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Original Article

Toluene Exposure Concentration and Neurotoxic Risk Quotient among Industrial Workers in Surabaya: A Cross-Sectional Study

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ABSTRACT

Background: Toluene poses significant health hazards to humans. Occupational exposure among workers who use toluene as a solvent may lead to various adverse health effects, including dizziness, vertigo, ocular and skin irritation, respiratory disturbances, as well as disorders of the liver, kidneys, and central nervous system. This study aimed to examine the association between toluene concentration and non-carcinogenic risk characteristics with neurotoxic effects across five industrial settings in the Surabaya region.
Methods: This observational study employed a *cross-sectional* design and was conducted in five industries in Surabaya that utilize toluene as a solvent in their production processes, located in Osowilangun, Ketintang, Jemursari, Kalijudan, and AUP Which will be implemented in 2025. The study population consisted of 90 workers exposed to toluene, of whom 77 participants were selected using an accidental sampling technique. The variables examined included toluene concentration, toluene risk quotient (RQ), and neurotoxic effects.
Results: Overall, 50 workers (65%) had unsafe risk quotient (RQ) levels, and 48 workers (62.3%) experienced neurotoxic effects. Although the majority of workers (52.0%) were exposed to toluene concentrations below the threshold limit value, those exposed to concentrations above the threshold had a 1.38-fold higher risk of neurotoxic effects, and workers with unsafe RQ had a 1.4-fold increased risk compared with those with safe RQ. Statistical analysis showed no significant association between toluene concentration or RQ and neurotoxic effects ($p > 0.05$).
Conclusion: Although not statistically significant, the study suggests that the Risk Quotient (RQ) of toluene is a key determinant of neurotoxic risk, highlighting the importance of monitoring and controlling exposure in the workplace.

INTRODUCTION

Toluene is a transparent, colorless organic liquid characterized by an aromatic odor similar to benzene. It is highly volatile and readily flammable (ATSDR, 2015). Toluene vapor has a higher density than air and is capable of dispersing over considerable distances. It becomes detectable by smell in air at concentrations of 8 ppm and in water at 0.04–1 ppm. Toluene exposure poses significant health risks. Evidence from earlier studies suggests that toluene exposure can lead to mortality and diverse systemic health effects involving numerous organ systems, including

respiratory, cardiovascular, neurological, hepatic, renal, and reproductive systems (ATSDR, 2015; Moeljosoedarmo, 2008; Toluene MSDS, 2009).

Globally, toluene consumption ranges from 0.5×10^7 to 1×10^7 tons. Industrial use reached 2.38 million tons in Europe (2007), 1 million tons in North America (2009), and 23 million tons in Asia (2006) ('Toluene Uses and Market', 2008). In 1994, U.S. production was over three million tons, with an estimated 4–5 million workers exposed annually. Data on industrial use in Indonesia remain limited. Toluene is commonly utilized as a solvent and base ingredient in paint production, thinners, inks, adhesives, pharmaceuticals, cosmetics, pesticides, petroleum, plastics, and synthetic fibers. In households, it is primarily found in glues and disinfectants, and it is also used in printing and tanning processes (Mckeown, 2013).

Exposure to toluene in occupational settings may lead to neurological symptoms, ocular and dermal irritation, respiratory problems, hepatic and renal impairment, and central nervous system disorders. Entry occurs mainly through inhalation, but also via skin contact and ingestion. Low doses can induce nerve disorders, classified as neurotoxic or neuropathic (Pratamasari, 2015). Neurotoxic effects involve adverse changes in the central and peripheral nervous system, leading to alterations in memory, attention, mood, orientation, thought processes, and somatic, sensory, and cognitive functions.

