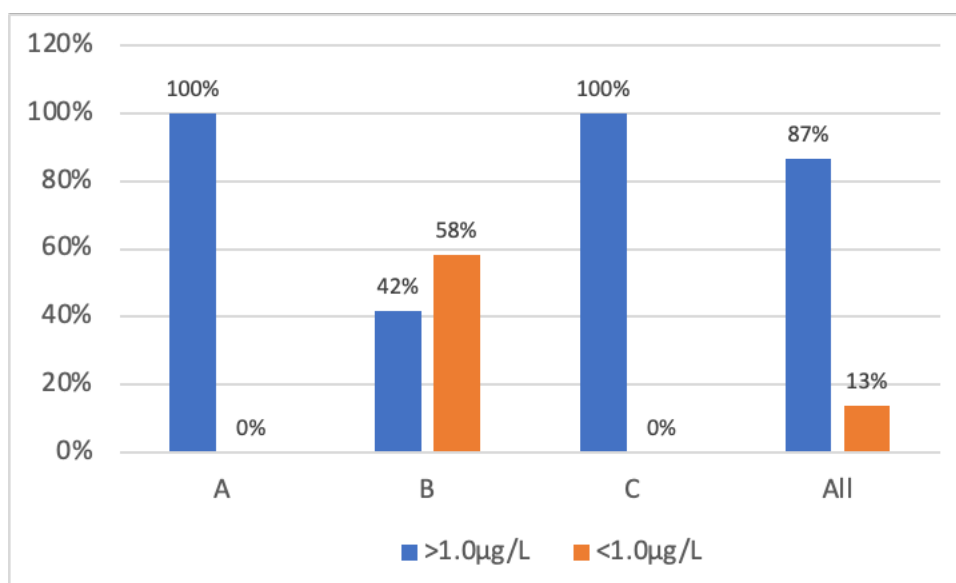


Fig. 27. Nickel Blood levels in all respondents.

Table 13 describes blood thallium levels (in $\mu\text{g/L}$) with a $2\mu\text{g/L}$ reference value. Figure 28 compares the bar chart of blood thallium levels in three locations. Only 10% of Industry A's respondents have TI-blood exceeding the reference value, and 97% of all respondents have blood thallium below the reference value.

Table 13. Comparison of Blood-Thallium Levels in all study locations (in $\mu\text{g/L}$)

TI-Blood	A	B	C	All
$>2\mu\text{g/L}$	10%	0%	0%	3%
$<2\mu\text{g/L}$	90%	100%	100%	97%
Min	0.60	0.50	0.30	0.30
Max	3.10	1.10	1.40	1.40
Mean	1.23	0.79	0.92	0.81
Standard Deviation	0.69	0.14	0.27	0.22

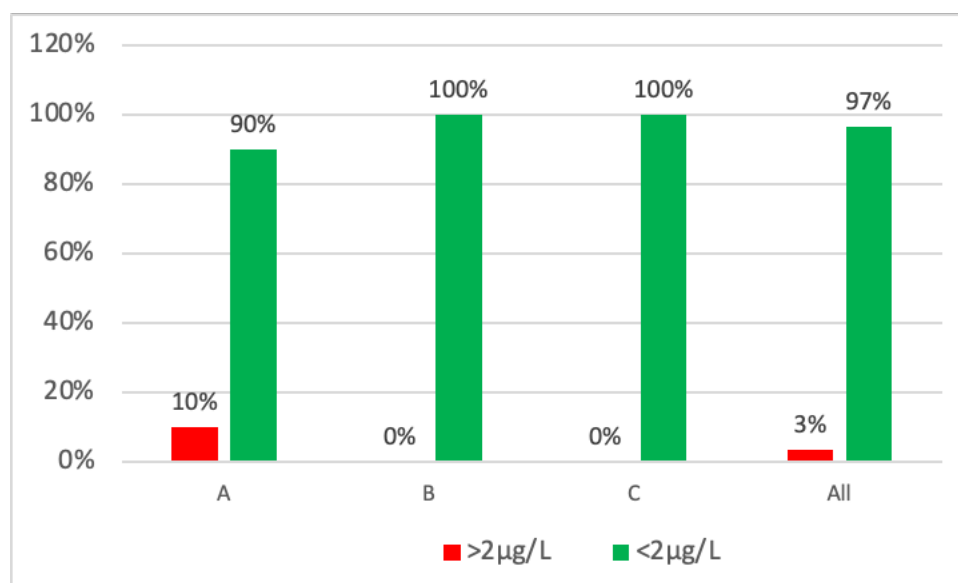


Fig. 31. Thallium Blood levels in all respondents

Heavy metals in the blood of respondents in every industry

Figure 29 shows other heavy metals in Industry A respondents' blood: arsenic, cadmium, mercury, nickel (in plasma), and thallium. The average mercury concentration in some Industry A respondents was approximately 3 $\mu\text{g/dL}$, almost the same as the average blood lead levels.

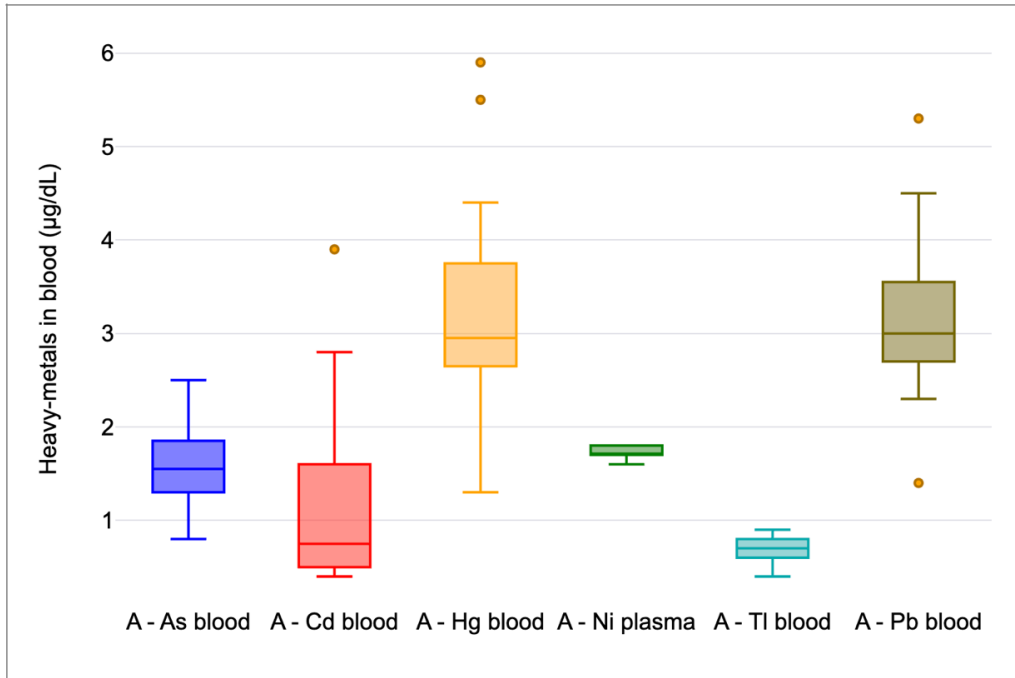


Fig. 29. Boxplot diagram of heavy metals in the blood of respondents in Industry A

Figure 30 shows other heavy metals in Industry A respondents' blood: arsenic, cadmium, mercury, nickel (in plasma), and thallium. The average mercury concentration in some Industry A respondents was approximately 3 $\mu\text{g/dL}$, almost the same as the average blood lead levels.

