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LITERATURE REVIEW **Open Access**

A Systematic Review on BTEX Exposure on Shoe-making Industry Workers

Tinjauan Sistematis tentang Paparan BTEX pada Pekerja Industri Pembuatan Sepatu

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ABSTRACT

Background: Many chemicals, including volatile organic compounds (VOCs) like benzene, toluene, ethylbenzene, and xylene (BTEX), are commonly used in the shoe industry. Because of these substances' toxicological characteristics, workers are exposed to serious health risks.
Objectives: This article aims to systematically review BTEX exposure among workers in the shoe-making industry, focusing on associated health risks and the effectiveness of mitigation strategies. It explores how occupational factors such as hand hygiene, age, job type, smoking habits, and personal protective equipment usage influence the severity of BTEX exposure effects.
Methods: This systematic review examined the impact of BTEX exposure on shoemaking industry workers, selecting 32 national and international articles based on keyword-based searches. Exclusion criteria included past publications, risk assessment, exposure measurement, and mitigation strategies. Inclusion criteria included publications from the past 10 years. Data extraction included BTEX exposure levels, health outcomes, and working conditions.
Results: The review highlights the health risks of BTEX exposure to shoemaking workers, including leukemia, neurological impairment, respiratory problems, and reproductive issues, emphasizing the need for improved safety protocols.
Conclusion: This review drew attention to the health risks that BTEX compounds pose to workers in the shoe industry, emphasizing the need for stronger safety regulations and enforcement as well as recommendations for future studies on safer procedures.

Keywords: BTEX compounds, Exposure, Health risk, Safe work, Shoe industry

ABSTRAK

Latar Belakang: *Banyak bahan kimia, termasuk Senyawa Organik yang Mudah Menguap (VOC) seperti Benzena, Toluena, Etilbenzena, dan Xilena (BTEX), umumnya digunakan dalam industri sepatu. Karena karakteristik toksikologi zat-zat ini, para pekerja terpapar pada risiko kesehatan yang serius.*
Tujuan: *Artikel ini bertujuan untuk meninjau paparan BTEX secara sistematis di antara pekerja di industri pembuatan sepatu, dengan fokus pada risiko kesehatan yang terkait dan efektivitas strategi mitigasi. Artikel ini mengeksplorasi bagaimana faktor pekerjaan seperti kebersihan tangan, usia, jenis pekerjaan, kebiasaan merokok, dan penggunaan alat pelindung diri memengaruhi tingkat keparahan efek paparan BTEX.*
Metode: *Tinjauan sistematis ini mengkaji dampak paparan BTEX pada pekerja industri pembuatan sepatu, dengan memilih 32 artikel nasional dan internasional berdasarkan pencarian berbasis kata kunci. Kriteria eksklusi meliputi publikasi*

sebelumnya, penilaian risiko, pengukuran paparan, dan strategi mitigasi Kriteria inklusi termasuk publikasi dari 10 tahun terakhir. Ekstraksi data mencakup tingkat paparan BTEX, hasil kesehatan, dan kondisi kerja.
Hasil: *Tinjauan ini menyoroti risiko kesehatan dari paparan BTEX pada pekerja pembuat sepatu, termasuk leukemia, gangguan saraf, masalah pernapasan, dan masalah reproduksi, yang menekankan perlunya protokol keselamatan yang lebih baik.*
Kesimpulan: *Tinjauan ini menarik perhatian pada risiko kesehatan yang ditimbulkan oleh senyawa BTEX terhadap pekerja di industri sepatu, menekankan perlunya peraturan dan penegakan keselamatan yang lebih kuat serta rekomendasi untuk penelitian di masa depan tentang prosedur yang lebih aman.*

Kata kunci: *Industri sepatu, Kerja aman, Paparan, Resiko kesehatan, Senyawa BTEX*

INTRODUCTION

The shoe industry has long been linked to the use of a variety of solvents and adhesives. Many of these contain BTEX compounds, which are volatile organic compounds (VOCs) commonly found in industrial settings and known to cause acute and long-term health effects, such as cancer, neurological disorders, and respiratory problems. Because these chemicals are used extensively in the shoe manufacturing process, it is imperative to comprehend the levels of exposure and health effects on workers in this industry. This systematic review examines the health effects of shoe industry workers' exposure to BTEX compounds (benzene, toluene, ethylene, and xylene) and the effectiveness of mitigation strategies, based on findings from pertinent journal articles.

