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Evaluation of Benzene Exposure and S-PMA as a Biomarker of Exposure to Workers in the Informal Footwear Industry

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Abstract

Benzene (C_6H_6) is one of the most widely used chemical compounds in the world. Although its use has been limited, humans may be exposed to benzene in the natural and industrial environments. Small-scale footwear industry still uses adhesives containing benzene. The benzene profile has been well-documented, and it has been classified as a carcinogen compound. The purpose of this study is to assess the risk of benzene exposure in the work environment and individual exposure in footwear factory in Ciomas, Bogor, West Java, during August–September 2017. Urine test with S-Phenylmercapturic Acid biomarker was performed on 40 workers and measurements performed simultaneously at 9 air sample points from 3 workshop locations in accordance with NIOSH 1501 method, risk-level assessment through calculation Risk Quotient (RQ) and Excess Cancer Risk (ECR). The S-PMA subject has not exceeded the exposure limit (>25 μg/g) as Biological Exposure Indices (BEIs) with a median value of 0.190 μg/g (min 0.019–max 17.61). The results of the air sample analysis showed 8 sampling points below the TLV (Threshold limit values) of 0.5 ppm (1.6 μg/m^3) and 1 point of air sampling has exceeded 0.5 ppm (1.6 μg/m^3) of 2, 1074 ppm. the result of calculation of minimum cancer risk, it has been obtained that 13 workers (32.5%) have cancer risk that has exceeded the reference value (ECR>1 · 10^{-4}) and 27 (67.5%) have ECR < 1•10^{-4}. In the calculation of real-time non-cancer risk, it has been obtained that 8 (20%) workers have had non-cancer risk (RQ>1) and 32 (80%) have RQ<1. The concentration of air and S-PMA of workers is still below the TLV, but considering the risk of cancer and non-cancer workers who have exceeded the reference value, it is necessary to improve the working conditions.

Keywords: benzene, S-PMA, risk assessment

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1. Introduction

The informal footwear industry is one of the small and medium sized industrial sectors developing in Ciomas since the 1980s to the present. According to the Ciomas UPT record (2016), there are ±476 numbers of footwear workshop workers in Ciomas sub-district, Bogor. The footwear industry is one of the labor-intensive export commodities. The success of shoemakers to maintain the existence of the products produced is often not matched by adequate health protection against their occupational risks associated with harmful equipment and materials. Length of working hours is not supported with required working conditions, often forcing manufacturers to work with fewer ergonomic body positions that is susceptible to injury. In the process of footwear production, glue is often used as an adhesive to unite certain parts to produce a shoe. Glue is a volatile organic solvent. the hazard identified in shoes production is benzene as an organic solvent that comes from glue.

The identification of the source of exposure by Pakasi in Panggabean [1] shows that the adhesive used in footwear production, still contain benzene although the most dominant is toluene because the use of benzene has been greatly restricted. benzene has been defined as a carcinogenic substance in humans or cancer-causing by several institutions including International Agency For Research On Cancer (IARC) [2], World Health Organization (WHO) (3), and also Environment Protection Agency (US EPA) [4]. Preliminary surveys have been conducted on adhesives used in the housing industry in Ciomas on average still using glue brands containing benzene, previous research also reported that benzene exposure in one of the informal footwear industries in Indonesia has exceeded the allowable limit. The entry of organic solvent vapor into the body can cause various reactions, ranging from mild irritation, addiction, renal impairment, pulmonary edema reactions and central nervous system disorders [5–7] The main exposure route is through inhalation, dermal (skin) and oral [7].

2. Methods

The study design used was cross-sectional design which is used to find out the description of benzene exposure in workers and work environment. Risk analysis method was used to assess carcinogen and non-carcinogen risks due to benzene exposure. The study was conducted in Ciomas, Bogor, West Java on August to September 2017.

2.1. Population and subject

Sampling was conducted using Purposif sampling method because the research population in Ciomas has characteristic, demography, socio-economic and activity type which tend to be similar. The population consists of 476 people. The first phase identifies villages that have informal footwear industry as clusters based on Ciomas Community Health Center data. It is recorded that 3 villages have informal footwear industries. Randomly, Pagelaran Village was selected. The sample size acquired by using the population estimation formula [8] was 40 workers as research subjects.

2.2. Workers data

Questionnaire data were collected to obtain the characteristics of the workers (Age, sex, weight, duration of exposure, occupation and smoking status).

2.3. Measurements of air benzene

The number of air samples is 9 points. In accordance with the method of NIOSH 1501 [9] air sampling using a simple vacuum pump device connected with a glass tube containing the activated carbon (coconut shell charcoal) was placed at each specified point and placed parallel to the worker's respiratory zone and flow rate, 0.2 liter/min for 30 minutes. The air samples collected were then stored at 5°C and can be stabilized for 30 days in accordance with the provisions. Preparation method for benzene measurement are as follows:

TABLE 1: Method of preparation.