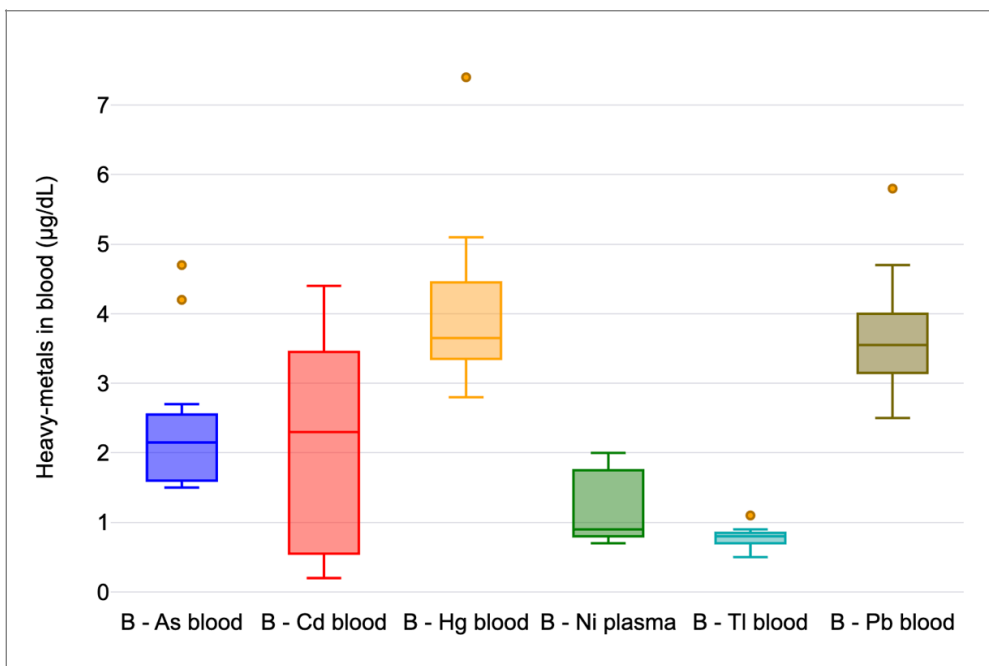


Fig. 30. Boxplot diagram of heavy metals in the blood of respondents in Industry B.

Figure 30 shows other heavy metals in Industry B respondents' blood. Interestingly, the range of cadmium concentration in Industry B was wider compared to Industry A and C. The average mercury level in Industry B blood was approximately 3.75 mg/L, and the maximum value was 7.4 mg/L. The reference level of WHO is 1 mg/L.

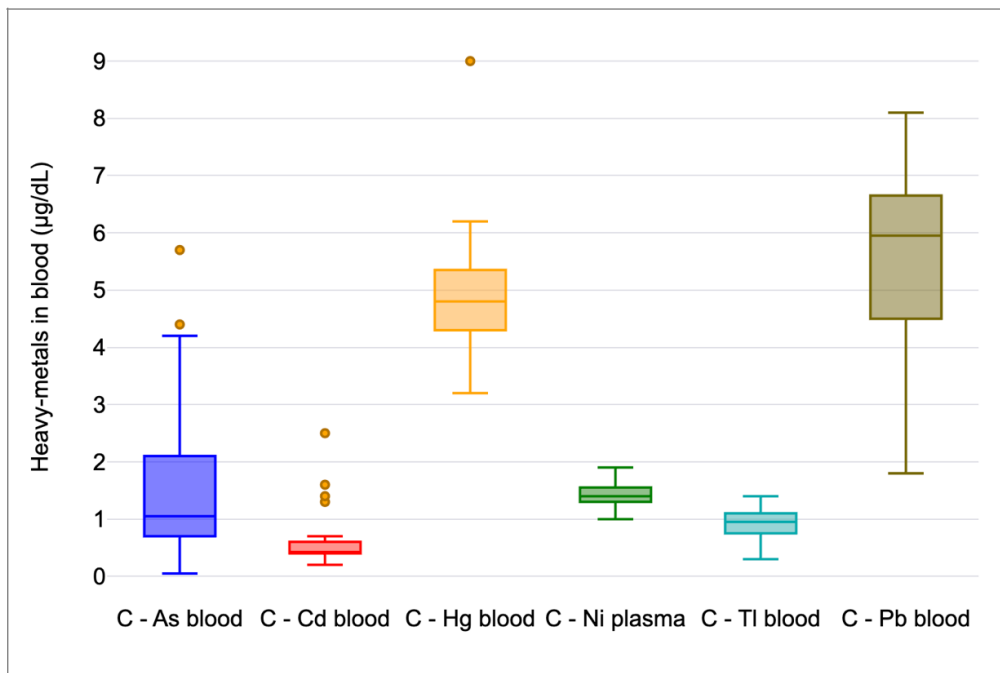


Fig. 31. Boxplot diagram of heavy metals in the blood of respondents in Industry C.

Figure 31 shows other heavy metals in Industry C's respondents. The average mercury level in Industry C's respondents was approximately 4.75 mg/L, and the maximum value was 9 mg/L. The reference for a safe level of mercury in blood set by the WHO is 1 mg/L. Please note that the location of Industry C is close to the coastal area of Surabaya, which has high fish and seafood consumption.

Indoor air lead level

Indoor air lead concentration was measured in various corners of every industry. The results were compared to the reference concentration set by the National Ambient Air Quality Standards (NAAQS) for lead concentration in indoor air, which is 0.15 $\mu\text{g}/\text{m}^3$ of air for a rolling three-month average over three years [78].

The results show that lead indoor air concentration in Industry A was two times higher than the reference standard and three times higher in Industry C, as shown in Table 14.

Table 14. Lead indoor air concentrations in three locations (using Low Volume Air Sampler).

Locations	Sampling point	Final concentration (8-hour) ($\mu\text{g}/\text{m}^3$)
A	Solvent production 1st floor	0.31
	Solvent production 2nd floor	0.31
	Laboratory/QC	0.31
	Raw materials warehouse	0.31
	Logistics	0.31
B	Tinting	0.15
	Packaging	0.07
	Premix	0.07
	Laboratory/QC	0.07
	Logistics	0.07
C	Production 1st floor	0.07
	Production 2nd floor	0.03
	Laboratory/QC	0.03
	Utility	0.63
	Raw materials warehouse	1.78

Lead Dust Concentration

In July 2023, USEPA proposed to tighten the dust lead clearance level to 3 $\mu\text{g}/\text{ft}^2$ for floors, 20 $\mu\text{g}/\text{ft}^2$ for windowsills, and 25 $\mu\text{g}/\text{ft}^2$ for window troughs. USEPA's current dust clearance levels are 10 $\mu\text{g}/\text{ft}^2$ for floors, 100 $\mu\text{g}/\text{ft}^2$ for windowsills, and 400 $\mu\text{g}/\text{ft}^2$ for window troughs [79].

Dust-lead clearance levels (DLCL) indicate the amount of lead in dust on a surface following the completion of an abatement activity. Surface dust is collected via dust wipe samples sent to a laboratory for analysis to determine whether clearance has been achieved. The post-abatement dust-lead levels are evaluated against and must be below the applicable clearance levels [80].