The harmful effects of volatile organic compounds, like BTEX, on the environment and human health have been the topic of many discussions (Zahed *et al.*, 2024). Therefore, mitigation and monitoring measures are necessary. BTEX exposures account for more than 90% of exposures in the general population and are primarily caused by inhalation (Saeedi, Malekmohammadi and Tajalli, 2024). BTEX exposure can lead to a number of health issues, such as detrimental effects on immune system performance, neurological system health, and human reproductive outcomes. Even worse, there is convincing evidence of a causal relationship between leukemia and benzene exposure from epidemiological studies and case reports (Qin *et al.*, 2022). The most prevalent and hazardous component of BTEX is benzene, which the US Environmental Protection Agency has categorized as a carcinogenic compound (group A) (Kamani *et al.*, 2023).

According to a study done between 2013 and 2018, adult cancer risk was raised by exposure to BTEX (benzene, ethylbenzene, and o-xylene). A total of 124,162 Mexican American men and women participated in the study. In BTEX, the overall cancer prevalence was higher (9.3% vs. 1.3%), with higher rates of lymphoma, leukemia, and blood cancer. The chance of developing cancer was also raised by exposure to benzene, ethylbenzene, and o-xylene components. Future studies are required to investigate the relationship between BTEX exposure and different cancer types (Malik *et al.*, 2022). The purpose of this article is to examine BTEX exposure among shoemakers, with an emphasis on related health risks and the efficacy of mitigation techniques. It investigates how the severity of the effects of BTEX exposure is influenced by occupational factors like age, job type, smoking habits, hand hygiene, and the use of personal protective equipment.

METHODS

This systematic review found, picked, and examined pertinent articles using a methodical process. During the review process, extensive searches were conducted in scientific databases and peer-reviewed journals to collect literature on BTEX exposure among shoemaking industry workers. A total of 32 articles were picked through keyword-based searches. The main focus of the inclusion criteria was studies that discussed BTEX exposure in work environments, specifically the shoe industry, and provided information on health risks, exposure factors, or mitigation techniques. Research that did not focus on BTEX compounds in industrial settings, was not in English, or did not have full-text access was disqualified.

Among the requirements for inclusion are publications from the past ten years, research on BTEX exposure and its effects on the health of employees in the shoe industry, studies pertaining to risk assessment, exposure measurement, or mitigation strategies that use quantitative or qualitative analysis.
Studies that don't focus on BTEX compounds or have nothing to do with occupational exposure are excluded. Review papers that lack original information or analysis, articles that are duplicates, or articles that don't adhere to quality standards (e.g.,

lack of peer review) are also excluded. To verify relevance, the first screening process involved looking over article titles and abstracts. The eligibility of full-text articles was then evaluated using inclusion and exclusion criteria. Data on important variables, such as BTEX exposure levels, health outcomes, mitigation strategies, and working conditions, were extracted from a selection of studies through a methodical analysis. From article identification to final inclusion, the review process was visualized using a flow diagram.

RESULTS AND DISCUSSION

Literature

Small And Medium-sized Enterprises (SMEs) are crucial to the creation of jobs and the expansion of the economy. The World Bank estimates that SMEs account for up to 60% of all employment and 40% of GDP (Savira, Tejamaya and Putri, 2021). Workers in the footwear manufacturing sector are susceptible to a wide range of risks, including intricate blends of organic solvents that can enter their bodies through the skin and respiratory systems (Savira, Tejamaya and Putri, 2021). The International Labor Organization (ILO) reports that 321,000 work-related accidents and 2.02 million work-related diseases resulted in fatalities in 2008, with work-related diseases carrying a significant mortality burden (Savira, Tejamaya and Putri, 2021). According to the National Institute of Occupational Safety and Health (NIOSH), 400,000 workers in Denmark and 9.8 million workers in the US have both been exposed to organic solvents (Tuasikal *et al.*, 2022).