The CNS is the primary target of toluene, with symptoms ranging from fatigue, drowsiness, headaches, nausea, confusion, improper judgment, staggering, and blurred vision, to severe effects such as loss of consciousness, coma, and death (ATSDR, 2015). Studies in Indonesian shoe industries, including Cibaduyut, Bandung, reported dizziness, nausea, weakness, and shortness of breath among workers exposed to toluene (Haen & Oginawati, 2011). The ILO (2004) documented frequent dizziness in 37.31% of workers in the Ciomas and Tasikmalaya shoe industries. Global studies have reported that exposure to toluene within the range of 11–42 ppm is associated with neurological manifestations such as tiredness, impaired attention, and headache (Orbaek & Nise, 1989; EPA, 2005).

Surabaya, with its rapidly growing industrial sector, utilizes toluene extensively in various production processes. Given its neurotoxic potential, understanding the relationship between toluene exposure and health outcomes is critical. Evidence regarding the association between toluene concentration, non-carcinogenic risk (RQ), and neurotoxic effects among workers in Surabaya remains limited. This study addresses this gap by examining these relationships in five industries, providing relevant insights for occupational health management in settings with routine toluene use.

METHODS

An observational cross-sectional study was performed across five Surabaya-based industries using toluene as a production solvent, situated in Romokalisari, Ketintang, Jemursari, Kalijudan, and AUP Which will be implemented in 2025. A total population of 90 workers were identified as being exposed to toluene, and 77 respondents were selected using an accidental sampling technique. It must be acknowledged that accidental sampling reduces sample representativeness and may introduce selection bias, limiting the generalizability of findings. No prior sample size calculatin was performed, which may affect the statistical power of the study in detecting significant associations.

Data were collected through interviewer-administered questionnaires, and all respondents provided informed consent prior to participation. Assessment of workplace toluene concentrations was conducted by qualified staff from UPTK3 Surabaya employing vacuum pump sampling with activated charcoal tubes. Analysis followed the NIOSH 1501 method using Gas Chromatography (GC), ensuring a valid and standardized assessment of environmental exposure. Neurotoxic effects were assessed using a questionnaire. However, the specific instrument used, its validity, reliability, symptom checklist structure, and whether any clinical neurological assessment was conducted were not described, which limits the precision of neurotoxic outcome measurement. Risk Quotient (RQ) Calculation Non-carcinogenic risk characterization was conducted using the Risk Quotient (RQ), calculated by dividing intake (Ink) by the reference

concentration (RfC) following Tualeka (2014). RQ ≥ 1 indicates an unsafe exposure level. It is important to note that key confounding variables were not controlled or measured. These include smoking habits, alcohol consumption, Co-exposure to other solvents or chemicals, duration of employment and cumulative exposure and Use of personal protective equipment (PPE). The absence of these controls may affect the observed associations between toluene exposure and neurotoxic effects.

RESULTS

Descriptive Statistics

The characteristics of the respondents consisted of age, gender, level of education, and work area. The table below summarizes the distribution of respondent characteristics in the Surabaya shoe industry.

Table 1. Distribution of Demographic and Work Characteristics of Toluene-Exposed Workers in Five Industries in Surabaya

Characteristics of Respondents	n	%
Age		
16-25	15	19.5
26-35	13	16.8
36-45	24	31.2
46-55	16	20.8
56-65	9	11.7
Sex		
Male	61	79.2
Female	16	20.8
Level of Education		
Primary	14	18.2
Junior High	19	24.7
Senior High	43	55.8
Univesrsity	1	1.3
Working Area		
Romokalisari	24	31.1
Ketintang	12	15.6
Jemursari	10	13.0
Kalijudan	20	26.0
AUP	11	14.3

As shown in Table 1, most industrial workers were aged 36–45 years (24 individuals; 31.2%). The majority were male (61 workers; 79.2%), and the predominant educational attainment was senior high school or vocational school (43 workers; 55.8%). In terms of work location, the largest proportion of respondents (24 workers; 31.1%) were employed in the Romokalisari area.

