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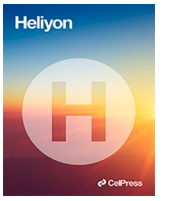

Occupational lead exposure health risk assessment and heme biosynthesis: A study on batik artisans in yogyakarta, Indonesia

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A R T I C L E I N F O

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A B S T R A C T

This study aims to assess dermal and inhalation lead exposure levels among batik industry workers and evaluate noncarcinogenic and carcinogenic health risks associated with lead exposure. We investigate potential relationships between lead exposure (dermal average daily dose and inhalation exposure concentration) and the workers' blood hemoglobin levels (Hb), as well as their urinary ALA (u-ALA) concentrations. Additionally, we explore any possible associations between Hb and u-ALA levels among the workers and identify various factors influencing lead exposure levels. A total of 30 workers were recruited for the study. Interviews and exposure sampling were conducted to measure dermal and inhaled lead exposure. Sample analysis methods include XRF for exposure samples, spectrophotometry for u-ALA, and HiCN colorimetric for Hb. Carcinogenic and noncarcinogenic risk assessments, correlation analysis, as well as ANOVA for factors analysis, were performed. The average dermal exposure dose and inhalation exposure concentration of lead were 6.53 ± 3.2 ng/kg/day and 0.021 ± 0.015 μg/m^3, respectively. Hazard Index (HI) values for all workers were below 1 (average: 0.372 ± 0.155), indicating no expected noncarcinogenic health effects due to lead exposure. The average Excess Lifetime Cancer Risk (ELCR) was $(5.18 \pm 3.84) \times 10^{-8}$, significantly below acceptable limits. Correlation analysis revealed a significant negative correlation between Hb and u-ALA ($r = -0.519$, $p = 0.058$ for male workers and $r = -0.531$, $p = 0.034$ for female workers), supporting their use as lead exposure biomarkers. The factors analysis demonstrated a significant impact of working conditions on inhalation exposure ($p = 0.018$), with outdoor workers experiencing lower lead inhalation. This research provides crucial insights into potential dangers faced by batik workers due to lead exposure, emphasizing the importance of targeted interventions. The strong correlation between Hb and u-ALA indicates their combined effectiveness in detecting lead exposure, even at low levels. The study underscores the significance of outdoor work as a protective measure against inhaling heavy metals, such as lead, present in the air. The assessment of health risks

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associated with lead exposure in the batik industry lays the groundwork for informed decision-making and interventions to protect workers' well-being, particularly in informal sectors workplaces where health risks are often overlooked.

1. Introduction

1.1. Background

Heavy metal pollution in the environment is caused by human utilization in many processes. The increase of industrial activities is a factor that causes hazardous materials that may result in heavy metal pollution in the environment, as found in wastewater or gas/particulate emission. The presence of toxic heavy metals in the environment increases worries about increasing human health risks and environmental impacts.

In the batik coloring process, both natural and synthetic colorants can be used. However, the use of synthetic colorants is often preferred for its cheap price and a broad choice of colors to develop batik patterns and designs. Synthetic colorants used in the batik coloring process contain some heavy metals. In previous study, we found that the dominant synthetic dyes used in the batik production in the study area were remazol, naphthol, and indigosol, and the heavy metals detected were Cu, Zn, Ni, Al, Fe, and Pb [1].

Several studies have explored the presence of heavy metals in the batik industry, focusing on wastewater [2,3], dyestuffs [1], and impact on water bodies and biota [4,5]. Previously, a research have confirmed the dermal exposure of lead among batik industry workers [1]. However, a notable gap in the literature remains regarding the assessment of health risks specifically associated with lead exposure in this occupational setting. This research aims to bridge this knowledge gap by conducting a risk assessment and investigating the specific health effects related to each chemical hazard present in the batik industry. By delving into the health risks associated with occupational exposure to lead, this study aims to start shedding light on the often-overlooked health hazards faced by workers in informal economic sectors like the batik industry. The goal is to move beyond the mere confirmation of the presence of health and environmental hazards and to establish a deeper understanding of the current state of health risks in this domain. The insights gained from this research can inform targeted interventions and enhance occupational health practices in the batik industry and similar settings.

In the Batik Industry, artisans possess unique expertise and are assigned to one of three specific artistry works: *celup* (dipping), *cap* (stamping), and canting (*pattern making*). *Celup* workers secure blank clothes and immerse them into textile colorants, allowing colored patterns to develop as the clothes dry. *Cap* workers utilize large stamp tools with fixed patterns to create batik designs on the clothes. *Canting* workers, on the other hand, manually draw patterns using a pen-like tool called a *canting*, employing a wax-resistant method.

Protecting the health of batik industry workers presents challenges due to the industry's informal nature, and the awareness of occupational health risks is limited among workers and owners alike. Exposure to lead in batik industry workers can occur through dermal contact and inhalation. Workers may come into contact with lead from colorants during the dipping, *canting*, or stamping processes. Additionally, the preparation and handling of colorants can produce vapor and dye dust that workers may inhale.

Lead (Pb) is one of five heavy metals (As, Cd, Cr, Pb and Hg) that are prioritized to be controlled in public health issues for their high toxicity and persistence [6,7]. Lead is a well-known toxic heavy metal that can have detrimental effects on various organs in the human body. Upon exposure, lead can accumulate in bones, kidneys, liver, and the central nervous system [8], leading to both acute and chronic health implications. Studies have shown that lead exposure can result in neurological disorders, such as cognitive impairment [9], developmental delays in children [10], and neurobehavioral abnormalities [11]. Additionally, lead has been associated with hematological disorders [12], as well as causing DNA damage and impairing the immune system [13].

Exposure and intake of lead in the human body may also cause inhibition of several steps in the heme biosynthesis process, which is critical in red blood cell formation. Lead inhibits the activity of delta-aminolevulinic acid dehydratase (ALAD) enzyme and also impairs the activity of intramitochondrial ferrochelatase enzyme, which has a role in Fe metal binding process in heme [14]. Some common effect biomarkers of lead exposure are blood zinc protoporphyrin (ZPP), delta-aminolevulinic acid in urine, blood, and plasma (ALA-U, ALA-B, and ALA-P), and urinary coproporphyrin (CP) [15].

ALAD enzyme activity is sensitively disrupted by lead intake. ALAD is an enzyme that catalyzes the molecule condensation of delta-aminolevulinic acid (ALA) into monopyrrole porphobilinogen (PBG). The ALA condensation rate into PBG will decrease even in low blood lead concentration (5 μg/dL), and a reduction of activity to 50% occurs on B–Pb concentration of >20 μg/dL [16]. Pregnant women are more susceptible to the reduction of ALA condensation rate due to lead exposure, as low as B–Pb concentration of 2.2 μg/dL [15].

A reduction of ALA condensation rate will increase blood ALA concentration, which is related to the formation of reactive oxygen species (ROS) and causes oxidative damage [17]. Blood ALA will then undergo elimination through urine. In summary, lead exposure to humans will further cause anemia along with elevated BLL (blood lead level) and increased u-ALA (urine ALA).

Lead is also classified as probable carcinogenic (Group 2A) based on the U.S. EPA (United States Environmental Protection Agency) and IARC (International Agency for Research on Cancer). One of the possible lead carcinogenicity mechanisms is related to the heme biosynthesis disruption by the formation of reactive oxygen species (ROS) caused by the increase of blood ALA concentration [17]. The reactive oxygen species (ROS) may impair the antioxidant defense mechanisms in cells, leading to oxidative stress. Prolonged exposure to oxidative stress can damage DNA, proteins, and lipids, potentially leading to the development of cancer [18]. In occupational settings, the carcinogenic risk is often overlooked for its imperceptible or delayed effects [19].