The health risks associated with inhaling chemicals are greater in the shoe manufacturing industry than those associated with dermal exposure (Savira, Tejamaya and Putri, 2021). The air quality is greatly impacted by man-made chemicals known as volatile organic compounds (VOCs), which are used in the shoe manufacturing industry and have higher concentrations indoors than outside. Being the primary air pollutants (Xiao *et al.*, 2025), VOCs can produce hazardous environmental effects like photochemical smog and organic aerosols, as well as pose major health risks to humans even at diluted concentrations (Quanli *et al.*, 2025). VOCs are characterized by their physicochemical properties, including vapor pressure, molecular structure, air/water partition coefficient, and boiling point (Sekar, Varghese and Varma, 2019). Among these, it is discovered that the ambient air contains more organic compounds known as BTEX compounds, which include benzene, toluene, ethylbenzene, and xylene (Sekar, Varghese and Varma, 2019). Because of its harmful effects on the environment, carcinogenic qualities, and respiratory and neurological effects, Benzene, toluene, ethylbenzene, and xylene (BTEX) pollution is a major threat to public health. Transportation-related emissions from vehicles, fuel evaporation, solvent use, industrial processes, waste decomposition, coal-fired power plants, petrochemical, solvent, dry cleaning, degreasing, and painting are the main human sources of BTEX (Jayaraj and Nagendra, 2025). Exposure to BTEX can result in kidney function biomarkers and reproductive hormone changes, as well as genotoxicity, hematotoxicity, and inefficient excretion of benzene metabolites (Abubakar and Sanusi, 2020).

In shoe factories, benzene and toluene, ethylbenzene and xylene are among the ingredients used in adhesives and solvents (Tualeka, Pathak, *et al.*, 2019; Savira, Tejamaya and Putri, 2021). During the glue process, there is also exposure to organic solvent vapors, which can cause cancer and other occupational diseases (Tuasikal *et al.*, 2022). The manual application of glue to the footwear and equipment components during assembly can also result in chemical exposure. The majority of employees in SMEs that produce shoes use their bare palms to apply glue. The workers who were interviewed stated that it was more efficient to use their hands rather than a brush or spatula. But they also acknowledged that after completing the gluing process, their palms would occasionally peel off and feel hot (Savira, Tejamaya and Putri, 2021).

Table 1. BTEX corresponding values and notations according to (ACGIH, 2024)

No.	Chemical [CAS No.]	TWA	STEL	Remarks	MW	TLV Basis
1	Benzene [71-43-2]	0.02 ppm	0.1 ppm	Skin; A1; BEI	78.11	Acute myeloid leukemia, leukemia, hematologic failure, chromosomal abnormalities, myelodysplastic syndrome.
2	Toluene [108-88-3] (2020)	20 ppm	-	OTO; A4; BEI	92.14	Impaired CNS, vision, and hearing; ineffective female reproductive system; loss of pregnancy.
3	Ethylbenzene [100-41-4] (2010)	20 ppm	-	OTO; A3; BEI	106.16	Nephropathy (kidney damage), cochlear impairment, and URT irr. Verified carcinogen in animals with unclear human relevance.
4	Xylene, all isomers [1330-20-7; 95-47-6; 106-42-3; 108-38-3] (2021)	20 ppm	-	A4; BEI; OTO (regarding poly-xylene and its mixtures)	106.16	Eye and URT irritation; hematologic effect; ototoxicity (for p-xylene and its mixtures); CNS impairment.