Tools	Gas Chromatography with Flame Ionization Detector
Analytical	Benzene
Desorption	1 mL CS2 that was allowed to stand for 30 minutes with agitation
Injection volume	1 μL
Injection temperature	250°C
Detector temperature	300°C
Colum temperature	40°C (10 minute)–230°C (increase of 10°C/min).
Carrier gas	Helium with a speed of 2.6 mL/min
Chromatography column	Capillary column, fused silica 30 m x 0.32 mm
Kalibrasi	Analytical solution in CS2
Benzene time retention	3.52 minute

2.4. Method of collecting urine samples

Urine sampling was done by the workers themselves as directed by the researcher on the correct sampling method and prioritizing individual hygiene. Urine samples collected in clean polyethylene bottles with a minimum size of 25 ml per worker which then labeled and stored immediately in a cooler box with a temperature of 4°C or below 5°C. The collected samples were all stored in the laboratory refrigerator. In the analysis phase, measurement of the level of S-Phenylmercapturic Acid (S-PMA) in urine was done by using High-performance liquid chromatography (HPLC) tools.

2.5. Risk assessment

The calculation of Intake and risk characterization using Microsoft excel from the primary data that has been collected in the field so that the results of the calculation directly described with the following values.

2.5.1. Calculation of benzene exposure intake

Measurement of the magnitude of exposure was done to analyze the amount of exposure, that is, by calculating the amount of benzene intake into the body.

Intake formula (10):

$$I = \frac{C.R.t_e.f_e.D_t}{W_b t_{avg}}$$

Notes:

I: Intake the number of risk agents received by individuals per unit of body weight each day (m^3/kg/day)

C: Concentration of *Risk agent*, benzene in air (mg/m^3)

R: Rate of intake (m^3/hour)

Normal inhalation rate (EPA 1997 in 14): y = 5,3 ln(x) – 6,9 with y = R (m^3/day) and x = Wb (Kg), inhalation rate can be predicted along with the characteristics of anthropometry of Indonesia citizens.

te: Exposure time per day (hour/day) for inhalation

fe: Frequency of annual exposure (day/year (365 days))

Dt: Duration of exposure (year)

W*b*: Weight (kg)

t_{avg}: Periods of average time, 30 years x 365 days/years (non-carcinogenic) or 70 years x 365 days/years (carcinogenic)

2.5.2. Risk calculation

Non-carcinogenic Risk, formula (10):

$$RQ = \frac{\text{Intake (m}^3\text{/kg/hari)}}{RfC\text{(m}^3\text{/kg/hari)}}$$

Carcinogenic Risk, formula (10):

$$ECR = Intake_{cancer} \times CSF(\mu g/kg/day)$$

Notes.

RQ: Risk Quotients

ECR: Excess Cancer Risk (Cancer Risk)

RfC: Reference Concentration

I cancer: Total intake of chronic (lifelong, i.e., 70 years)

CSF: Cancer Slope Factor

3. Result

3.1. Workers characteristics

The results showed that male workers (Table 2) were 32 (80%) and female 8 (20%), the average age of workers was 32.93 years old, the youngest being 16 years old and the oldest being 58 years old. Worker smoking status comprised 65 percent of smokers, 22.5 percent non-smokers or passive smokers, 12.5 percent ex-smokers. Duration of exposure > 8 hours comprising of 14 (35%) workers and ≤ 8 hours comprising 26 or (65%) workers. Working time < 4 years consisting of 11 (27.5%) workers, 4–8 years were 10 (25%) workers and over 8 years there were 19 (47.5%) workers. Body weight, where the cut of point of the average result of worker weight measurement, was 55 kg, for workers ≤ 55 kg amounted to 21 (52.5%) and > 55 kg there were 19 (47.5). The number of workers by type of work was consecutively divided into 20 (50%) design, gluing 15 (12.5%), finishing 5 (37.5%).

TABLE 2: Characteristic of study subject.