Measurement of the effect of lead exposure in humans can be done with biomarker testing. Biomarkers of lead exposure are often detected in blood, urine, or bone. Out of the three, lead concentration in blood and urine are more commonly used as exposure biomarkers of lead for the occupationally exposed group [16]. Blood biomarkers reflect recent exposure, and urine biomarkers indicate the body's response to lead exposure and its metabolism [14]. These biomarkers are sensitive and widely utilized due to their ability to provide valuable information on lead exposure levels. However, it is crucial to consider their limitations. False positives possibly occur if lead is stored in bones and gradually released [20], leading to elevated biomarker levels even after exposure has ceased. False negatives may arise if biomarkers fail to capture intermittent or recent high exposures [21]. Nonetheless, the utilization of these biomarkers, both as indicators of exposure and effect, can prove valuable in assessing workers' lead exposure levels [14,22].

Studies assessing heavy metals and human health risks from the exposure have provided valuable insights into potential health hazards in various settings. A recent study in the Mekong Delta evaluated groundwater quality and found heavy metal contamination, posing health risks, both carcinogenic and noncarcinogenic [23]. Given the occupational context of the batik industry and its potential for lead exposure, conducting a comprehensive health risk assessment becomes crucial to safeguard the well-being of workers. By employing similar methodologies, our research aims to estimate the health risks of workers in this artisan occupational setting due to chronic occupational exposure to lead through dermal and inhalation exposure routes. The study also seeks to determine the relationship between lead exposure and heme biosynthesis using a cross-sectional epidemiology study approach. The X-Ray Fluorescence (XRF) method was used to analyze retained heavy metals in the filter, while hemoglobin and urinary ALA of the workers were examined as biomarkers of lead exposure.

1.2. Objectives

The main objectives of this study are to assess the levels of dermal and inhalation lead exposure among batik industry workers and to evaluate both noncarcinogenic and carcinogenic risks associated with lead exposure in this occupational setting. Additionally, we aim to investigate potential relationships between lead exposure (measured as dermal average daily dose and inhalation exposure concentration) and the workers' blood hemoglobin levels, as well as their urinary ALA (u-ALA) concentrations. Furthermore, we aim to explore any possible associations between blood hemoglobin levels and urinary ALA (u-ALA) concentrations among the workers. Lastly, the study aims to identify and analyze various factors that may influence the lead exposure levels experienced by these batik industry workers.

2. Materials and methods

2.1. Sample and data collection

Thirty workers (16 female workers and 14 male workers) were randomly sampled from three batik industries located in the same district. The research population consisted of all workers (N = 70) employed in the three batik industries included in this study, with a total of 37 female workers and 33 male workers. we selected a sample size of 30 batik industry workers, adhering to ethical standards, and ensuring voluntary participation. Additionally, we followed the NIOSH occupational exposure sampling strategy manual, which considers a sample size of 30 to be adequate for a confidence level of 0.95, capturing the top 10% risk of the workers [24]. To enhance representation, we made efforts to ensure an equal distribution of gender and industry origin among the sampled workers. The study location is shown in Fig. 1.

Out of the thirty workers sampled for this study, eleven workers were selected from the first batik industry, ten from the second, and nine from the last. The aim was to maintain a proportional representation of workers from each industry. However, the final distribution depended on the voluntary participation of the workers. Data for analysis were collected through interviews (Table 1), and biomarker data were acquired through urine and blood sample collection. Lead exposure data on workers through dermal and

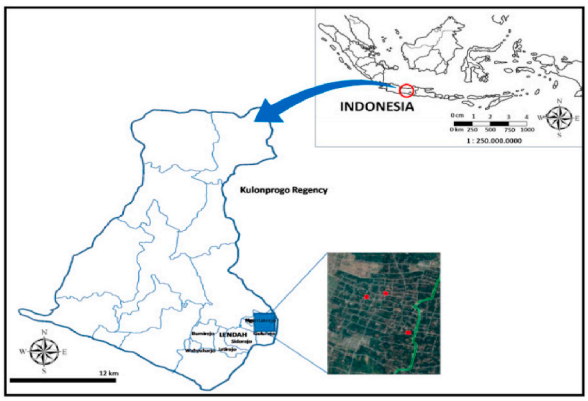

Fig. 1. Location of the study.

inhalation routes were also collected.

A simple observation method was employed during the data collection process. We visited each participant's workplace and conducted direct observations to determine the specific working conditions. The working space type was categorized into three groups: indoor, outdoor, and semi-outdoor, based on the physical characteristics of the workspace and its exposure to external environmental factors. The data was recorded for all participants, considering its relevance in analyzing the potential influence of different working environments on exposure levels.

In the interview, several key questions were asked to gather relevant data for the research objectives. The questions pertaining to age, work experience, and work division were included to categorize the workers into different groups, enabling further analysis using ANOVA to explore potential differences in exposure levels among various categories. On the other hand, data on weight, working days per week, and working hours per day were collected to facilitate the calculation and estimation of parameters required for conducting the health risk assessment.

Air sampling was conducted in the workers' breathing zone using a personal sampler pump to estimate the inhaled lead concentration while working. The personal sampler pump, known for its portability, was conveniently carried in a small waist bag worn by each worker. The air sampling pipe's receiving end was strategically located around the workers' chin by attaching them to the collar of workers' attire, capturing the air they breathe while performing their tasks in the batik industry. This approach ensured that the collected air samples accurately represented the workers' breathing zone, allowing for a reliable estimation of their lead exposure levels. Based on NIOSH 7300 issue 2 [25], sampling of metals in the air may be conducted using a personal sampler pump with a Mixed Cellulose Ester (MCE) filter Ø 25 mm with a pore size of 0.8 μm. The personal sampling pump type used in this study is the HFS-513A. The personal sampling pump draws in air around the worker's breathing zone, and then the metals in the air will be retained on the Mixed Cellulose Ester (MCE) filter.

Dermal exposure sampling was also conducted using Mixed Cellulose Ester (MCE) filters Ø 25 mm with a pore size of 0.8 μm. Filters were attached to potentially exposed body parts (forehead, the back of both hands, and both feet). After 4 h, each MCE filter was stored in a Petri dish sealed with parafilm. The dishes were then stored inside a box filled with silica gel and placed at room temperature.

The collection of blood samples was conducted by hired trained phlebotomists, following standard procedures to ensure accuracy and minimize discomfort to the participants. The blood samples were drawn from the workers' arm veins using sterile needles and evacuated blood collection tubes. The collected blood samples were then appropriately labeled and transported to the laboratory for further analysis.

For urine sample collection, the workers were provided with clean, leak-proof urine containers and instructed on the proper procedure for sample collection. The workers were advised to collect a mid-stream urine sample to obtain the most representative urine composition. To ensure consistency, all participants were asked to collect their urine samples during their regular working hours to capture exposure levels during their typical workday.

Ethical considerations were strictly adhered to throughout the sample collection process, and informed consent was obtained from all participants. Additionally, the study protocol was approved by the relevant institutional review board or ethics committee to ensure compliance with ethical guidelines and safeguard the participants' rights and well-being.

2.2. Sample analysis

Pb retained on MCE filters was analyzed in the laboratory using XRF (X-Ray Fluorescence) method with PANalytical AXIOS XRF Spectrometer. Prior to analysis, rigorous calibration procedures were conducted using certified reference materials with known lead concentrations to establish accurate and reliable calibration curves. Additionally, quality assurance procedures, including repeated measurements of standard samples and analysis of blank samples, were employed to ensure the precision and accuracy of the analytical results. The collected filters were carefully cleaned and dried to eliminate potential contaminants, and then securely mounted on sample holders for analysis. X-rays were irradiated onto the filters, causing characteristic X-ray fluorescence emission from lead particles. The emitted X-rays were detected and quantified by the spectrometer, enabling the determination of lead concentration in each filter sample. These calibration and quality assurance measures were undertaken to ensure the validity and reproducibility of the XRF analysis results.