The dust wipes results showed that in Industry A and B, the dust lead concentration on the facilities' floors was below the current USEPA clearance level of 10 µg/ft²; however, in Industry C, the dust lead levels were **5 to 410 times higher than the clearance level** as shown in Table 15.

Table 15. Dust lead floor concentration (in µg/ft²)

Location	Sampling spots	Lead dust levels (floor) (µg/ft ²)
Industry A	Logistic area (finished goods)	< 20
	Solvent room	< 20
	Solvent chamber/filling area	< 20
	Mixing area	20
	Quality Control room	< 20
	Raw materials area	< 20
Industry B	Filling production area	< 20
	Production room 2nd floor/process room	30
	Quality Control room	< 20
	Fill in area	< 20
	Productions/raw materials room	< 20
	Small production area	< 20
	Final packaging hall	< 20
Industry C	Tinting/coloring area (front)	760
	Warehouse	260
	Premix area	2,700
	Quality Control room	<20
	Tinting Section 2	4,100
	Meeting room terrace	50
	Old factory	930

Note:

- The current CDC Dust Clearance Level (floor) is 10µg/ft²
- The proposed CDC Dust Clearance Level (floor) is 3µg/ft²

Lead concentration in LVAS filters and dermal patches

The lead concentration captured on filters and patches analyzed in the lab showed that the average lead inhalation filter in Industry B was the highest—potentially due to impurities—but the highest concentration was found in Industry C, with a maximum concentration of 35 ng/cm². However, the average lead concentration in dermal patches of Industry C’s respondents is the highest, with a maximum concentration of almost 350 ng/cm².

Figure 32 shows lead concentrations captured in inhalation filters at three sites, and Figure 33 shows those captured in dermal patches.

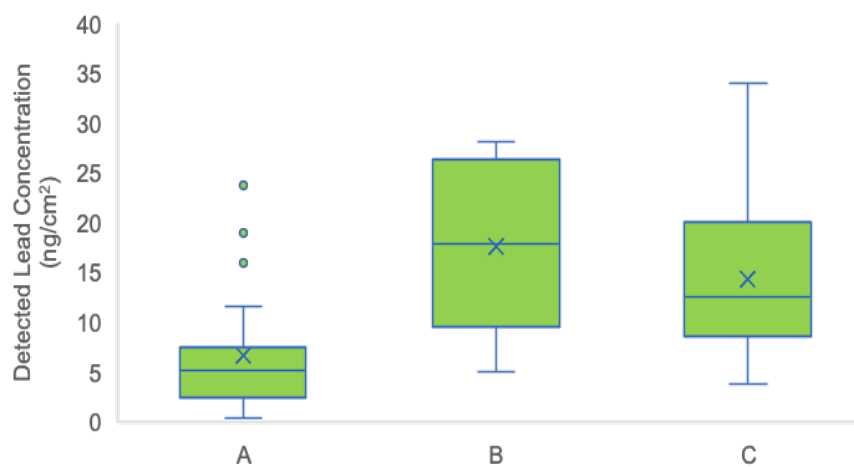


Fig. 32. Lead captured on inhalation filter.

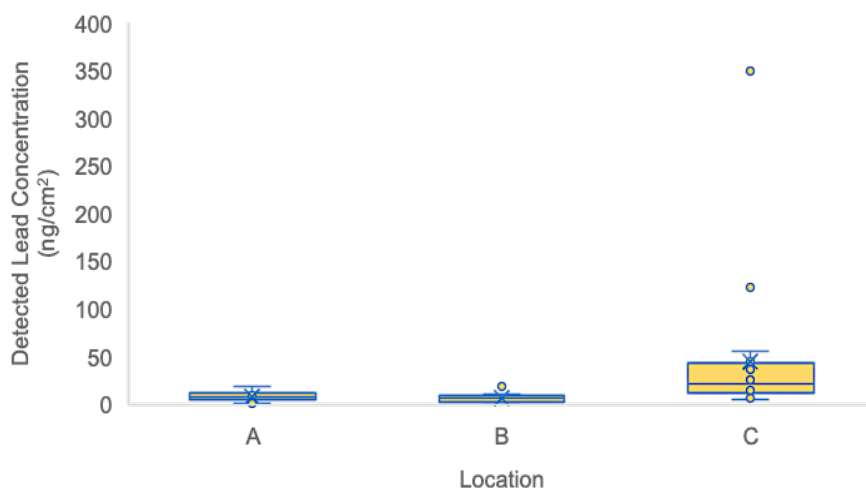


Fig. 33. Lead captured on dermal patch.

Table 16 presents the concentration of lead captured on filters, and Table 17 shows the concentration captured in dermal patches.

Table 16. Lead in inhalation filters (in ng/cm²)

Industry	A	B	C
Min	0.041	5.08	3.78
Median	5.14	17.91	12.64
Max	23.75	28.14	34.07
Mean	6.67	17.60	14.30
Standard Deviation	6.30	8.50	8.50

Table 17. Lead in dermal patches (in ng/cm²)

Industry	A	B	C
Min	1.24	2.32	5.520
Median	8.53	6.64	22.42
Max	19.54	19.70	349.75
Mean	8.67	7.08	44.80
Standard Deviation	4.80	5.00	76.50

The estimated external exposure of lead was calculated using both parameters above. Table 18 shows the concentration of inhaled lead external exposure (in µg/m³), while Table 19 shows dermally absorbed lead external exposure (in mg/cm²-day).

Table 18. Inhaled lead external exposures (in µg/m³)

Industry	A	B	C
Min	0.006	0.083	0.060
Median	0.070	0.261	0.181
Max	0.323	0.438	0.462
Mean	0.090	0.256	0.194
Standard Deviation	0.090	0.100	0.100

Table 19. Dermal absorbed lead external exposures (in mg/cm²-day)

Industry	A	B	C
Min	3.3×10 ⁻⁶	6.2×10 ⁻⁶	1.5×10 ⁻⁵
Median	2.3×10 ⁻⁵	1.8×10 ⁻⁵	6×10 ⁻⁵
Max	5.2×10 ⁻⁵	5.3×10 ⁻⁵	9.3×10 ⁻⁴
Mean	2.3×10 ⁻⁵	1.9×10 ⁻⁵	1.2×10 ⁻⁴
Standard Deviation	1.3×10 ⁻⁵	1.3×10 ⁻⁵	2×10 ⁻⁴

Tables 18 and 19 present data which were used to calculate the estimated concentration (EC) of lead inhalation intake and the carcinogenic and non-carcinogenic estimated concentrations of inhaled lead (in µg/m³).

Similarly, the Average Daily Dose (ADD) of dermal intake was used to calculate the carcinogenic and non-carcinogenic Average Daily Dose of Dermal Absorbed Lead (in mg/kg-day), as explained in Figure 34.