Source: (ACGIH, 2024)

Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)

Benzene

Benzene, a group 1 human carcinogen, as classified by the International Agency for Research on Cancer (IARC), can enter the body through eating, dermal contact, and respiration, causing adverse health effects and affecting the blood circular system (Chaiklieng, Suggaravetsiri and Autrup, 2019). It is classified with ethylbenzene as a type A carcinogen (Jayaraj and Nagendra, 2025), and can harm various biosphere components due to its synergistic action with other pollutants (Sekar, Varghese and Varma, 2019). Most benzene exposure occurs inhalation, accounting for 40–60% of exposure (Tuasikal *et al.*, 2022). According to the Agency for Toxic Substances and Disease Registry (ATSDR), benzene exposure can have dermal effects, such as irritation of the skin and eyes (Savira, Tejamaya and Putri, 2021). One industry that requires attention is the home shoe-making sector, as the number of workers in this field is constantly increasing and there is an inherent risk of illness from their work. Because the home shoe industry uses benzene, workers there may be exposed to high levels of benzene. It is well known for being an excellent organic solvent for use in a variety of industrial processes, including those in the shoe, motor fuel, rubber, detergent, pesticide, and pharmaceutical industries. It is also used as a component in paint solvents. It is also one of the contaminants in the shoe manufacturing industry that can lead to worker cancer. Most industrial benzene values have been discovered to be higher than the allowable limit (Tuasikal *et al.*, 2022). According to the findings of (Attaqwa, Bead and Prastawa, 2020) literature review, worker exposure to benzene was being exacerbated by regulatory features, handwashing practices, and duration of exposure.

Toluene

One important solvent used in shoe industry adhesives, toluene, can produce free radicals, which raise the concentration of malondialdehyde and lower glutathione levels (Rachma *et al.*, 2020). Chronic exposure to Polycyclic Aromatic Hydrocarbons (PAHs), such as toluene, has been linked to a range of harmful effects on the body's organs (Abubakar and Sanusi, 2020). The liver and kidneys are the primary organs targeted by the high toxicity of safat found in toluene (Tualeka *et al.*, 2018). Toluene can remove lipids from the skin, which can lead to skin damage when it comes into contact with the skin. It has been discovered that workers who are exposed to solvent mixtures, which primarily contain toluene, have skin issues on their hands. Furthermore, human exposure to toluene vapor at work may result in eye irritation (Savira, Tejamaya and Putri, 2021). The use of detoxification through diets high in CYP2E1 enzyme and glycine could help reduce and even completely eradicate chemical components containing toluene toxins (Tualeka, Rahmawati, *et al.*, 2019). By contrast, Group 3 includes both toluene and xylenes, which cannot be categorized according to their carcinogenicity to humans. Nevertheless, case reports and epidemiological research have suggested a potential role for toluene in AML and myelodysplastic syndrome (Jiménez-Garza *et al.*, 2018). Hippuric acid, which is produced when benzoic acid reacts with glycine, can be used as a

marker of toluene detoxification in urine (Tualeka *et al.*, 2018).

Ethylbenzene

VOCs, which include ethylbenzene, are present in tobacco smoke and are found in industrial and environmental sources such as solvent use and vehicle exhaust. VOCs also contribute to air pollution (Jiménez-Garza *et al.*, 2018). Several Volatile Organic Compounds (VOCs) with a risk of cancer exceeding 10^4 should be the subject of particular attention. These include benzene, bromodichloromethane, ethylbenzene, and 1,1,2-trichloroethane (Li *et al.*, 2019). According to IARC (2010), ethylbenzene is categorized as "possibly carcinogenic to humans" in Group 2B (Jiménez-Garza *et al.*, 2018; Li *et al.*, 2019).