Urinary ALA (u-ALA) concentration was determined using a simple spectrophotometry method developed by Tomokuni et al. [26]. The spot urine sample from batik workers were diluted threefold with distilled water. The 2-methyl-carbethoxy-4-(3-propionic acid) pyrrole, produced by the condensation of delta-aminolevulinic acid with methyl acetoacetate is determined colorimetrically by treating an aliquot of the extract with a modified Ehrlich's reagent [26].

Table 1
Interview questions.

No	Question
1	Age
2	Body Weight
3	Work Division
4	Work Experience
5	Working days/week
6	Working hours/day

Hemoglobin levels was determined using the HiCN (Hemoglobin Cyanide) colorimetric method. The HiCN reagent was added to the blood samples, and the resulting color change was measured using a spectrophotometer or colorimeter. The absorbance of the colored solution was compared to a calibration curve with known hemoglobin concentrations to determine the hemoglobin levels accurately. This method provides a reliable and cost-effective approach for assessing hemoglobin levels, allowing for the evaluation of potential health effects related to lead exposure among batik industry workers in this study.

2.3. Dose and risk calculation

Exposure data were then processed to acquire the exposure dose in accordance with health risk assessment method. Evaluation of human exposure to heavy metals refers to the Risk Assessment Guidance for Superfund Vol. I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment and Part F, Supplemental Guidance for Inhalation Risk Assessment) [27,28]. Equations (1) and (2) are used accordingly to calculate averaged exposure dose, and equations (3)–(8) are used to evaluate the risk associated with the dose. All the equations used are taken from the Risk Assessment Guidance.

$$ADD = (D\mathrm{Aday} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{SA} \times \mathrm{ABS})/(\mathrm{BW} \times \mathrm{AT}) \quad (1)$$

$$\mathrm{EC} = (\mathrm{CA} \times \mathrm{E}T \times EF \times ED)/AT \quad (2)$$

ADD = Average Daily Dose (mg/kg.day)
DAday = Dose Available in a Day (mg/cm2.day)
ED = Exposure Duration (year)
EF = Exposure Frequency (day/year)
SA = Skin Area (cm2)
ABS = Dermal absorbance factor (1%)
BW = Body Weight (kg)
AT = Averaging Time (day)
EC = Exposure Concentration (μg/m3)
CA = Measured Concentration in Air (μg/m3)
ET = Exposure Time (hour/day)

$$\mathrm{HQd} = \mathrm{ADDnc}/\mathrm{RfD} \quad (3)$$

$$\mathrm{HQi} = \mathrm{EC}_{\mathrm{nc}}/\mathrm{RfC} \quad (4)$$

$$\mathrm{HI} = \mathrm{HQ}_{\mathrm{d}} + \mathrm{HQ}_{\mathrm{i}} \quad (5)$$

HQ_d = Dermal Hazard Quotient.
HQi = Inhalation Hazard Quotient.
HI = Hazard Index

$$\mathrm{ELCRd} = \mathrm{ADDc} \times \mathrm{CSF} \quad (6)$$

$$\mathrm{ELCRi} = \mathrm{ECc} \times \mathrm{IUR} \quad (7)$$

$$\mathrm{ELCRt} = \mathrm{ELCR}_{\mathrm{d}} + \mathrm{ELCR}_{\mathrm{i}} \quad (8)$$

ELCRd = Excess Lifetime Cancer Risk, dermal.
CSF = Cancer Slope Factor.
ELCRi = Excess Lifetime Cancer Risk, inhalation.
IUR = Inhalation Unit Risk.
ELCRt = Excess Lifetime Cancer Risk, total.

In health risk assessment study, the estimation of non-carcinogenic risk is carried out in the risk characterization stage by calculating the hazard index (HI), and the carcinogenic risk by calculating the excess lifetime cancer risk (ELCR). The risk values are determined first for each exposure route, then summed to determine the aggregated risk [28].

2.4. Statistics

In this study, both descriptive and inferential statistical analyses were employed to gain insights into lead exposure in workers and to assess the relationships between exposure and biomarker responses. For the analysis of lead exposure in workers, we utilized Pearson correlation tests to examine the associations between dermal and inhalation exposure levels and the corresponding biomarker responses, namely hemoglobin and urinary ALA concentrations. Additionally, we conducted Pearson correlation analysis between hemoglobin and urinary ALA levels to explore potential interrelations between these biomarkers.

Furthermore, to investigate the potential influence of various factors on lead exposure levels and biomarker responses, we employed analysis of variance (ANOVA). This analysis was conducted to assess the impact of different factors, such as working

conditions, working division, and work experience, on lead exposure among the workers.

The selection of these specific statistical tests was based on their appropriateness to address the research objectives and investigate the relationships between exposure and biomarker responses. Pearson correlation analysis allows for the examination of linear associations between continuous variables, making it suitable for assessing the strength and direction of relationships between lead exposure and biomarkers. ANOVA, on the other hand, facilitates the comparison of means among different groups, making it well-suited to explore potential differences in lead exposure levels based on various factors.

All statistical analyses were performed using the SPSS Version 22 (SPSS 22.0) software, and a significance level of $\alpha = 0.05$ was applied throughout to assess statistical significance.

3. Results and discussion

3.1. Interview result

All 30 workers recruited for this study answered the survey questions in Table 1. The summary for the survey questions result are shown in Table 2.

The respondents' age ranged from a minimum of 19 years to a maximum of 70 years, with a mean age of 40 years (SD = 14.84), indicating a diverse age distribution among the participants. The survey also captured respondents' body weight, which is a required information when performing risk assessment, ranging from a minimum of 42 kg to a maximum of 73 kg, with a mean weight of 56.1 kg (SD = 8.22). Participants reported a range of work experience, from a minimum of a half year to a maximum of 11 years, with an average of 4.4 years (SD = 2.85), reflecting the varying levels of professional experience in batik industry among the respondents. 21 of 30 respondents work 6 days a week while 9 respondents who are originated from a certain batik industry work everyday each week. All of the respondents are involved in their own division's work at least 8 h a day. These informations provide important insight in estimating the individual exposure as well as investigating potential significant factors to control in order to manage the risk.

3.2. Exposure assessment

The calculation of ADD (Average Daily Dose) and EC (Exposure Concentration) involves the use of Equations (1) and (2) respectively. The values for DA_{day} (Dose available in a day) and CA (Chemical Concentration in Air) were obtained through exposure sampling, using dermal patches and personal samplers, as described in the Methods section. The laboratory analysis results of the samples are presented in Table 3.

Two categories of ADD and EC were calculated for risk characterization: noncarcinogenic (ADD_{nc} and EC_{nc}) and carcinogenic (ADD_c and EC_c). The main difference between the two categories of ADD and EC is the AT (Averaging Time) used in the calculation. In noncarcinogenic ADD and EC, The approach is to even out the exposure received by the workers throughout the times when they work (EF × ED) to each day of their years working in batik industry (AT). In carcinogenic ADD and EC, the AT is fixed to (70 years × 365 days/year), standardized lifetime years according to the Risk Assessment Guidance [27,28]].

EF, BW, and ET are acquired through survey questions. Skin Area (SA) value was taken from The US EPA Supplemental Guidance for Dermal Risk Assessment [27], which informs body part-specific surface area calculations. In this case, the workers' body parts that were assumed to be potentially exposed at work are face, forearm, hands, and feet, based on observation of the workers' daily work attire. Using this assumption and the guidance, the value of 3704 cm2 is used for calculation.