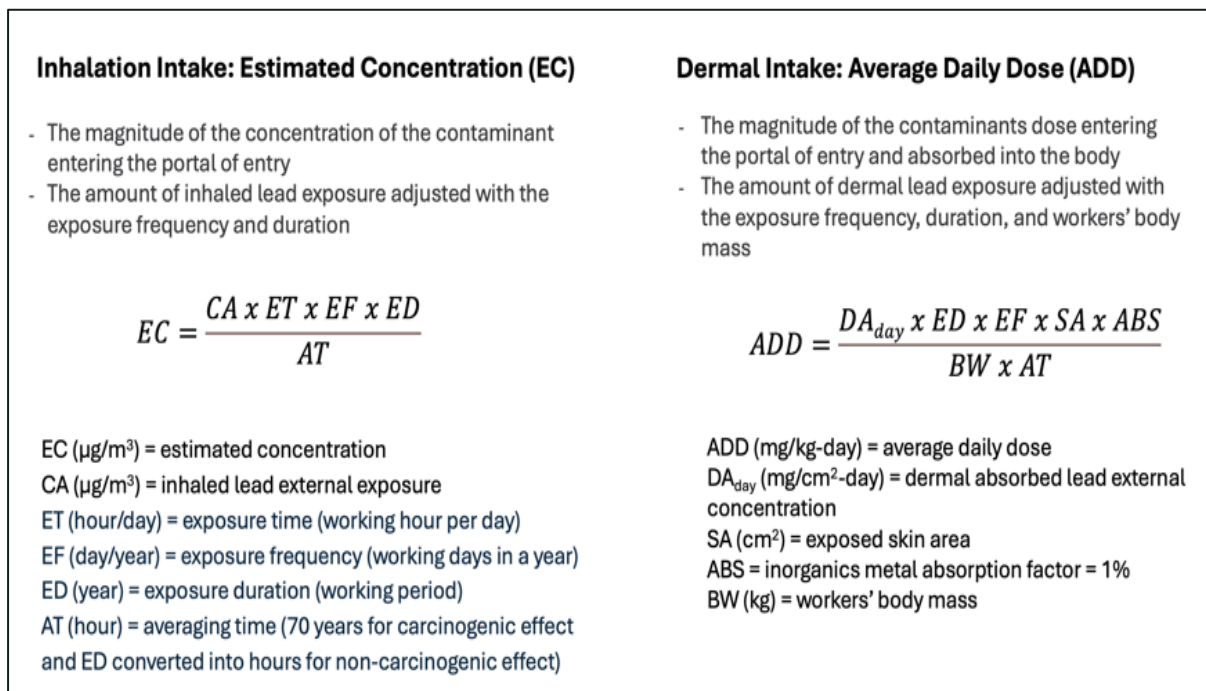


Fig. 34. Calculations used to assess exposure to lead via inhalation and dermal absorption.

Risk Characterization

Risk characterization combines the results of the exposure assessment and the toxicity assessment to estimate potential carcinogenic risks and noncarcinogenic health effects associated with exposure to chemicals.

The Hazard Index (HI) and Excess Lifetime Cancer Risk (ELCR) are the outputs for noncarcinogenic and carcinogenic risk characterisation [81, 82]. Before characterizing the risks, the value of the RfD/reference dose (or RfC/reference concentration for inhalation exposure) is determined, which is the highest dose or concentration limit that will not cause any severe health effects, often derived from toxicology experiments' 'No Observed Adverse Effect Level' (NOAEL) [83].

Similar values characterize carcinogenic risk, called the Cancer Slope Factor (CSF) and the Inhalation Unit Risk (IUR). These values represent the estimated increase in cancer risk per unit of exposure to a carcinogenic substance [84] and are used to estimate the probability of developing cancer at different exposure levels.

The formulas in Figure 35 calculate cancer risks from inhalation and dermal exposures, including the RfD, RfC, SF, and IUR values used to calculate the risks.

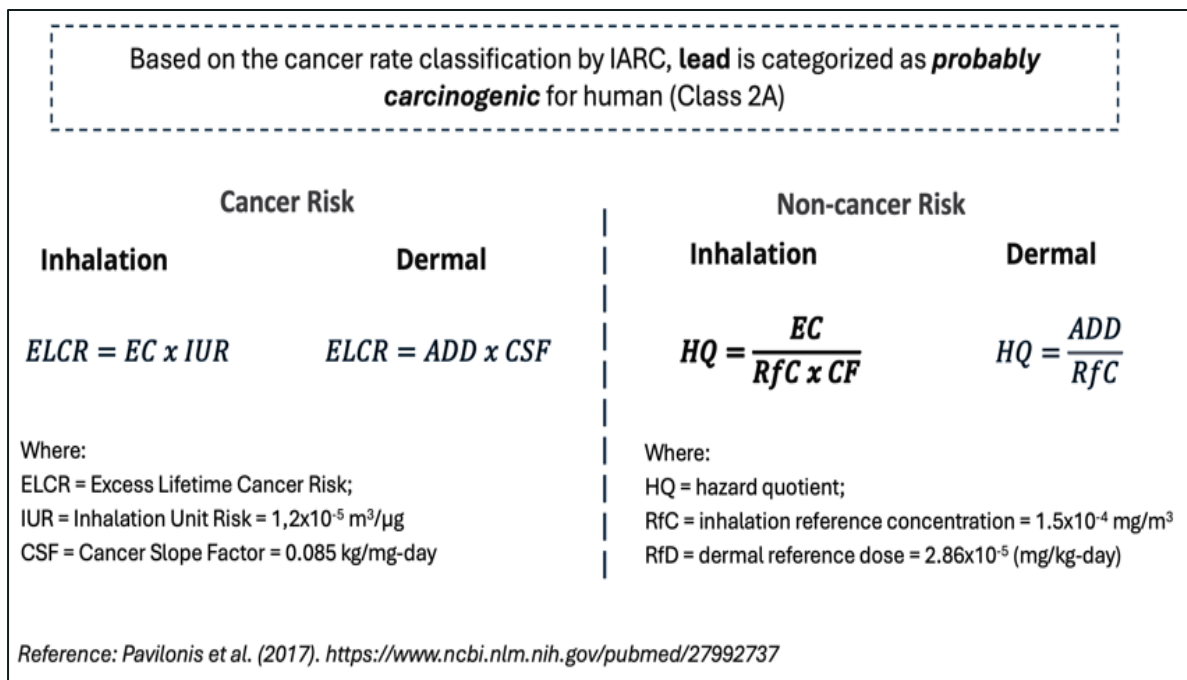


Fig. 35. Risk characterization calculations for cancer and non-cancer risks from inhalation and dermal exposure pathways.

Figure 36 shows the hazard index of lead exposures through inhalation and dermal compared to the safety limit for hazard index. Almost half of Industry C's respondents have a dermal hazard quotient higher than the safety limit.

Figure 37 presents the results of the hazard identification, exposure assessments, and risk characterization through the inhalation pathway. The same calculation for the dermal exposure pathway is shown in Figure 38.

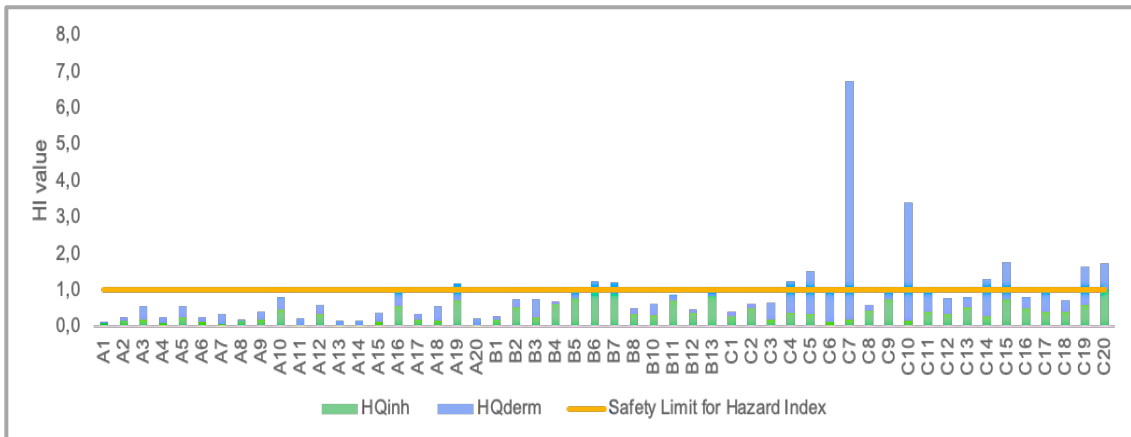


Fig. 36. Hazard index value from inhalation and dermal exposure pathways compared with the safety limit for Hazard Index value (=1).