Xylene

The most often produced Volatile Organic Compounds (VOCs) in the footwear manufacturing sector include phenol, methyl ethyl ketone, acetaldehyde, formaldehyde, toluene, styrene, ethylene, and xylene. All of these have a negative impact on the environment and seriously harm people's health. The growing number of shoe factories has a negative impact on human health and the environment (Mahmud *et al.*, 2021). Both xylene and toluene belong to Group 3, which means that they cannot be categorized based on their ability to cause cancer in people (Jiménez-Garza *et al.*, 2018). In the production of shoes, the use of xylene-containing adhesives and paints is crucial. Exposure to xylene may have effects on the CNS (Am and Hermawati, 2018). According to (Abubakar and Sanusi, 2020) study, the evidence available suggested that exposure to petroleum products such as xylene as well as toluene and benzene in the workplace could result in genotoxicity and hematotoxicity.

Research indicates that benzene exposure can be exacerbated by factors like smoking, age, task type, PPE use, exposure duration, regulations, hand washing practices, and nutritional status. Cigarette smoke is a common source, and older workers are more susceptible to benzene poisoning. The type of task, such as oil distribution, also increases exposure risk. The recommended daily exposure threshold is eight hours, but the safe duration varies. Regulations are crucial in managing chemical risks in the shoe manufacturing industry, requiring continuous counseling, 5R workplace regulations, personal hygiene, ventilation expansion, and plantation reduction measures.

BTEX Exposure in Shoe-making Industries and Other Industries

Hazardous chemicals are used in the footwear industry's manufacturing process, and the risks involved are not adequately managed. In SMEs, OSH risk assessment needs to be prioritized far more. Inhalation exposure to chemicals posed a moderate to high risk of chemical exposure. Prolonged exposure to benzene can lead to detrimental effects on the bone marrow as well as cancer. While there was a moderate risk of skin and eye irritation through the dermal route (Savira, Tejamaya and Putri, 2021). The health risks associated with benzene exposure include heart failure, respiratory issues, depression of the central nervous system, and shortness of breath. It is extremely uncommon for benzene to enter the body via the digestive system. The reason for this is that any accidental ingestion of benzene can result in symptoms like dizziness, vomiting, and unconsciousness. If the skin comes into direct contact with substances that contain benzene, benzene may enter the body through the skin (Tuasikal *et al.*, 2022). As a result, this study highlights the health concerns associated with chemical use among workers in this industry.

The risk of inhaling chemicals can be reduced by using masks and other Personal Protective Equipment (PPE), as well as adequate ventilation and workspace separation. To reduce the amount of dermal exposure they would experience, gloves should be supplied. Additionally, workers should receive adequate OSH awareness regarding their entire work process (Savira, Tejamaya and Putri, 2021). While precise statistical information regarding BTEX exposure incidents in particular nations may not be consistently reported globally, studies on BTEX compound exposure are displayed in the table below, which includes exposure type, industry, and important findings.