Table 4 summarizes the results of exposure assessment, namely the Average Daily Dose (ADD) and Exposure Concentration (EC), both for carcinogenic and noncarcinogenic risk characterization (see Figs. 2 and 3).

The calculated average dose and concentration for noncarcinogenic characterization (ADD_{nc} and EC_{nc}) are approximately ten times higher than their carcinogenic parameter counterparts. This difference in averaging time used in the calculation could account for these contrasting values. The carcinogenic parameters (ADD_c and EC_c) are dependent on the worker's working period or experience (ED), while the noncarcinogenic parameters depend on the proportion of working days to total days in the worker's years of employment (ED/AT). Consequently, the values of the carcinogenic exposure parameters will continuously increase as the workers receive daily exposure while working in the batik industry, indicating the long-term carcinogenic effects of lead exposure.

3.3. Risk characterization

The output for noncarcinogenic and carcinogenic risk characterization is the Hazard Index (HI) and Excess Lifetime Cancer Risk

Table 2
Survey questions answer summary.

	Min.	Mean	Max.	SD.
Age	19	40	70	14.84
Body weight (kg)	42	56.1	73	8.22
Experience (years)	0.5	4.4	11	2.85
Working days/week	6	6.3	7	0.47
Working hours/day	8	8	8	0

Table 3
DA_{day} and CA result.

	DA_{day} ($\times 10^{-6}$ mg/cm^2.day)	CA (μg/m^3)
Max	23.95	0.196
Min	2.11	0.001
Mean	11.72	0.077
SD.	5.81	0.053

The DA_{day} parameter indicates the mass of lead retained in filters used in dermal exposure sampling throughout the sampling period. The values ranged from 2.11 to 23.95 ng/cm^2.day, with a mean ± SD value of 11.72 ± 5.81 ng/cm^2.day. On the other hand, the CA parameter represents the average lead concentration in the air that workers inhaled. The values ranged from 0.001 to 0.196 μg/m^3, with a mean ± SD value of 0.077 ± 0.053 μg/m^3.

Table 4
Exposure assessment summary.

	ADD_{nc} (mg/kg/day)	EC_{nc} (μg/m^3)	ADD_c (mg/kg/day)	EC_c (μg/m^3)
Max	1.39×10^{-5}	0.061	1.27×10^{-6}	0.0058
Min	1.42×10^{-6}	4.3×10^{-4}	2.09×10^{-8}	2.42×10^{-5}
Mean	6.53×10^{-6}	0.021	4.19×10^{-7}	0.0013
SD.	3.20×10^{-6}	0.015	3.49×10^{-7}	0.0014

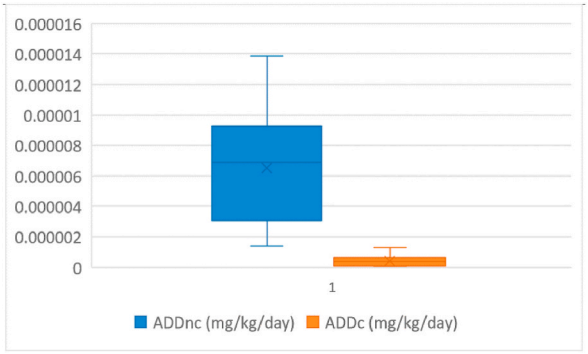

Fig. 2. Average daily dose results Boxplot.

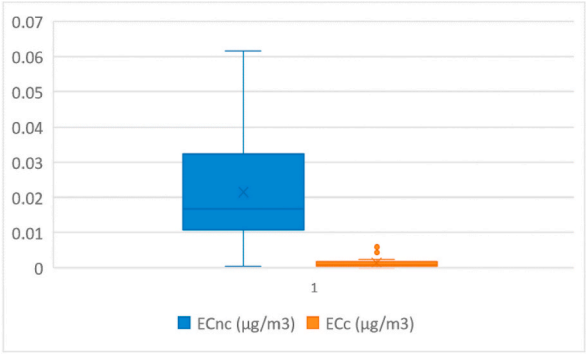

Fig. 3. Exposure concentration results Boxplot.

(ELCR), rescpectively. Prior to 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 effect, often derived from toxicology experiments' 'No Observed Adverse Effect Level' (NOAEL) [29]. For characterizing carcinogenic risk, similar values are used, called the Cancer Slope Factor (CSF) and the Inhalation Unit Risk (IUR). These values represents the estimated increase in cancer risk per unit of exposure to a carcinogenic substance [30] and is used to estimate the probability of developing cancer at different exposure levels. Table 5 shows the RfD, RfC, SF, and IUR values used for the calculation of the risks.

3.3.1. Noncarcinogenic risk

The HQ (Hazard Quotient) is the ratio between the noncarcinogenic exposure level (ADD_{nc} and EC_{nc}) and the reference value. Meanwhile, the HI (Hazard Index) is the total sum of HQs from different exposure pathways. In risk analysis, this summation or aggregation is carried out to determine the total risk of all exposure pathways.

Result of Lead Hazard Quotient and Index calculation for all workers using Eq. (3) to Eq. (5) is summarized in Table 6 and shown in a diagram in Fig. 4 and Fig. 5.

HI serves as a valuable tool in risk assessment, enabling the evaluation of potential health effects resulting from simultaneous exposure to multiple chemicals [27,28], as in this case, a chemical with multiple exposure pathways. Table 6 presents the average values of HQ_d, HQ_i, and HI as 0.228 ± 0.112, 0.143 ± 0.103, and 0.372 ± 0.155, respectively. Although HQ_d tends to be higher than HQ_i on average, not all workers exhibit this condition. The maximum recorded HI value is 0.659, and Fig. 1 illustrates that all workers' HI values are below 1. An HI value below 1 indicates that the exposure is below the reference dose/reference concentration derived from the 'No Observed Adverse Effect Level (NOAEL)' in toxicology tests. Therefore, an HI value below 1 suggests that there is no expectation of severe health effects resulting from exposure to the assessed substances. It indicates that the combined exposure to the considered chemicals is unlikely to pose a significant risk to human health.

However, it is important to note that the reported hazard index value pertains only to lead exposure. The average lead HI (0.372 ± 0.155) raises concerns about the possibility of a more adverse condition since batik workers are exposed to various other metals [1]. Therefore, exposure to lead alone at this level is unlikely to cause severe noncarcinogenic health effects, such as hematotoxic, neurotoxic, or organotoxic effects [32,33], in any of the workers in this study. However, the combined risk effect of lead and other metals, which requires future assessment, may cause such effects.

3.3.2. Carcinogenic risk

Excess Lifetime Cancer Risk (ELCR) is a critical parameter used in risk assessment to estimate the potential increase in cancer incidence within a population due to exposure to specific carcinogens or hazardous substances over a lifetime. It represents the excess number of cancer cases expected to occur above the baseline cancer rate in an exposed population.

Result of ELCR calculation for all workers using Eq. (6) to Eq. (8) is summarized in Table 7 and shown in a diagram in Fig. 6 and in a boxplot in Fig. 7.

Table 7 presents the average values of $ELCR_d$, $ELCR_i$, and $ELCR_t$ as $(3.56 \pm 2.96) \times 10^{-8}$, $(1.61 \pm 1.75) \times 10^{-8}$, $(5.18 \pm 3.84) \times 10^{-8}$, respectively. Similar to hazard quotient result, the excess cancer risk associated with dermal exposure ($ELCR_d$) appears to be higher than inhalation exposure ($ELCR_i$) on average. Unlike the HI, there are differences of the acceptable limit of ELCR used in studies, which depends on the specific context and regulatory guidelines in different countries. For instance, the United States Environmental Protection Agency (EPA) generally considers an ELCR of 1 in 1 million (1×10^{-6}) as an acceptable risk level for regulatory decision-making in environmental assessments. This means that if the estimated ELCR from exposure to a particular substance is below 1 in 1 million, it is considered an acceptable risk [34]. The '1 in 1 million' limit means less than one extra cancer case per one million people is acceptable. A more recent study and discussion [35] proposed an even higher excess cancer risk (up to 10^{-3}) as an acceptable limit for occupational settings. This suggestion takes into account the relatively small number of the population in occupational settings and is based on a review of international policies.