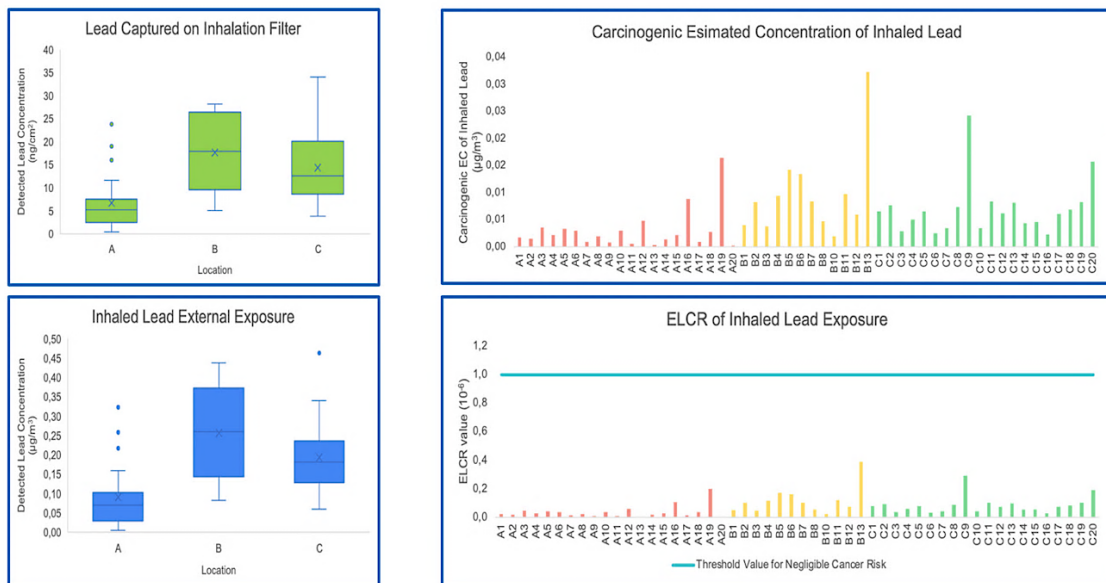


Fig. 37. Results of hazard identification, exposure assessment, and risk characterization from inhalation.

The results show that the cancer risk of lead exposure in two workers from Industry C is significant. One worker from Industry A, three from Industry B, and 11 from Industry C exceeded the safe level of non-cancer risk.

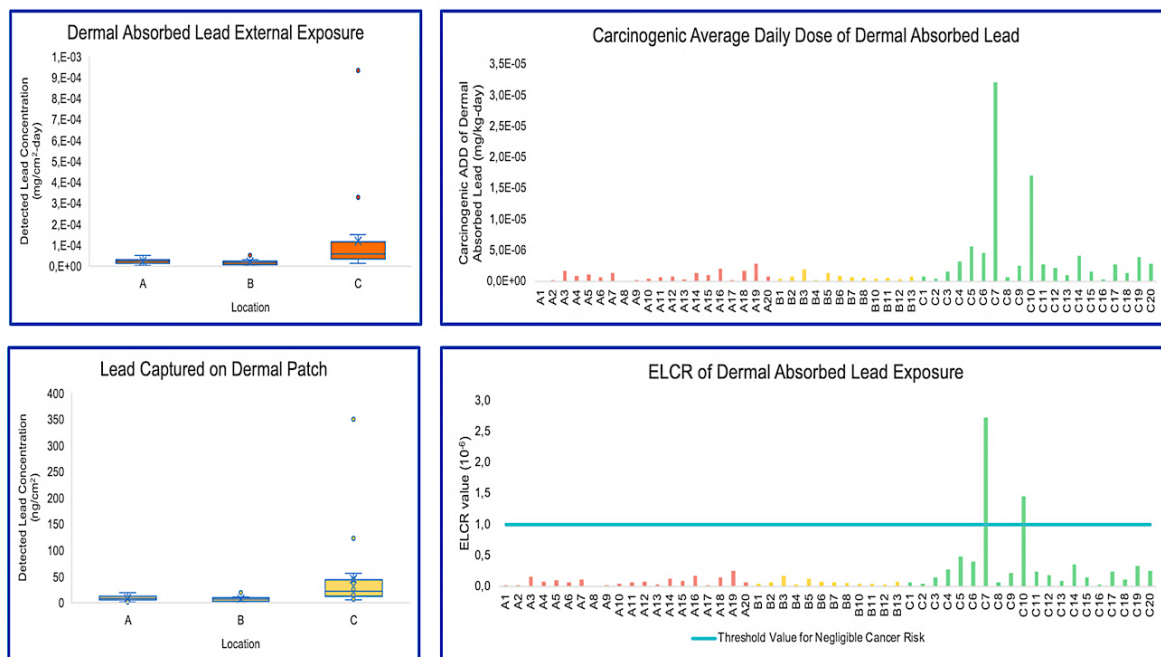


Fig. 38. Hazard identification, exposure assessment, and risk characterization results from dermal exposure pathway.

The “lifetime cancer risk” is the probability of an individual developing cancer during a lifetime [85]. For instance, an American man's absolute risk of developing prostate cancer in his lifetime is about 13%.

The term “excess lifetime cancer risk” or ELCR means the risk of death from cancer in excess of the “natural” background risk resulting from a lifetime exposure to carcinogens. In reality, exposure is not for a lifetime; the exposure usually comprises more than one carcinogen, and the risk of cancer death could be substantially reduced by therapy.

For Chromium and Nickel, the carcinogen risk posed by exposure to these metals via inhalation and dermal is very significant.

Figure 39 shows the total Excess Lifetime Cancer Risk from chromium exposure, identifying the inhalation pathways as the major cancer risks in all three industries.