	Frek.	Persent. (%)	Median (Min - Maks) S-PMA μg/g cr*	Mean Rank	Range of amount
Sex					
Male	32	80	0,14 (0,01-17,61)	18,63	
Female	8	20	0,48 (0,11-3,58)	28,00	
Age					
<20	5	12,5	4,71 (0,10 -17,6)	29,20	16 -58
20-25	6	15	0,23 (0,07-0,31)	19,33	
26-30	7	17,5	0,14 (0,02-0,57)	16,00	
>30	22	55	0,18 (0,01-3,58)	20.27	
Weight					
≤ 55 kg	21	52,5	0,24 (0,01-17,61)	21,52	35-93
> 55 kg	19	47,5	0,12 (0,02-7,61)	19,37	
Smoking Status					
Not a smoker/ passive smoker	9	22,5	0,22 (0,05-17,61)	22,44	
Ex smokers	5	12,5	0,49 (0,10-0,97)	26,00	
Smoker	26	65	0,14 (0,01-7,61)	18,77	
Duration of Exposure (hour)					
≤ 8 Hours	26	65	0,15 (0,01-7,61)	20,12	6-11
> 8 Hours	14	35	0,24 (0,03-17,61)	21,21	
Time of Exposure (years)					
<4 years	11	27,5	0,31 (0,07-7,61)	25,45	1- 30
4-8 years	10	25,0	0,15 (0,05-17,61)	19,60	
> 8 years	19	47,5	0,14 (0,01-1,35)	18,11	
Occupation					
Design	20	50	0,14 (0,02-1,35)	17,65	
Gluing	15	12,5	0,16 (0,01-1,06)	18,93	
Finishing	5	37,5	4,71 (0,49-17,6)	36,60	

3.2. S-PMA concentrations

Result of S-PMA analysis of laborer urine showed that all respondents detected by benzene exposure through S-PMA. The subjects had not exceeded exposure limit of 25μg/g as Biological Exposure Indices (BEIs) for benzene exposure in workplace [15] with S-PMA level median of 0.190 μg/g (min 0.019–max 17.61). It can also be seen in the

median (min–max) S-PMA table based on age, sex, weight, smoking status, duration of exposure (hours), duration of employment and occupation which showed that the median value is still below the standard of Biological Exposure Indices (BEIs) or still < 25 μg/g.

3.3. Air benzene concentration in work environment

The results of the analysis of air samples (Table 3) showed all 9 sampling points detected benzene vapor exposure, while most or 8 sampling points were still below 0.5 ppm (1.6 μg/m^3) as the limit of exposure to benzene TLV (Threshold limit values) by ACGIH and only one air sampling point that has exceeded 0.5 ppm (1.6 μg/m^3), that is, at point 9 with the type of glue activity of 2.1074 ppm. This result is the same as the exposure threshold value according to the Regulation of Menteri Tenaga Kerja dan Transmigrasi Republik Indonesia [16] Number Per.13/MEN/X/2011 on the Threshold Limit of Physical Factor and Chemical Factor in the Workplace is 0.5 ppm [16].

TABLE 3: The concentration of benzene each sampling point.

Sampling Point	Occupation	(ppm)	mg/m3
A1	Design	0.0035	0.0111
A 2	Finishing	0.0026	0.0082
A 3	Gluing	0.0035	0.0112
B 4	Gluing	0.0029	0.0092
B 5	Gluing	0.0323	0.1033
B 6	Finishing	0.0229	0.0734
C 7	Finishing	0.0224	0.0715
C 8	Design	0.0185	0.0591
C 9	Gluing	2.1074	6.7326

Notes: TLV–TWA 0,5 ppm.

3.4. Risk assessment

3.4.1. Minimum cancer risk

The calculation of minimum cancer risk (Table 6) it was found that workers who had cancer risk had exceeded the threshold (ECR>1 · 10–4) that occurred when 10 years benzene exposure, that is, 13 workers (32.5%). While at 5 years exposure, the number of workers at risk for cancer maximum 14 workers (35%). In non-cancer risk calculation

in real time, workers who have had non-cancer risk (RQ>1) currently have 8 workers (20%) and who have non-cancer risk life time (RQ<1) for 30 years are 9 workers (22%).

TABLE 4: Risk assessment calculations.

Cancer Risk	Median	Min–max	Standard deviation	Reference Value
ECR minimum	0.00000	0.0000–0.165	0.0007	$ECR > 1 \cdot 10^{-4}$
ECR maximum	0.00008	0.00001–0.591	0.1672	
RQ Real Time	0.080	0.000–62	16.561	$RQ > 1$
RQ Life Time	0.52	0.000–69		

TABLE 5: Characterization of cancer and non-cancer risk.