Hence, even the reported highest value of the total Excess Lifetime Cancer Risk ($ELCR_t$) at 1.29×10^{-7}, which can be roughly interpreted as an estimated additional 1.29–2 cases per ten million (10^7) people, may be deemed acceptable. Furthermore, none of the individual total ELCR values reported for the workers approached the acceptable limit. As mentioned in the previous part, it is essential to emphasize that the reported Excess Lifetime Cancer Risk (ELCR) pertains exclusively to lead exposure. However, when comparing it to the noncarcinogenic risk, the observed excess cancer risk associated with lead exposure raises fewer concerns about the overall carcinogenic risk in the batik industry exceeding the acceptable limit. Nevertheless, it is crucial to recognize that the actual combined carcinogenic risk effect of lead and other metals might lead to different conclusions regarding the level and acceptability of the excess cancer risk in the batik industry.

3.4. Hemoglobin and urinary ALA test result

The test results of hemoglobin (Hb) and urinary δ-aminolevulinic acid (u-ALA) levels among the batik industry workers are presented in Table 8. The collected data includes maximum, minimum, mean, and standard deviation (SD) values for both Hb and u-ALA. Additionally, boxplots are provided to visualize the distribution of these biomarkers (see Figs. 8 and 9).

The analysis of hemoglobin levels in the workers' blood showed an average concentration of 15.3 ± 1.6 g/dL for males, with a minimum value of 11.2 g/dL, and an average concentration of 13.1 ± 1.3 g/dL for females, with a minimum value of 9.5 g/dL. The

Table 5
Lead RfD, RfC, SF, and IUR.

No	Parameter	Value	Units	Reference
1	RfD Pb	2.9×10^{-5}	mg/kg.day	Pavilonis et al., 2017 [31]
2	RfC Pb	0.00015	mg/m^3	
3	CSF Pb	0.085	$(mg/kg.day)^{-1}$	
4	IUR Pb	1.2×10^{-5}	$(mg/m^3)^{-1}$	

Table 6
Noncarcinogenic risk summary.

	HQ_d	HQ_i	HI
Max	0.485	0.411	0.659
Min	0.050	0.003	0.102
Mean	0.228	0.143	0.372
SD.	0.112	0.103	0.155

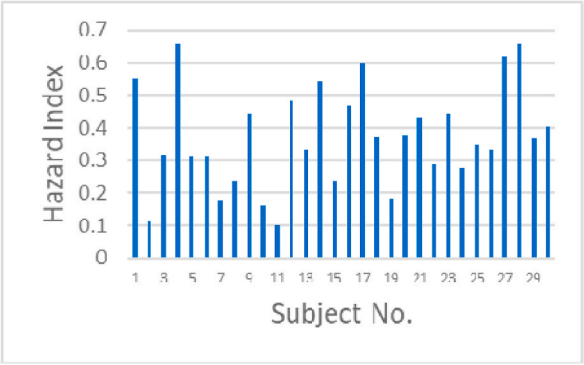

Fig. 4. Lead hazard index diagram.

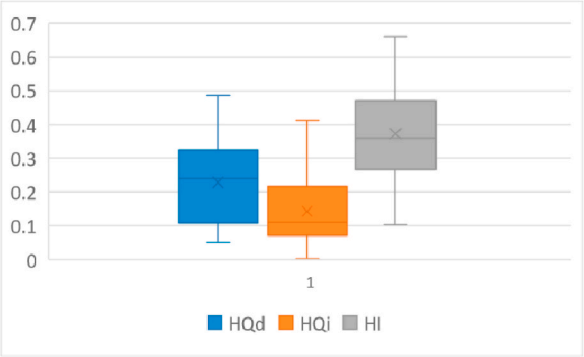

Fig. 5. Noncarcinogenic risk Boxplot.

Table 7
Carcinogenic risk summary.

	$ELCR_d$	$ELCR_i$	$ELCR_t$
Max	1.08×10^{-7}	7.08×10^{-8}	1.29×10^{-7}
Min	1.78×10^{-9}	2.91×10^{-10}	3.59×10^{-9}
Mean	3.56×10^{-8}	1.61×10^{-8}	5.18×10^{-8}
SD.	2.96×10^{-8}	1.75×10^{-8}	3.84×10^{-8}

normal range for hemoglobin concentrations in adult males typically falls between 14 and 18 g/dL, while for adult females, it ranges from 12 to 16 g/dL [36]. Notably, two male workers and one female worker exhibited hemoglobin levels below the reference values.

Regarding the aminolevulinic acid (ALA) content in the urine of the batik workers, the analysis revealed an average concentration of 4.164 ± 2.139 mg/L. The reference values for urinary ALA were obtained from a medical study conducted by Lane et al. [37]. The normal category for urinary ALA is below 6 mg/L, and concentrations in the range of 6–20 mg/L are considered higher than normal but still deemed acceptable and tolerable. Conversely, urinary ALA concentrations exceeding 20 mg/L are considered excessive. The analysis indicated that six workers had urinary ALA concentrations surpassing the normal range, while the remaining workers had normal urinary ALA levels.

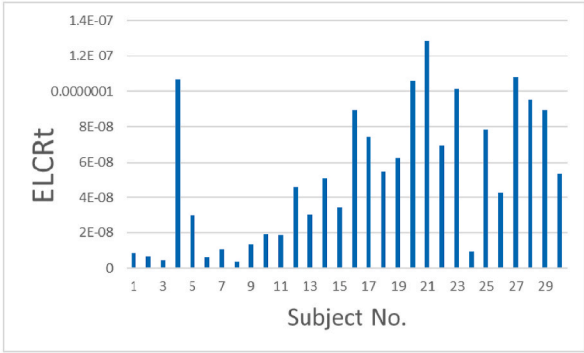

Fig. 6. Excess lifetime cancer risk diagram.

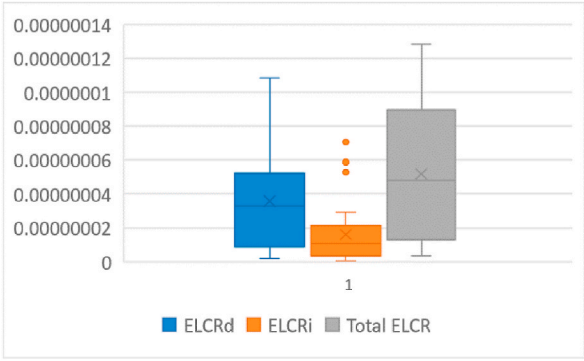

Fig. 7. Carcinogenic risk Boxplot.

Table 8
Hb and u-ALA Test Result.

	Hb (M)	Hb (F)	u-ALA
Max	16.8	15.1	7.821
Min	11.2	9.5	0.061
Mean	15.3	13.1	4.164
SD.	1.6	1.3	2.139

3.5. Correlation analysis of intake – u-ALA

Pearson correlation was used to determine the relationship between ADD_{nc} and u-ALA, as well as EC_{nc} and u-ALA. The results of statistical analysis using SPSS software are shown in Table 9 below.