Table 2. An Overview of Review Articles on BTEX Exposure

No.	Articles	BTEX Exposure	Industry or Workplace	Exposure Measurement or Outcome	Key Findings
1	Abubakar & Sanusi, (2020)	Benzene	Petrol industry workers	Genetic polymorphisms (GSTM1, GSTT1) influencing petrol-induced toxicities	Genetic differences impact benzene toxicity susceptibility.
2	Am & Hermawati, (2018)	Xylene	Footwear industry	Methylhippuric acid levels in urine	In informal workers, methylhippuric acid levels are correlated with exposure to xylene.
3	Attaqwa et al., (2020)	Benzene	Oil and gas industry	Benzene exposure analysis among workers	Worker attributes impact the amount of benzene exposed to.
4	Bada et al., (2018)	Benzene	Footwear industry	Urinary trans, trans-muconic acid (TT-MA) levels	Elevated TT-MA values signify heightened exposure to benzene.
5	Chahyadhi & Tualeka, (2019)	Benzene	Footwear industry	Excess cancer risk (ECR) and ventilation assessment	Exposure to benzene increases the risk of cancer due to poor ventilation.
6	Chaiklieng et al., (2019)	Benzene	Gasoline stations	Benzene risk assessment	Workers at gas stations are exposed to benzene, which puts them at serious risk.
7	Febrianti et al., (2020)	Benzene	Footwear industry	Blood profile (leukocytes, hematocrit, hemoglobin)	Workers' blood profiles are impacted by prolonged exposure to benzene.
8	Jayaraj & Nagendra, (2025)	BTEX	General urban environment	Spatiotemporal variation of BTEX concentrations	Seasons and locations have a substantial impact on BTEX concentration variations.
9	Jiménez-Garza et al., (2018)	VOCs (including BTEX)	Various industries	Aberrant promoter methylation in genes	Exposure to BTEX is associated with epigenetic modifications in genes related to hematopoietic malignancy.
10	Li et al., (2019)	VOCs (BTEX)	Rubber footwear industry	VOC emissions and ozone formation potential	BTEX emissions raise worker health risks and contribute to the formation of ozone.
11	Mahmud et al., (2021)	VOCs (BTEX)	Footwear industry	VOC emissions and carbon footprint	The health of workers and the carbon footprint are greatly impacted by BTEX emissions.
12	Setiawan et al., (2020)	Benzene	Footwear industry	NOAEL determination for benzene in mice	Based on animal models, the study establishes acceptable levels of benzene exposure for workers.
13	Tualeka et al., (2018)	Toluene	Footwear industry	Detoxification strategies with glycine-rich food	Glycine helps eliminate the harmful effects of toluene by detoxifying it.
14	Tualeka, Martiana, et al., (2019)	Benzene	Footwear industry	Effect of diet on LDL cholesterol levels in benzene-exposed workers	Foods high in antioxidants reduce the rise in LDL cholesterol caused by benzene.
15	Tualeka, Pathak, et al., (2019)	Benzene	Footwear industry	Relationship between benzene exposure and blood profile	Exposure to benzene modifies blood profiles and raises TT-MA levels.
16	Tualeka, Rahmawati, et al., (2019)	Toluene	Footwear industry	Toluene detoxification with foods rich in CYP2E1 enzyme and glycine	Certain foods and glycine help shield the kidneys and nerves from toluene damage.
17	Tuasikal et al., (2022)	Benzene	Footwear industry	Benzene exposure via urine analysis	Significant exposure among workers is indicated by urine benzene levels.

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Previous research has demonstrated the effect of benzene exposure. It can be made worse by smoking, age, type of task, use of Personal Protective Equipment (PPE), duration of exposure, regulations, hand washing practices, exposure duration, and nutritional status (Tualeka, Pathak, *et al.*, 2019; Attaqwa, Bead and Prastawa, 2020). Peer reviews of earlier studies have yielded the following conclusions regarding workers' exposure to BTEX:

Smoking Habits

Cigarette smoke is one of the most common sources of benzene in indoor air, and it was discovered that smokers' homes had a median level of benzene higher than non-smokers' homes (Sekar, Varghese and Varma, 2019). While the older generation is more prone to cohabiting alcohol and tobacco, the younger and second generations especially the educated and tertiary-educated males are more addicted to both substances (Wankhede and Paswan, 2020). Studies reveal that smoking has a major effect on the body's benzene levels. Urine samples and SPMA values of ethylbenzene are higher in smokers due to personal air exposure. Smoking is a significant confounding factor when determining benzene exposure in oil refinery workers. Some 83.7% of respondents reported having a smoking habit, meaning that most workers are light smokers (Attaqwa, Bead and Prastawa, 2020). While smoking does not significantly change oestradiol levels, Ruiz show lower oestradiol levels in smokers as a result of the synergistic effect of VOCs and cigarette smoke.