Toluene Concentration

Table 2. Levels of Toluene Concentration in Five Industrial Settings in Surabaya

Working areas	Measurement Points	Toluene Concentrations (Threshold Value= 20 ppm)	
		<TV	≥TV
Ketintang	Point 1	2.15	
	Point 2	0.42	
	Point 3	0.30	
Jemursari	Point 4	2.99	
	Point 5		40.27
	Point 6	1.9	
AUP	Point 7	0.99	
	Point 8	0.04	
	Point 9	0.003	

Working areas	Measurement Points	Toluene Concentrations (Threshold Value= 20 ppm)	
		<TV	≥TV
Kalijudan	Point 10	0.43	
	Point 11		33.89
	Point 12		38.38
Osowilangun	Point 13		289.3
	Point 14		30.5
	Point 15		62.7
	Point 16		58.5
	Point 17	15	
	Point 18		137.5
	Point 19	9.3	

Table 2 indicates that airborne toluene concentrations ranged from 0.003 ppm to 289.3 ppm, with an average of 32.9 ppm. Eight sampling points exceeded the ACGIH (2011) threshold of 20 ppm, while eleven points were below the recommended limit.

Table 3. Levels of Toluene Exposure in Workers across Five Industries in Surabaya

Toluene Concentration	Total	
	n	%
>20 ppm	37	48.0
≤20 ppm	40	52.0
Total	77	100.0

A total of 37 respondents (48.0%) were exposed to toluene concentrations exceeding the 20 ppm threshold limit recommended by the American Conference of Governmental Industrial Hygienists (ACGIH, 2007), while 40 respondents (52.0%) were exposed to concentrations below 20 ppm.

Non-Carcinogenic Risk

Table 4. Risk Quotient (RQ) Distribution among Toluene-Exposed Workers in Five Surabaya Industries

Variable	Category	n	%
Risk Quotient (RQ)	Unsafe (≥1)	50	65.0
	Safe (<1)	27	35.0
Neurotoxic Effects	Neurotoxic	48	62.3
	Non-neurotoxic	29	37.7
Total		77	100

Table 4 presents the distribution of non-carcinogenic risk and neurotoxic effects among toluene-exposed workers. Overall, 65% of workers were classified as having an unsafe Risk Quotient (RQ ≥1), indicating potential non-carcinogenic health risk. In addition, neurotoxic symptoms were reported by 62.3% of respondents, while 37.7% did not report such symptoms.

Table 5. Association between Toluene Exposure, Risk Quotient, and Neurotoxic Effects

Variable	Category	OR	p-value
Toluene concentration	>20 ppm vs ≤20 ppm	1.38	0.064
Risk Quotient (RQ)	Unsafe (≥1) vs Safe	1.40	0.059

In Table 5, workers exposed to toluene concentrations above the threshold limit had higher odds of neurotoxic effects (OR = 1.38), and workers with unsafe RQ values had increased odds (OR = 1.4), although these associations were not statistically significant.

DISCUSSION

Concentration Toluene

This study demonstrates that workers in toluene-using industries in Surabaya are exposed to a wide range of airborne toluene concentrations, with several measurement points exceeding the ACGIH threshold limit of 20 ppm. Although not all workers were exposed above this limit, a substantial proportion exhibited unsafe Risk Quotient (RQ) values and reported neurotoxic symptoms. These findings suggest that occupational exposure to toluene in informal and semi-formal industrial settings may pose health risks even when average airborne concentrations appear acceptable.

Importantly, more than half of the workers experienced neurotoxic symptoms, indicating that adverse neurological effects may occur at exposure levels below established threshold limits (Hopf NB, 2024). This supports the growing evidence that chronic, low-level exposure to organic solvents can lead to cumulative neurotoxic effects that are not adequately captured by single-point air concentration measurements (Seo et al, 2024).

Concentration Toluene and Neurotoxic

The absence of a statistically significant association between airborne toluene concentration and neurotoxic symptoms does not necessarily indicate the absence of risk. Workers exposed to concentrations above the threshold showed a higher risk of neurotoxic symptoms, suggesting a trend toward adverse effects. This finding may reflect a threshold phenomenon, in which neurological symptoms develop gradually over prolonged exposure rather than immediately following short-term increases in concentration.