The correlation coefficients for the relationship between u-ALA & ADD and u-ALA & EC were 0.239 and 0.015, respectively, both of which were positive, indicating a unidirectional relationship between ADD and u-ALA, as well as between EC and u-ALA. These results suggest that higher levels of dermal exposure and inhalation exposure concentration correspond to higher concentrations of ALA detected in urine. However, the values of r are quite small and close to 0. The 2-tailed significance (sig.) value for the ADD-u-ALA correlation is 0.204, and for the EC-u-ALA correlation, it is 0.94, both of which are greater than 0.05, the significance level (α) used in this study. Therefore, these sig. values indicate that the correlations between ADD & u-ALA and EC & u-ALA are not statistically significant. In other words, the observed associations between dermal exposure (ADD) and urinary ALA, as well as between inhalation exposure concentration (EC) and urinary ALA, could have occurred by chance. The low R^2 values obtained further indicate that the parameters of ADD_{nc} and EC_{nc} can only explain about 5.7% and 0.023% of the u-ALA data, respectively.

In conclusion, the relationship between ADD-u-ALA and EC-u-ALA is weak. This result can be explained in two ways. Firstly, the risk characterization showed that all workers' Hazard Index (HI) values were <1, meaning there are no expected noncarcinogenic health effects due to exposure. It is possible that the exposure levels have not reached the dose and concentration that causes significant differences between workers with high and low doses, leading to a lack of linear relationship (correlation) found between intake and u-ALA as a biomarker of noncarcinogenic health effects.

Furthermore, lead exposure has been shown to sensitively and stoichiometrically inhibit ALAD enzyme activity in blood [38].

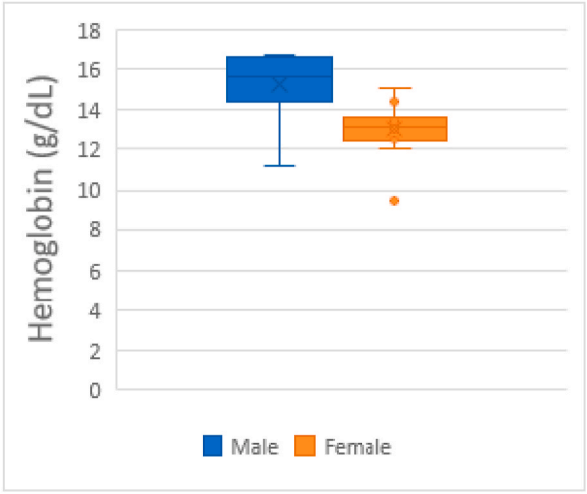

Fig. 8. Hemoglobin result Boxplot.

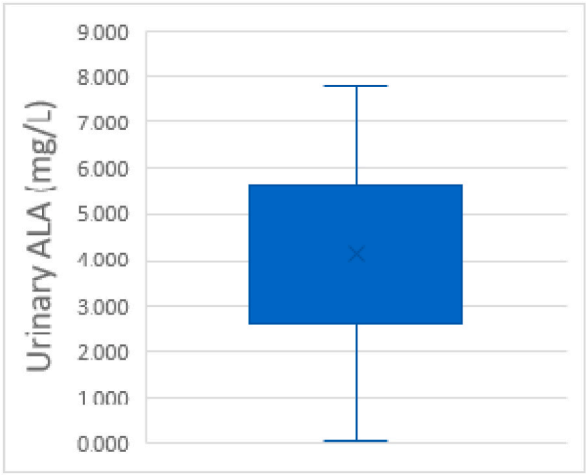

Fig. 9. Urinary ALA Boxplot.

Table 9
Intake – u-ALA Correlation.

Correlation	r	Sig.	R^2
ADD – u-ALA	0.239	0.204	0.0571
EC – u-ALA	0.015	0.94	0.00023

Consequently, δ-aminolevulinic acid, which is normally involved in heme synthesis through dehydration reactions, accumulates and undergoes oxidation instead of being properly dehydrated, unless eliminated through urine [39]. While ALAD enzyme activity serves as a sensitive indicator for low lead exposure (showing a decrease in activity even at BLL as low as 10 g/dl [40]), an increase in urinary ALA concentration may not be as sensitive since not all δ-aminolevulinic acid is excreted through urine. Nonetheless, during the examination of workers' u-ALA levels, it was observed that six individuals exhibited u-ALA concentrations above normal levels, although still falling within the acceptable category.

3.6. Correlation analysis of intake – Hb

Pearson correlation was used to determine the relationship between ADD_{nc} and Hb, as well as EC_{nc} and Hb. The results of statistical processing using SPSS software are shown in Table 10 below.

For the relationship between ADD and Hb, the correlation coefficients were −0.018 for male workers and −0.5 for female workers.

Both coefficients showed a negative relationship, indicating an inverse association between ADD and Hb. However, the 2-tailed significance (sig.) values for the ADD-Hb correlation were 0.952 for male workers and 0.048 for female workers, suggesting that no significant correlation was observed in male workers, while the correlation was significant in female workers (sig. $< \alpha$). The R^2 value revealed that the ADD parameter explained only about 0.03% of the Hb data in the male worker group, while in the female worker group, approximately 25% of the Hb data could be explained by ADD.

Similarly, for the relationship between EC and Hb, the correlation coefficients were −0.054 for male workers and −0.046 for female workers. Both coefficients showed a negative relationship, indicating an inverse association between EC and Hb. However, the 2-tailed significance (sig.) values for the EC-Hb correlation were 0.854 for male workers and 0.866 for female workers (sig. $> \alpha$), indicating no significant correlation between EC and Hb in both male and female worker groups. The R^2 value indicated that the EC parameter explained only about 0.21–0.29% of the Hb data in both male and female worker groups.

In terms of the relationship between Intake and Hb, as well as Intake and u-ALA, the overall correlation was found to be weak and insignificant. However, the weak and insignificant correlation aligns with the findings from the risk characterization results in the previous section, where the Hazard Index (HI) of all workers was <1, indicating no expected non-carcinogenic health effects due to exposure, including anemia characterized by low hemoglobin levels. While anemia is commonly considered an indicator of lead exposure, it is not prevalent unless lead poisoning is severe or there are comorbidities such as iron deficiency [41]. This is also consistent with the explanation provided in the previous section, indicating the weak relationship between intake and u-ALA, likely due to the lead exposure level in batik workers not being high enough to cause a detectable effect, such as increased u-ALA or a significant decrease in Hb.

Nevertheless, cases of anemia caused by chronic lead exposure have been extensively studied. Chronic lead exposure interferes with the enzymatic steps in hemoglobin synthesis [16,17], leading to an inhibition of hemoglobin production, which is related to u-ALA [14,15]. Moreover, lead absorption can cause iron deficiency and reduce the lifespan of red blood cells [42]. Among the batik workers in this study, two male workers and one female worker had hemoglobin levels below normal (<14 g/dL for males and <12 g/dL for females). The observed decrease in hemoglobin levels among some workers is a matter of clinical significance. Hemoglobin plays a crucial role in transporting oxygen throughout the body, and lowered levels may result in reduced oxygen-carrying capacity and potential anemia [41]. Anemia caused by chronic lead exposure can lead to various symptomps and health issue, including fatigue, weakness, and impaired cognitive function [9], negatively impacting the workers' overall health and work performance.

To conclude, the correlation analysis revealed statistically insignificant and weak associations between lead exposure and hemoglobin levels in the studied workers. Thus, it would be premature to definitively attribute the low hemoglobin levels observed in three workers solely to lead exposure. Nonetheless, we cautiously encourage considering the observed low hemoglobin levels in the three workers as a potential effect of chronic lead exposure. It is essential to acknowledge the limitations of this part, primarily its cross-sectional design, which restricts our ability to infer causality. The study's snapshot approach may not capture the lifelong accumulation and concentration of lead exposure experienced by the workers. Thus, the observed low hemoglobin levels may be a result of chronic exposure over an extended period rather than a direct consequence of the current exposure levels measured in this study.