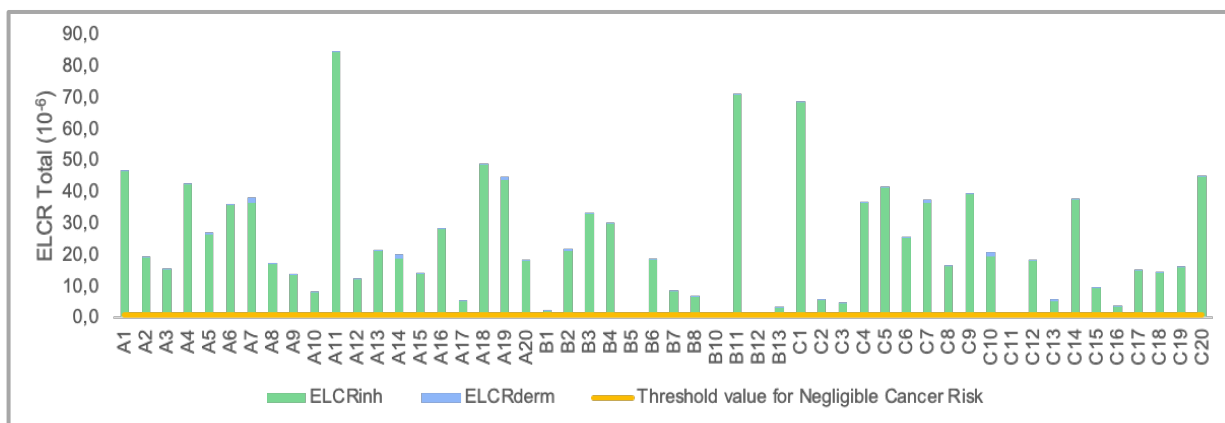


Fig. 39. Total excess lifetime cancer risk (ELCR) from chromium exposures through inhalation and dermal pathways.

Figure 40 describes the Excess Lifetime Cancer Risk (ELCR) from nickel exposure, where the dermal pathway is the major cancer risk in all three industries.

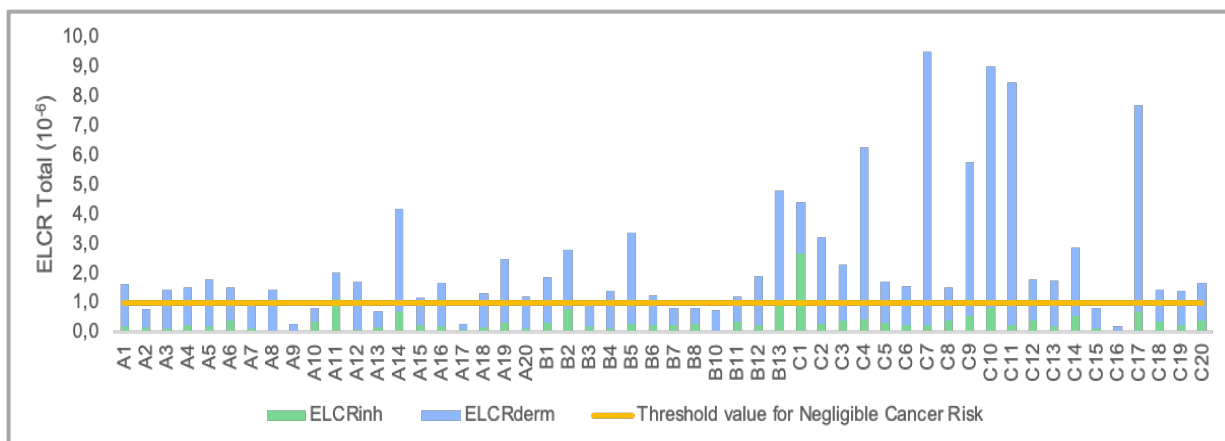


Fig. 40. Total excess lifetime cancer risk (ELCR) from nickel exposures through dermal is the major pathway in all locations.

Correlation between parameters

Based on the normality test and the small sample size, we could only assess the correlation between several normally accepted parameters, such as blood lead levels, inhaled lead air, lead dermal absorption, working experience, and age.

The correlation between blood lead level and working experience using Pearson’s correlation tests is weak ($R=0.2594$) in the directly exposed group and mild in the indirectly exposed group. However, comparing blood lead and lead concentration in dermal patches in both directly and indirectly exposed groups shows a mild correlation.

Figure 41 shows the weak correlation between directly exposed Blood Lead Levels (X or Dataset A) and working experiences (Y or Dataset B). Meanwhile, in the indirectly exposed group, there was a mild correlation between blood lead levels and lead concentration in dermal patches, as shown in Figure 42.

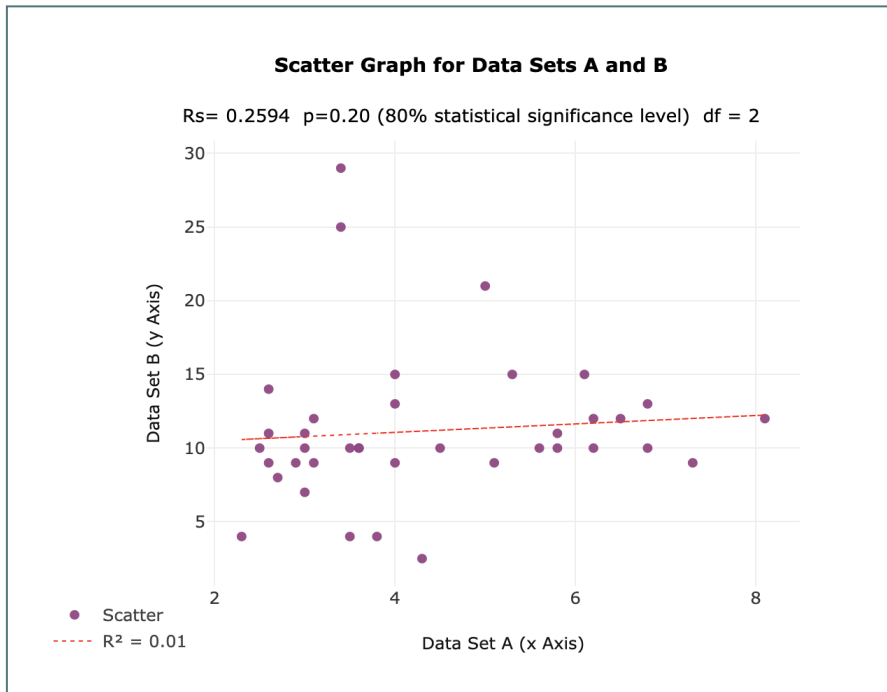


Fig. 41. Weak correlation between directly exposed BLL (X or Dataset A) vs working experiences (Y or Dataset B)

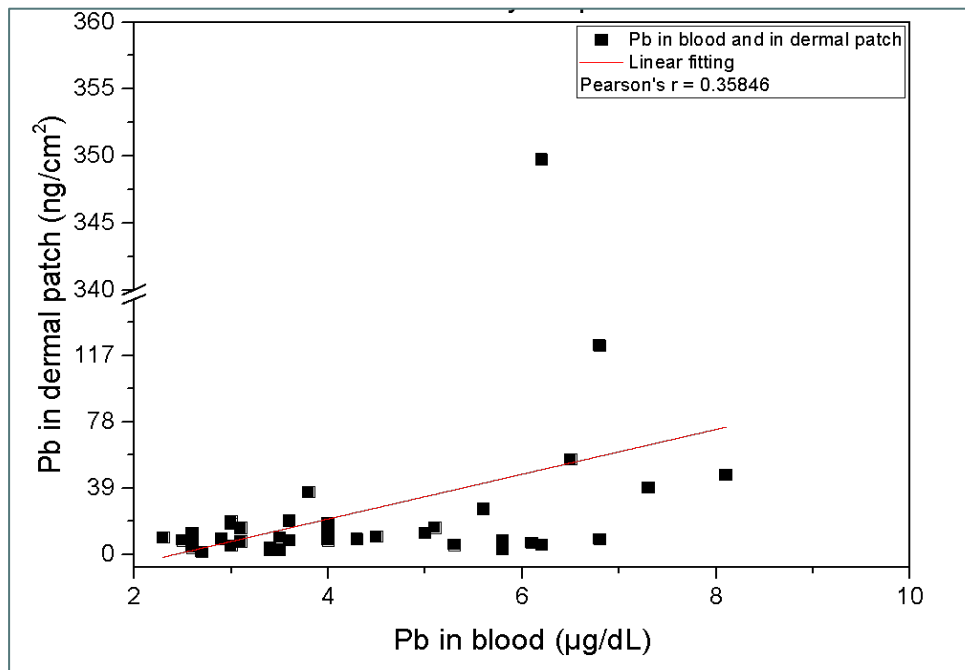


Fig. 42. A mild correlation exists between the directly exposed group's blood level and lead concentration in dermal patches.