Additionally, airborne concentration measurements represent environmental exposure at a specific time and location, which may not accurately reflect individual cumulative exposure (Khoshakhlagh AH, 2025). Variability in work practices, duration of exposure, ventilation conditions, and individual behaviors such as inconsistent use of personal protective equipment could dilute observable statistical associations (Virji MA, 2021).

RQ Toluene and Neurotoxic

Although the association between RQ and neurotoxic symptoms was also not statistically significant, the observed risk ratios were consistently higher for workers with unsafe RQ values. This finding underscores the potential value of RQ as a more sensitive indicator of occupational health risk compared to airborne concentration alone.

RQ incorporates multiple exposure-related parameters, including inhalation rate, duration and frequency of work, years of employment, and body weight. As such, it reflects cumulative internal dose rather than momentary environmental exposure. Neurotoxicity, particularly from organic solvents such as toluene, is known to be influenced by chronic accumulation in the central nervous system, which may explain why RQ demonstrates a stronger association with neurotoxic outcomes than airborne concentration alone. This interpretation aligns with occupational risk assessment frameworks that emphasize dose accumulation and individual susceptibility, rather than relying solely on threshold limit values.

Comparison with Previous Studies

The findings of this study are consistent with international research reporting neurotoxic symptoms among workers exposed to toluene at moderate concentrations. Studies in shoe manufacturing, printing, and fuel-related occupations in Asia and Europe have documented increased prevalence of headaches, fatigue, dizziness, and cognitive complaints even when exposure levels were near or below regulatory limits. Similar patterns reported by Yin et al. and Tunsaringkarn et al. suggest that chronic occupational exposure to toluene may result in subclinical or early-stage neurotoxicity that is not easily detected through standard exposure metrics. Differences in statistical significance across studies may be attributed to variations in sample size, exposure duration, industrial settings, and assessment methods.

Implications for Public Health

The findings underscore the importance of adopting a risk-based approach to occupational exposure assessment, particularly in industries that utilize volatile organic solvents. Reliance solely on airborne concentration thresholds may underestimate health risks associated with long-term exposure. Incorporating RQ into routine occupational health monitoring may improve early detection of at-risk workers and support more effective preventive strategies.

Regular neurological health surveillance, improved ventilation systems, consistent use of appropriate personal protective equipment, and worker education should be prioritized to mitigate neurotoxic risks. These measures are especially critical in informal industrial settings where regulatory oversight may be limited.

Limitations and Cautions

This study has several limitations. The cross-sectional design restricts causal inference between toluene exposure and neurotoxic outcomes. The relatively small sample size may have limited statistical power, contributing to the lack of significant associations despite elevated risk estimates. Neurotoxic symptoms were self-reported, which may introduce reporting bias. Additionally, potential confounders such as co-exposure to other chemicals, smoking status, and individual metabolic differences were not fully controlled. Environmental measurements were conducted at specific time points and may not represent long-term exposure variability.

Recommendations for Future Research

Future studies should employ longitudinal designs to better capture cumulative exposure effects and temporal relationships between toluene exposure and neurotoxicity. Larger sample sizes, biological monitoring, and objective neurobehavioral assessments would strengthen causal interpretation. Further validation of RQ as a predictive tool for neurotoxic risk is warranted to support its integration into occupational health policy and practice.

CONCLUSION

The study found that although more than half of the workers (52.0%) were exposed to toluene concentrations below the established threshold limit value, a considerable proportion (65%) still had Risk Quotient (RQ) values categorized as unsafe. A total of 48 workers (62.3%) reported neurotoxic symptoms, including dizziness, vertigo, and cognitive disturbances. Workers exposed to toluene concentrations above the threshold limit had 1.38 times higher odds of reporting neurotoxic effects, and those with unsafe RQ values had 1.4 times higher odds compared with workers in the safe RQ category. While these associations suggest a potential relationship between exposure indicators and neurotoxic outcomes, the results were not statistically significant, and therefore should be interpreted with caution. The study does not provide sufficient evidence to conclude a definitive or dominant role of RQ or concentration level in determining neurotoxic risk. Further research with larger sample sizes and controlled study designs is needed to clarify these relationships.

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