3.7. Correlation analysis of u-ALA – Hb

Pearson correlation was used to determine the relationship between u-ALA and Hb. The results of statistical analysis using SPSS software are shown in Table 11 below.

The correlation coefficients for the relationship between u-ALA and Hb in male and female workers were −0.519 and −0.531, respectively, both showing a negative inverse relationship between the two variables. A higher concentration of ALA detected in the urine was associated with a lower hemoglobin level in both male and female workers. Based on the significance (sig.) values, the 2-tailed sig. for the u-ALA – Hb correlation was 0.058 for the male worker group and 0.034 for the female worker group. The significance level used was 0.05. A significant correlation was observed between u-ALA and Hb in the female worker group only, while in the male worker group, the sig. value was close to the significance level. Therefore, it may be premature to conclude that there is no significant correlation in the male worker group due to the limited data size. The proximity of the significance level suggests that a larger data pool may yield a clearer confirmation of the strong negative correlation between the two variables among male workers as well. Therefore, it is important to acknowledge that the limited data size in the current study could have influenced the statistical outcome. As such, future research endeavors with a larger and more diverse sample of male workers could provide valuable insights into the comprehensive relationship between u-ALA and Hb. The R^2 values indicate that the u-ALA parameter explains about 26.9% and 28.2% of the Hb data in male and female workers, respectively.

To summarize, a robust correlation exists between ALA concentration in urine and hemoglobin levels. The negative correlation

Table 10
Intake – Hb correlation.

Correlation	r	Sig.	R^2
ADD – Hb (M)	−0.018	0.952	0.0003
ADD – Hb (F)	−0.5	**0.048***	0.25
EC – Hb (M)	−0.054	0.854	0.0029
EC – Hb (F)	−0.046	0.866	0.0021

Table 11
u-ALA – Hb Correlation.

Correlation	r	Sig.	R^2
u-ALA – Hb (M)	−0.519	0.058	0.269
u-ALA – Hb (F)	−0.531	**0.034***	0.282

aligns with the hypothesis of this study, which is supported by the underlying mechanism of heme biosynthesis inhibition due to lead exposure. This inhibition leads to the accumulation of ALA, resulting in its elimination through urine, leading to high u-ALA concentration and low hemoglobin levels [43]. These findings further support the presence of heme biosynthesis inhibition to some degree among batik industry workers.

The strong negative correlation observed between hemoglobin (Hb) levels and urinary ALA (u-ALA) concentration highlights the potential of these biomarkers as effective tools for detecting the presence of lead exposure in batik industry workers. The robustness of the correlation can be attributed to the clear underlying mechanism of heme biosynthesis inhibition caused by lead exposure. If lead exposure were not present, the correlation would not be strong and significant, as no inhibition of heme synthesis would occur. This strong correlation between Hb and u-ALA enhances the utility of these biomarkers in tandem, providing a valuable and sensitive means to detect lead exposure among workers in the batik industry. By recognizing the diagnostic potential of these biomarkers, early detection and timely intervention can be prioritized, ensuring effective safeguarding of workers' health and well-being. Consequently, implementing regular testing and monitoring of Hb and u-ALA levels can serve as a proactive measure to mitigate potential health risks associated with lead exposure and promote the overall health and safety of the workers in this occupational setting.

3.8. Factors analysis

Three factors potentially influencing exposure levels were observed: working condition, working type, and worker's personal work experience. The term 'working condition' refers to the type of room where the workers perform their tasks, categorized as indoor, semi-outdoor, or outdoor. 'Working type' pertains to the specific work in the batik-making process that the workers specialize in, including *cap* (stamping), *canting* (pattern painting), and celup (*dipping*). On the other hand, 'experience' refers to each worker's personal work history in the batik industry, specifically in their current work type. Workers are categorized into three groups or ranks, based on their experience: beginner (<3 years), intermediate (3–6 years), and expert (>6 years). This division in rank is based on the coaching system applied by the batik industry owners.

The rationale behind investigating these factors was to gain insights into potential strategies for improving worker health and safety. By examining the impact of working conditions, such as outdoor working systems or the presence of proper ventilation, we aimed to determine if specific adjustments could lead to health benefits for workers. The analysis of working type/division or division sought to identify whether certain divisions posed a higher risk of lead exposure, which could inform the implementation of a rotating work system to minimize exposure risk. Additionally, exploring the influence of work experience allowed us to assess if experienced workers demonstrated a heightened awareness of safe working practices, potentially highlighting the need for targeted training initiatives.

ANOVA was employed to assess the significance of differences between the means of exposure levels categorized by these factors and to explore potential interaction effects contributing to exposure levels. The dependent factor tested was the measured lead concentration in filters/patches used in inhalation and dermal exposure measurement. The ANOVA test results on the factors are summarized in Table 12 below.

The ANOVA test results on the factors revealed that almost all assessed factors and interactions had no significant effect on exposure, except for the working condition factor on inhalation exposure ($p = 0.018$). The average inhaled lead concentration for indoor, semi-outdoor, and outdoor workers was 0.0864 μg/m^3, 0.0939 μg/m^3, and 0.0242 μg/m^3, respectively. The semi-outdoor workers' group had the highest maximum inhalation concentration (0.19 μg/m^3), while the outdoor workers' group had the lowest (0.001 μg/m^3). Thus, it can be concluded that outdoor workers experience significantly lower inhalation exposure levels compared to indoor and semi-outdoor workers. Benjamin et al. [44] found that ventilation reduces volatile organic compound exposure in the workplace, and Murga et al. [45] reported that increasing airflow can decrease indoor pollutant concentrations up to 91%. When batik workers perform their tasks outdoors, pollutants containing lead may disperse, leading to lower concentrations. However, no significant effect of working condition was found on dermal exposure.

Initially, it was hypothesized that differences in the type and quantity of chemicals/dyes used in each work process contribute to variations in exposure levels. However, working type, which includes stamping, pattern painting, and dipping processes, was found to have no significant effect on inhalation and dermal exposure.

Regarding the experience factor, it was initially presumed that experts would have more knowledge on working safely compared to intermediate and beginner workers, leading to significant differences in exposure levels between experience groups. However, experience was also found to have no significant effect on inhalation and dermal exposure.

3.9. Risk management

Considering the HI value below 1 for the entire sampled worker population, the immediate need for risk management may not be urgent. Nevertheless, given the uncertainties and potential underestimation of risks, coupled with the possibility of additional risks

Table 12
ANOVA on factors.

No	Factor	Dependent	Sig.
1	Working Condition	**Inhalation**	**0.018***
		Dermal	0.15
2	Working Type	Inhalation	0.144
		Dermal	0.862
3	Experience	Inhalation	0.209
		Dermal	0.9
4	Working Condition * Working Type	Inhalation	0.66
		Dermal	0.576
5	Working Condition * Experience	Inhalation	0.625
		Dermal	0.761
6	Working Type * Experience	Inhalation	0.99
		Dermal	0.99
7	Working Condition * Working Type * Experience	Inhalation	0.99
		Dermal	0.99

from other toxicants, proactive risk management measures are prudent. The overarching goal of risk management is to mitigate workers' exposures and minimize associated risks effectively. In the context of informal sectors like the batik industry, the implementation of risk management strategies may encounter specific challenges that demand careful consideration. Therefore, we propose the following risk management actions, tailored to the characteristics of the batik industry.

1. Considering natural colorants

Given that synthetic colorants are the primary source of heavy metal exposure in the batik industry, it is crucial to explore the utilization of natural dyes as an alternative. Substituting synthetic dyes with natural ones or employing a blend of synthetic and natural dyes can significantly reduce workers' exposure to heavy metal toxicants across all exposure pathways. Implementing this strategy, however, may require addressing challenges such as sourcing sustainable natural dyes, adjusting production processes, and ensuring color consistency.