Results show a moderate correlation ($R_s=0.4209$, $p=0.20$) between blood lead levels and working experiences in the indirectly exposed group (Figure 43). Meanwhile, a moderate correlation was also observed between blood lead level and lead in dermal patches (Pearson's $r=0.46178$) in respondents from the directly exposed group (Figure 44).



Fig. 43. A moderate correlation was observed between the directly exposed group's blood level and working experiences.

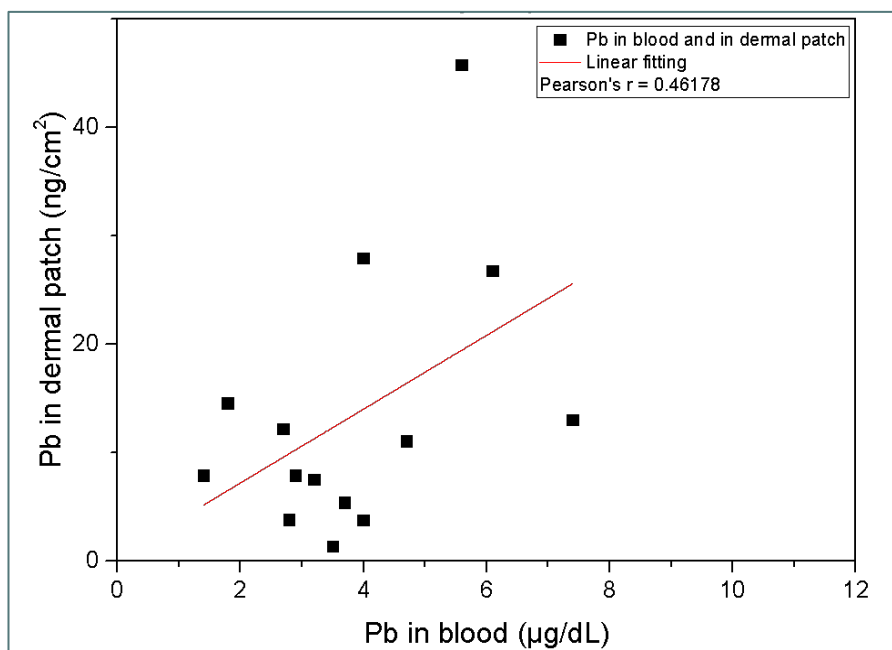


Fig. 44. A moderate correlation exists between the directly exposed group's blood level and working experiences.

Discussions

Blood Lead Levels (BLL) are measured in micrograms per deciliter (abbreviated $\mu\text{g}/\text{dL}$). Several studies demonstrated the correlation between lead exposure and hypertension and chromosomal aberrations [14, 15]. A study shows that $\text{BLL} \geq 6.87 \mu\text{g}/\text{dL}$ was associated with hypertension [13]. However, a recent cohort study revealed that increased lead concentration in blood from $1.0 \mu\text{g}/\text{dL}$ to $6.7 \mu\text{g}/\text{dL}$ was associated with all-cause mortality, cardiovascular disease, and ischaemic heart disease mortality [86].

Global and regional health authorities have established various thresholds for understanding and reacting to blood lead levels. Our study references the standard adopted by the WHO, the California Department of Public Health (CDPH), and the U.S. National Agency for Toxic Substances and Disease Registry (ATSDR). These agencies and the American College of Occupational and Environmental Medicine recommend monitoring adults with a blood lead level higher than $5 \mu\text{g}/\text{dL}$ but less than $10 \mu\text{g}/\text{dL}$ [87, 88].

In our study, 75% (15 of 20) of workers in Industry C had blood levels in this range (above $5 \mu\text{g}/\text{dL}$ and less than $10 \mu\text{g}/\text{dL}$). CDPH recommends minimizing lead exposure for workers in this category and retesting blood lead levels every three months until the levels decline to under $5 \mu\text{g}/\text{dL}$. Fortunately, none of the workers in the study had higher blood lead levels, which would trigger recommendations for more aggressive health interventions.

Nonetheless, the evidence shows that chronic, low-level lead exposure in adults is linked to cancer and other serious health concerns, and all lead exposures should be eliminated to the extent possible.

Heavy metal concentrations in indoor dust were associated with human activities such as mining, melting, e-waste recycling, and Pb-related industries. Workers who are highly likely exposed to lead at work may inadvertently transport lead home from work, known as “take-home exposure” [89, 90].

Some heavy metals and chemicals of concern, such as Pb, Cr, Ni, and solvents used in paint manufacturers, were highly bio-accessible. The levels of heavy metals in indoor dust were mainly affected by a combination of outdoor and indoor sources and related critical factors.

Based on the health risk assessment, studies revealed that dust Pb exposure is a significant health concern in electronic waste recycling sites and areas where lead paints are used, warranting more significant attention [91].

Lead exposure from indoor dust significantly contributes to children's blood lead poisoning in many developing countries [91, 92].

Dust particles from solvent- and water-based paints could be considered hazardous since almost all dust particles were smaller than 10 μm . Particular attention should be given to the containment of solvent-based paint dust particles since it was shown that most of them were very fine in size ($<1 \mu\text{m}$) and had high lead and zinc concentrations [93].

A couple of in-vivo genotoxic studies have demonstrated that dust and fumes from lead-based paints cause chromosomal damage [94, 95], which results in a significant increase in heritable chromosomal aberrations (CAs) or chromosomal abnormalities [96] in painters.

Dialogues with the relevant government agencies and parliament members and lobbying to the paint industry association have already been conducted to change the situation. Additionally, Nexus3 participates in the public awareness-raising campaign calling for eliminating lead paint every fourth week of October, including a petition in 2020 signed by over 16,000 supporters.²

The laws and regulations prohibiting toxic metals and their compounds must be established to enforce and support the goal of eliminating toxic exposures at the source. Protective standards must also be established to protect workers' and consumers' health.

UNEP (2018) has already issued a model law and guidance for regulating lead paint to be used by LMICs, who are still looking for insights on developing legal control measures [97].

Indonesia's quality standard for lead (Pb) in ambient air has existed for 22 years since the issuance of Government Regulation (PP) No. 41 in 1999 concerning air pollution control. Until the issuance of PP No. 22 year 2021, and the Indonesian Minister of Health Indonesia Regulation No. 2 year 2023 concerning Regulations on the Implementation of Government Regulation No. 66 year 2014 concerning Environmental Health, the quality standard value for lead (Pb) in ambient air was still 2 $\mu\text{g}/\text{Nm}^3$.