Age

Most of the time, children and the elderly live in residential settings (Sekar, Varghese and Varma, 2019). VOCs can have serious negative effects on health, such as respiratory disorders, allergies or immunological reactions in children, headaches, nausea, throat irritation, liver and kidney damage, and central nervous system damage (Jayaraj and Nagendra, 2025). According to research, the risk of benzene poisoning increases with age, and older workers are more likely to experience negative health effects. Oil workers are 40 years old on average, with a 38-year-old exposure group. The average age of oil refinery employees is between 49 and 52, whereas tankers are 36 years old (Attaqwa, Bead and Prastawa, 2020). The majority of the workers in Tuasikal *et al.*'s (2022)study in the Surabaya home shoe industry were between the ages of 31 and 40, which accounts for 50% of workers; smoking regularly and never donning a mask when working (Tualeka, Martiana, *et al.*, 2019). The second and younger generation of males exhibit higher rates of tobacco smoking, chewing, and alcohol addiction (Wankhede and Paswan, 2020).

Type of Task

Attaqwa, Bead and Prastawa (2020) show that filling jobs raise the risk of benzene exposure, especially in the petroleum distribution industry. Work assignment is the most predictive independent variable, older workers are more vulnerable to tanker loading, and maintenance workers are most exposed to eight-hour shifts. Solvent toluene, used in adhesives for the shoe industry, can generate free radicals that increase malondialdehyde concentrations and decrease glutathione levels (Rachma *et al.*, 2020). Ethylbenzene is one of the VOCs that can be found in vehicle exhaust, industrial and environmental sources, and tobacco smoke, which contribute to air pollution (Jiménez-Garza *et al.*, 2018). In the process of making shoes, xylene-containing adhesives and paints are essential, but prolonged exposure to xylene can have negative effects on the central nervous system (Am and Hermawati, 2018).

Use of Personal Protective Equipment

Research indicates that PPE can reduce benzene exposure through inhalation, but most workers still don't use it at service stations (Attaqwa, Bead and Prastawa, 2020). According to Savira, Tejamaya and Putri's (2021) study of workers in the shoe manufacturing industry most workers used their hands to apply the glue; very few used a brush or spatula. The glue application method made it more likely for the workers at the glueing stations to be exposed to solvents through their skin and/or respiration (Savira, Tejamaya and Putri, 2021). Counseling is essential for employees wearing Personal Protective Equipment (PPE) because prolonged exposure to benzene increases health risks (Tualeka, Martiana, *et al.*, 2019).

Exposure Duration

One of the variables taken into account in the carcinogenic risk assessment from benzene exposure, in accordance with the guidelines provided by the United States Environmental Protection Agency (USEPA)-Integrated Risk Information System (IRIS), was the amount of personal time spent actively or on a daily basis at a worksite (Chaiklieng, Suggaravetsiri and Autrup, 2019). Although the recommended daily exposure threshold for benzene is eight hours, the safe amount of time for each individual varies by the number of hours (Febrianti *et al.*, 2020). Research indicates the duration of benzene exposure a worker experiences, with the most common exposure duration being 22-25 years in service stations and 6.1 years in oil refineries, with a safe lifetime exposure duration of 30 years (Attaqwa, Bead and Prastawa, 2020). Workers with a length of service of 20–24 years dominated by 30%, according to Tuasikal *et al.*'s (2022) study on home shoe industry workers. Most of the metabolites of benzene leave the body in the

urine, and the chemical enters the bloodstream within 48 hours of exposure. The amount of benzene exposure in a worker's body can be determined through human biomonitoring. Human biomonitoring of benzene can be done using biomarkers–markers of benzene exposure in the body. SpmA is a marker of benzene exposure in the human body (Tuasikal *et al.*, 2022). In the shoe manufacturing industry, poor ventilation worsens the possibility of being exposed to organic vapors. Despite being used, wall exhaust fans were found to not improve airflow (Savira, Tejamaya and Putri, 2021). Less air enters the vent when its size is smaller, which means that the contaminated air cannot be replaced. There could be residual benzene vapor in the work area if the ventilation system is inadequate (Tuasikal *et al.*, 2022).