Cancer Risk	Frequency	Percentage (%)
ECR minimum		
$ECR < 1 \cdot 10^{-4}$	27	67.5
$ECR > 1 \cdot 10^{-4}$	13	32.5
ECR Maximum		
$ECR < 1.10^{-4}$	26	65
$ECR > 1.10^{-4}$	14	35
RQ Real Time		
RQ <1	32	80
RQ >1	8	20
RQ Life Time		
RQlf <1	31	77.5
RQlf >1	9	22.5

4. Disscussion

The results of the study, which is indicating that 20% of workers are women, are things to worry about and be aware of. The study, summarized in ATSDR 2007 [7], which looked at benzene-exposed and non-benzene-exposed women in the 20–40 year age group, showed that the percentage of women exposed to benzene had experienced functional impairment in the menstrual cycle compared to the control group. An increased exposure time can even worsen the reproductive system [11]. A study [13] also found that breast cancer could potentially result from benzene exposure. Regarding age, we see in the middle table that the highest S-PMA level was obtained in the young age category < 20 years, after re-examining the data, some of them have

been smoking for years and started smoking at a young age of $\pm$ 13 year. Previous research has also shown that levels of BTX (Benzene, Toluene and Xylene) at a young age are greater than any other age group [13]. In general, workers are thought to have the risk of work-related illness [14, 15] because the room at the footwear production site does not have any specific barriers that separate each type of activity so that the adhesive vapor used in the production can be spread and inhaled by anyone who is working there. However, the risks that arise in the gluing section may be higher due to exposure of various hazardous chemicals [9]. Exposure time over 8 hours has a higher middle value than the exposure time $\leq$ 8 hours. For the type of task category, the mean S-PMA of finishing section is higher than the gluing section. This can be due to the irregular work system and the accumulation of hazardous materials used at each of footwear making groove, so the exposure level of the finishing part is higher.

Based on the results of direct interviews with workers in the informal footwear industry, the average explains the reasons for not using personal protective equipment because they feel uncomfortable at work such as having to use a mask. In addition, when the temperature conditions in the work room increases, workers prefer to work freely without using personal protective equipment and even sometimes their clothes are not worn because of heat in the room when working. Although the average room in the informal footwear industry is already ventilated, it is found in one where it does not open the ventilation cover in the form of a material made of clear plastic or cloth so that the steam from gluing activity is very intense in the room.

Based on the results of urine examination, it can be seen that the S-PMA levels of workers have not exceeded 25 μg/g as the standard of Biological Exposure Indices (BEIs). Based on the results of environmental monitoring at all sampling points, there were benzene levels in the air, but most were below the 0.5 ppm (1.6 μg/m^3) TLV (Threshold limit values). The association of benzene air content was significantly related to each task in shoe production although the study conducted by Azari [16] did not show significant differences between the task groups and benzene exposure. S-phenylmercapturic acid levels can also be correlated with environmental benzene exposure [18], which may indicate utility as a biomarker [7]. S-PMA allows reliable determination of benzene exposure below 0.3 ppm (8 h TWA-Total Weight Average) due to superior specificity for low exposure [19]. S-PMA, as a biomarker, is also more reliable than tt-MA for benzene exposure because S-PMA has a longer elimination half-life, that is, for 12 hours [20]. S-PMA in urine has been shown to be sensitive to benzene exposure at sub-ppm and not affected by other sources of exposure, other than benzene exposure. S-PMA has also been proposed as a better biomarker than

other biomarkers such as trans, trans-muconic acid (t, tMA) for exposure below 1 ppm (5.6) because t, tMA can increase the concentration of t, tMA in the urine, although not exposed benzene. This is because t, tMA is a common food addict sorbate metabolite that can increase t, tMA even though there is no benzene exposure. Minimum cancer risk (32.5%) and non-cancer risk (20%) had exceeded benzene exposure reference level. These findings are similar to other study [13, 14] where their cancer risk calculations had also exceeded the reference value. Previous studies [16, 21] have analyzed estimates of carcinogenic and non-carcinogenic health risks due to benzene exposure in the process of preparing the shoe closely to the source of exposure as in the use of glue, because in this process, the exposure of an organic solvent vapor, particularly benzene, contained in the glue may allow the occurrence of health effects when it is inhaled continuously.

5. Conclusion

In the shoe making process most of the workshops still allow benzene to be exploited through adhesives and workers still obtain exposure to benzene inhalation pathways through evaporation of glue containing benzene. Although most of the air concentrations are still below the threshold value and the S-PMA level is still below the TLV value but through the calculation of intake obtained cancer and non-cancer risk for workers who exceed the value reference so that it needs to be done controlling or improving working conditions such as rolling worker duties, work room ventilation repaired or replacing glue with water base glue and pattern reinforced with seams. Further research can strengthen efforts to reduce the health hazards that must be done to create a safer work environment and protect workers from occupational hazards, especially in the informal industry. Then social and health associations can support health and safety policies in informal working environments.

Conflict of Interest

There is no conflict of interest.

Ethical Clearance

This research has been through ethical review and has been approved by the Department of Environmental Health, Faculty of Public Health, UI.

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