Meanwhile, WHO has set the reference level (RL) for Pb in ambient air to 0.5 $\mu\text{g}/\text{Nm}^3$, and the US EPA has also revised the quality standard for Pb in total suspended particulate matter (TSP) to 0.15 $\mu\text{g}/\text{Nm}^3$ [98].

² <https://www.change.org/p/pak-jokowi-larang-penggunaan-timbal-di-cat-selamatkan-anak-cucu-kita>

Recommendations

For Paint Industry

Since 1919, the ILO has warned women and children about the hazardous exposure of lead. In 1921, the first lead convention was adopted and restricted the use of white lead for paintings [99]. Eliminating lead paint is the best way to protect workers from lead exposure. Our study shows companies can protect their workers and consumers from harmful lead exposures by eliminating lead paint. For decades, alternatives to lead paint have demonstrated that they are as effective and safer than lead paint. There is no advantage to continuing the use of lead in paint.

While transitioning to lead-safe paint, companies can take steps to minimize worker exposures,³ including providing systems so workers can:

- Use tools and equipment with dust collection systems to keep lead out of the air.
- Provide changing room for workers and adequate washing basins.
- Clean surfaces using wet methods and HEPA vacuuming instead of dry sweeping or blowers [100].
- Avoid shaking out, brushing off, or blowing off dusty clothing.
- Scrub hands and nails and wash faces thoroughly before eating and drinking. The use of lead-removal soap or foam [101] should be provided, as studies show that regular soap and water may not adequately remove lead particles.

Studies have also shown that workers can bring lead contamination home from their workplace. To reduce risks, employers should have systems so workers can:

- Reformulate the paint production and replace lead-based pigments and driers with safer alternatives.
- Change the solvent-based paint to water-based paint.
- Communicate the risk of chemical exposure in the factory regularly.
- Workers should wash up at the end of the day to remove lead from their hair, nails, and exposed skin; if possible, they should also have showers at work before going home.
- Use separate working clothes, shoes/boots while at work that they do not take home.
- Store their street clothes in a clean place.
- Launder lead-contaminated clothing at work, if possible. When it is not possible, workers should be provided with plastic bags to store their soiled work clothes and advised to wash and dry work clothes separately from other clothes.
- Avoid taking home tools, materials, or anything contaminated with lead.

³ See more at https://lni.wa.gov/safety-health/safety-rules/rulemaking-stakeholder-information/_leaddocs/LeadRuleDraftWorkerPoster.pdf and <https://www.cdc.gov/niosh/topics/lead/workerinfo.html>

For the Government of Indonesia

Experts noted that occupational and non-occupational exposures to metals are most severe in low- and middle-income countries where mining, waste processing, and rapid industrial development are taking place but weak occupational and environmental safeguards [102].

Interventions to prevent exposure to metals should be based on the “hierarchy of controls” concept, where the most effective priority is reducing and preventing exposure at the source. The reduction measure requires the identification, evaluation, control, and, if possible, elimination of the sources of exposure. In some cases, exposure reduction is achieved by changes in industrial processes or raw materials.

The key elements of exposure prevention are Hazard Identification and Hazard Control, as recommended by experts, as follows:

- Prohibit the use of lead-based pigments and driers for all paint manufactured in Indonesia.
- Apply Extended Producer Responsibility (EPR) regulation and oblige paint manufacturers to take back lead-paint cans from consumers, classifying them as hazardous waste.
- Adopt and make a mandatory regulation with a protective lead content standard for all paints below 90 ppm based on SNI 8011:2022.
- Hazard Identification is an essential factor in the prevention process. It includes recognizing potential sources and routes of exposure and identifying the full range of health effects, including those in children's early development.
- Evaluation involves regular workplace environment, biological aspects, and workers' health monitoring.
- Hazard Control involves reducing environmental exposure at the workplace using better or best available technologies, best environmental practices, and safer alternatives. The control measures also include administrative controls, biomonitoring of at-risk workers, and applying personal protective equipment.
- Eliminating exposure at its source or primary prevention is the most effective and cost-effective prevention measure.

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Annex 1

Ethical clearance for the study was obtained from Universitas Padjadjaran's Research Ethics Committee No. 1066/UN6.KEP/EC/2022



KEMENTERIAN PENDIDIKAN, KEBUDAYAAN,
RISET DAN TEKNOLOGI
UNIVERSITAS PADJADJARAN
KOMISI ETIK PENELITIAN
RESEARCH ETHICS COMMITTEE

Jl. Prof. Eycckman No. 38 Bandung 40161
Telp. & Fax. 022-2038697 email kep@unpad.ac.id, website: kep.unpad.ac.id

No. Reg.: 2208081012

PERSETUJUAN ETIK
ETHICAL APPROVAL

Nomor: 1066/UN6.KEP/EC/2022

Komisi Etik Penelitian Universitas Padjadjaran Bandung, dalam upaya melindungi hak asasi dan kesejahteraan subjek penelitian serta menjamin bahwa penelitian yang menggunakan formulir survei/registrasi/surveilans/Epidemiologi/Humaniora/Sosial Budaya/Bahan Biologi Tersimpan/Sel Punca dan non klinis lainnya berjalan dengan memperhatikan implikasi etik, hukum, sosial dan non klinis lainnya yang berlaku, telah mengkaji dengan teliti proposal penelitian berjudul:

The Research Ethics Committee Universitas Padjadjaran Bandung, in order to protect the rights and welfare of the research subject, and to guaranty that the research using survey questionnaire/registry/surveillance/epidemiology/humaniora/social-cultural/archived biological materials/stem cell/other non clinical materials, will carried out according to ethical, legal, social implications and other applicable regulations, has been thoroughly reviewed the proposal entitled:

BAHAYA KESEHATAN DARI PAJANAN TIMBAL BAGI PEKERJA DI BEBERAPA PABRIK CAT DI INDONESIA

Nama Peneliti Utama : Dr. Ir. Katharina Oginawati, MS.
Principal Researcher

Pembimbing/Peneliti Lain : Rinaldy Jose Nathanael, S.T.
Intan Nur'azizah Rahman, S.Tr.T.
Sharnella Janet Yapfrine, S.T.
Supervisor/Other Researcher

Nama Institusi : Toxic dan Zero Waste Program Toxic dan Zero Waste
Institution Program Nexus3 Foundation

proposal tersebut dapat disetujui pelaksanaannya.
hereby declare that the proposal is approved.

Ditetapkan di : Bandung
Issued in
Tanggal : 26-10-2022
Date



Ketua,
Chairman,



Nur Atik, dr, M.Kes., PhD
NIP. 19811010 200801 1 019

Keterangan/notes:

Persetujuan etik ini berlaku selama satu tahun sejak tanggal ditetapkan.

This ethical clearance is effective for one year from the due date.

Pada akhir penelitian, laporan pelaksanaan penelitian harus diserahkan ke Komisi Etik Penelitian.

In the end of the research, progress and final summary report should be submitted to the Research Ethics Committee.

Jika ada perubahan atau penyimpangan protokol dan/atau perpanjangan penelitian, harus mengajukan kembali permohonan kajian etik penelitian.

If there be any protocol modification or deviation and/or extension of the study, the Principal Investigator is required to resubmit the protocol for approval.

Jika ada kejadian serius yang tidak diinginkan (KTD) harus segera dilaporkan ke Komisi Etik Penelitian.

If there are Serious Adverse Events (SAE) should be immediately reported to the Research Ethics Committee

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