Regulations

Compiling and analyzing benzene ambient air quality standards across countries can help policymakers revise guidelines for human health protection, regardless of economic status (Sekar, Varghese and Varma, 2019). Research indicates that not following regulations increases the risk of benzene exposure in gasoline storage and distribution facilities in developing countries (Attaqwa, Bead and Prastawa, 2020). In accordance with Minister of Manpower Regulation Number 13 of 2011, the benzene concentration is still below the threshold value at 0.5 ppm (Setiawan *et al.*, 2020). For shoemakers to effectively manage chemical risks in their industry, they must implement continuous counseling, 5R workplace regulations, personal hygiene, ventilation expansion, and plantation reduction measures (Bada, Tualeka and Widajati, 2018).

Hand Washing Habits

For hundreds of years, people have recognized the advantages of hand washing in preventing infections (MD *et al.*, 2022). Research indicates poor handwashing habits increase risk, with 38.4% of Ciputat Timur gas station operators found as having weak handwashing habits in 2017 (Attaqwa, Bead and Prastawa, 2020). The proper way to wash your hands is in seven steps: inside, outside, clip, back, thumb, fingertips, and wrists. Every step should involve more than 15 seconds of rubbing. Hand sanitizer, hand washing, and finger rubbing are the steps in the procedure. For every step, the rubbing should be done for five to 15 seconds (Zhou *et al.*, 2022).

Length of Exposure

There have been some documented negative effects on the reproductive system from occupational exposure to volatile organic compounds (VOCs) or mixtures of VOCs (Ruiz-García *et al.*, 2020). Adverse pregnancy outcomes, fertility impairments, and occupational exposure to a mixture of compounds have all been related to menstrual disorders. Unfortunately, the lack of precise exposure levels and biomonitoring techniques in earlier research limits the comprehension of these effects. Research shows longer working hours increase risk of t-muconic acid urine levels in oil refineries. The safe exposure limit for a lifetime of work is 1.6 hours per day, while service station exposure is eight hours per day (Attaqwa, Bead and Prastawa, 2020). After exposure to benzene at high concentrations (3,000 ppm for five minutes) through inhalation or respiration, or for 30 to 60 minutes through digestion, benzene toxicity to the central nervous system develops. The concentration of benzene at the shoe manufacturing facility is 0.206 mg/m^3, whereas the safe level for this carcinogen is 0.023 mg/m^3 (Chahyadhi and Tualeka, 2019).

Nutritional Status

It appears that additional variables, including the amount of time spent working, one's nutritional state, the length of exposure, weight, and frequency of exposure, all play a significant role in determining how much xenobiotic material is ingested by the body and how that affects blood profiles in particular (Tualeka, Pathak, *et al.*, 2019). Research suggests that higher weight reduces risk for oil refinery workers, while no difference exists between abnormal and significantly normal nutritional status between employees exposed to benzene (Attaqwa, Bead and Prastawa, 2020).

CONCLUSION

This systematic review highlights the significant health risks associated with BTEX exposure among workers in the shoemaking industry. The findings demonstrate that occupational factors, including poor hand hygiene practices, advanced age, specific job roles, smoking habits, and inadequate use of personal protective equipment, exacerbate the severity of BTEX exposure effects. These factors highlight the urgent need for tailored interventions to mitigate risks in this sector.

This review also highlights the need for stronger regulatory frameworks, better workplace safety measures, and extensive training on appropriate protective practices. It also reveals the limited effectiveness of current safety protocols. Reducing exposure risks and protecting workers' health require effective mitigation techniques, such as regular use of personal protective equipment, enhanced ventilation in the workplace, and worker counseling.

Long-term studies on the health effects of BTEX exposure should be prioritized in future research, developing creative, workable solutions for lowering occupational exposure in the shoe industry.

Protecting vulnerable workers and establishing sustainable industrial practices will require strengthening safety regulations and making sure they are enforced. One limitation of this review is that it relies heavily on published literature, which may introduce publication bias. Also, this research focuses heavily on benzene due to the abundant research on benzene, which may be due to its adverse effects, while other studies focus on BTEX as a whole.

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The authors state that, no conflicts of interest exist between the study's participants.

Author Contributions

AOO: writing–review and editing; ART: supervision; IP: supervision.

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