2. Reconsidering working hours

Optimizing working hours is crucial to promote worker well-being. For the batik industry, particularly for workers above 55 years old, reviewing the current 6–7 day work week and 8-h workday by aligning them with effective labor regulations can alleviate fatigue and overburdening. However, to achieve this, collaboration with industry stakeholders and addressing potential resistance to change are essential.

3. Improving nutrition

Improving workers' nutritional status offers multifaceted benefits. A balanced diet can enhance workers' immunity, reducing their susceptibility to diseases and lowering the risk of malnutrition and underweight, thereby enabling workers to achieve their ideal body weight. This will reduce both noncarcinogenic and carcinogenic health risks. To implement this strategy effectively, providing access to nutritious food, promoting health education, and fostering a culture of healthy eating may be required.

4. Using PPE

Dermal and inhalation PPE usage is instrumental in reducing workers' exposure to lead. Encouraging the correct and consistent use of dermal PPE such as gloves and inhalation PPE like masks can be challenging, especially in informal settings. To address this, comprehensive training and supervision by workplace managers, along with ensuring the availability of appropriate PPE, are crucial.

5. Improving workplace conditions

Opting for outdoor working settings can significantly improve air change and pollutant dispersion, thereby reducing workers' inhalation exposure to lead and other hazardous substances. Overcoming challenges such as providing adequate outdoor workspace and ensuring worker comfort in varying weather conditions may be essential to implementing this strategy effectively.

3.10. Limitations

This study has several critical limitations that should be acknowledged. Firstly, the assumptions made during the process of exposure sampling and analysis need to be addressed. Specifically, the exposure and biomarker samples were collected simultaneously, following a cross-sectional design. In this design, it is assumed that the workers' exposure remains uniform throughout the study period

due to their consistent work division and location. Additionally, certain values used in the calculation of exposure dose and concentration are estimates based on generalized information and may not accurately reflect the actual conditions experienced by the workers. Therefore, it is crucial to recognize that the study results are influenced by these assumptions.

Furthermore, this study solely focuses on the risks associated with lead exposure, disregarding other heavy metals and potentially hazardous substances present in the batik industry occupational setting. As previously discussed, the limitations outlined earlier may lead to an overestimation or underestimation of the reported risks. However, considering this secondary limitation, it is plausible that the risk assessment and findings reported in this study might underestimate the actual health risks faced by batik workers. This emphasizes the urgent need for greater attention to this matter.

Lastly, the limited number of workers who participated in this study has an impact on its statistical strength. While 30 workers aligns with the recommendations of NIOSH for studies conducted in occupational settings, a larger sample size would be advantageous for assessing health risks in the batik industry and could yield more reliable results. Additionally, the lack of a control group in this study makes it difficult to move beyond mere correlations and establish a direct link between lead exposure and the observed health effects. A control group would be advantageous for making valuable comparisons, enabling the formulation and testing of hypotheses more rigorously, and leading to more robust conclusions.

4. Conclusion

The average dermal exposure dose and inhalation exposure concentration of lead on batik workers are 6.53 ± 3.2 ng/kg/day and 0.021 ± 0.015 μg/m^3, respectively. The Hazard Index (HI) for all batik workers falls below 1, with the average value of 0.372 ± 0.155. In noncarcinogenic risk assessment, the HI values provide a valuable metric to interpret the overall risk associated with multiple chemical exposures or a chemical with multiple exposure pathways. HI values below 1 indicate that the combined exposures are below the reference dose, suggesting that adverse health effects are not expected. Therefore, it is concluded that no noncarcinogenic health effects due to the lead exposure are expected. However, the results showing values close to 1 indicate the need for continuous monitoring and precautionary measures to safeguard workers' well-being, as well as considering other chemicals potentially expose the workers. The average Excess Lifetime Cancer Risk (ELCR) of batik workers are $(5.18 \pm 3.84) \times 10^{-8}$, significantly below the acceptable limit set by references and regulations (10^{-6} up to 10^{-3}). However, it is important to note that the ELCR reported is specific to lead exposure in this study and may not reflect the total cancer risk in the batik industry, as workers are exposed to other carcinogenic hazards as well. Further research encompassing other carcinogens is necessary for a comprehensive carcinogenic risk assessment.

The correlations between dermal and inhalation intake and u-ALA were positive but insignificant ($r = 0.239$, $p = 0.204$ and $r = 0.015$, $p = 0.94$, respectively). Similarly, correlations between dermal and inhalation intake and Hb were negative and insignificant for male workers ($r = -0.018$, $p = 0.952$ and $r = -0.054$, $p = 0.854$, respectively) and for female workers ($r = -0.5$, $p = 0.048$ and $r = -0.046$, $p = 0.866$, respectively). A negative and significant correlation was found between Hb and urinary ALA ($r = -0.519$, $p = 0.058$ for male workers and $r = -0.531$, $p = 0.034$ for female workers). The correlation analysis results demonstrate that blood Hb and u-ALA concentration can serve as biomarkers for lead exposure effects, although their sensitivity to low lead levels is limited. The low and insignificant correlation with exposure dose reinforces this observation. In conclusion, while individually less sensitive, their combined utilization proves to be a valuable approach for detecting lead exposure, even at lower concentrations.

The factor analysis demonstrated a significant impact of working conditions on inhalation exposure ($p = 0.018$). Specifically, batik workers in outdoor settings had substantially lower lead inhalation compared to those working indoors or in semi-outdoor environments. This critical finding highlights the importance of outdoor work as a protective measure for batik workers against inhaling heavy metals, such as lead, present in the air.

The assessment of noncarcinogenic and carcinogenic health risks associated with lead exposure in this occupational setting provides crucial insights into the potential dangers faced by these workers, shedding light on previously unexplored risks. The results of this study establishes a foundation for informed decision-making and targeted interventions to protect the well-being of batik workers and ensure a safer and healthier work environment, despite the limitations of assumptions made throughout the study, a small sample size, and focus solely on lead. Future research should explore other hazards, increase sample size, and employ advanced analytical techniques for a comprehensive understanding.

Author contribution statement

Conceived and designed the experiments: Katharina Oginawati, Rinaldy J. Nathanael, Nurul Chazanah, Suharyanto, Muhayatun Santoso, Sri A. Febriana, Dwiaris A. Nugrahaningsih, Sri Suhartini, Cita R. S. Prakoeswa, Ikeu Tanziha.

Performed the experiments: Rinaldy J. Nathanael, Dyah Prabandari, Meutia F. Basuki, Buggie Oclandhi.

Analyzed and interpreted the data: Katharina Oginawati, Rinaldy J. Nathanael.

Contributed reagents, materials, analysis tools, or data: Katharina Oginawati, Nurul Chazanah, Suharyanto, Dyah Prabandari, Meutia F. Basuki, Buggie Oclandhi.

Wrote the paper: Katharina Oginawati, Rinaldy J. Nathanael.

Data availability statement

Data will be made available on request.

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Ethics approval

This research was conducted following the guidelines and principles set forth by the Padjajaran University Research Ethic Clearance Committee. The study received ethical approval under the reference number: 560/UN.6/KEP/EC/2022. Informed consent was obtained from all individual participants who took part in the study, ensuring their voluntary and informed participation. Confidentiality and anonymity of the participants' personal information were strictly maintained throughout the research process. The research was carried out in adherence to the ethical standards and regulations governing human research, prioritizing the welfare and rights of the participants.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

The authors affirm that human research participants provided informed consent for publication of this paper for no private data or any name are included in this paper.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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