RESEARCH ARTICLE **Open Access**

Gema Lingkungan Kesehatan
Vol. 23, No. 4 (2025), pp 503-511
e-ISSN 2407-8948 p-ISSN 16933761
doi: https://doi.org/10.36568/gelinkes.v23i4.371 *Journal Homepage: https://gelinkes.poltekkesdepkes-sby.ac.id/*

Respiratory and Neurological Health Effects of Chromium and PM Exposure among Troso Woven Fabric Workers: A Cross-Sectional Study in Jepara

Yusniar Hanani Darundiati*, Tri Joko, Onny Setiani, Mursid Raharjo, Nurjazuli Nurjazuli, Muhammad Auliya Rahman

Department of Environmental Health, Faculty of Public Health, Diponegoro University, Semarang, Indonesia

*Correspondence: darundiatiyh@lecturer.undip.ac.id

The Troso weaving industry in Jepara, Indonesia, is a traditional craft sector that relies on synthetic dyes and manual production, thereby exposing workers to chromium (Cr) and particulate matter (PM2.5 and PM10) with potential respiratory and neurological risks. This study aimed to analyze their association with respiratory and neurological disorders among workers. A cross-sectional design was applied involving 101 weaving workers from four production sites. Environmental sampling measured Cr concentrations in wastewater and PM2.5/PM10 in the ambient air, while worker characteristics and health complaints were assessed using the ECSC-87 and Q18 questionnaire. Data were analyzed using chi-square tests and prevalence ratios. Cr concentrations in wastewater ranged from <0.010 to 0.104 mg/L, remaining below the effluent quality standard of 1.0 mg/L but confirming the continuous use of chromium-based dyes discharged without treatment. Average PM2.5 and PM10 levels were 108.75 µg/m³ and 117.75 µg/m³, both exceeding national air quality standards (55 and 75 µg/m³). Bivariate analysis showed that respiratory disorders were significantly associated with exposure duration ≥40 hours/week (PR=7.33; p=0.001) and working period >5 years (PR=20.94; p=0.001), whereas dye type, dyeing frequency, and PPE use were not significant. Neurological disorders were significantly associated with exposure duration (p=0.001), working period (p=0.001), type of dye (p=0.001), frequency of dyeing (p=0.018), and PPE use (p=0.001). Environmental monitoring confirmed elevated PM levels and chromium-based dye use, while statistical analysis showed that prolonged exposure and longer working periods associated with respiratory disorders, and neurological disorders were linked to multiple occupational factors.

Keywords: Weaving industry, Chromium, Respiratory disorders, Neurological disorders

INTRODUCTION

The textile industry is one of Indonesia's leading non-oil sectors, ranking among the top 10 producers globally, and significantly contributing to the country's exports and job creation (Sarasi et al., 2023). Within this sector, Troso Village in Jepara Regency, Indonesia is nationally recognized as a center of "ikat" weaving, a traditional craft that has been developed using non-mechanical weaving tools from 1946 to the present. This industry supports the livelihoods of 11,332 workers in 282 business units with a production volume of 37,322,128 tons in 2022 (Regency, 2023). Troso weaving, made from cotton, fiber, or silk yarn, is characterized by its distinctive dyeing technique and unique tied yarn patterns, producing distinctive motifs that remain popular in the domestic market (Sarwono et al., 2023).

Despite its play an important and unique role, the weaving process poses significant health risks for the artisan. The fabric dyeing stage uses powdered synthetic dyes, derived from mordants containing color-binding agents, including $Cr(NO_3)_3$ and $PbCrO_4$, which contains lead (Pb) and chromium (Cr) that are often used to produce brighter and more durable colors (Islam et al., 2024; Kishor et al., 2020). In addition, spinning, weaving, and fabric dyeing activities release fine textile fibers in the form of Particulate Matter 10 dust (PM10) and Particulate Matter 2.5 (PM2.5) and chemical particles into the air, which can accumulate in poorly ventilated workplaces (Kumie et al., 2020; Maksuk et al., 2022).

Previous studies have shown that workers exposed to PM10, PM2.5, Cr, and other hazardous chemicals such as caustic soda, acids, auxiliaries, and synthetic dyes are at high risk of developing respiratory problems, neurological disorders, anemia, skin irritation, and even permanent tissue damage (Islam et al., 2020; Zeviani & Viscomi, 2022). Long-term exposure, particularly to hexavalent chromium (Cr[VI]), has also been linked to asthma, lung irritation, nasal ulcers, allergic reactions, reproductive and developmental problems, cardiovascular and endocrine disorders, neurological impairment,

immune dysfunction, and increased cancer risk in humans following inhalation and skin exposure (Saxena & al., 2022); (Iyer et al., 2023). Meanwhile, exposure duration, work period, habits of handling textile dyes without personal protective equipment (PPE), and dyeing frequency can influence the onset of symptoms or severity of respiratory and neurological problems due to exposure to Cr and PM (Berlian et al., 2023; Ramadan et al., 2024; Wilson et al., 2023).

Preliminary findings in Troso Village indicate serious occupational and environmental health concerns. Interviews with weaving workers revealed that six out of ten frequently experienced respiratory complaints such as persistent coughing and shortness of breath, while observations showed that most workers (8 out of 10) did not use complete PPE. Wastewater samples from Troso showed Cr concentrations exceeding the permissible threshold by approximately 60% (≥ 0.2 µg/dL), indicating that the dyes used in the weaving process contain Cr, which is discharged directly into local waterways and surrounding land without an adequate treatment system. These conditions underscore the potential health risks from exposure to Cr and PM2.5 and PM10 for weaving workers in Troso. Therefore, this study aims to emphasize the relationship between Cr, PM2.5, PM10 exposure and respiratory and neurological disorders in Troso weaving industry workers in Troso Village, Pecangaan District, Jepara Regency.

METHOD

This study was an analytical observational study with a cross-sectional design, aiming to identify the relationship between independent and dependent variables. All variables were measured simultaneously at the time of the data collection. The study population consisted of woven fabric workers in Troso Village, Jepara Regency, engaged in dyeing and weaving activities, totaling 3,432 workers. A sample of 101 workers was selected from four of the largest home industries using the Slovin formula. Exclusion criteria included workers who were sick during the study, those with health problems that prevented interviews, and those with a history of lung infection (e.g., tuberculosis), asthma, allergies, or alcohol consumption.

The dependent variables were (1) respiratory disorders and (2) neurological disorders. Independent variables included length of exposure, duration of employment, type of dye, frequency of dyeing, and completeness of personal protective equipment (PPE). Potential confounding factors in this study included individual factors such as age, gender, education level, nutritional status, and smoking habits, which were measured and presented in tabular form to describe the characteristics of the sample. Other confounding factors, including alcohol consumption, history of lung disease, allergies, and asthma, were controlled for by excluding individuals with these conditions. Environmental confounding factors such as humidity and temperature were measured simultaneously with the independent and dependent variables to ensure that these factors were not the main causes of the Cr and PM measurement results.

Respiratory symptoms were assessed using the ECSC-87 Questionnaire (German version), which is a standardized instrument that was adapted and modified to fit the study context. Respondents were categorized as (1) symptomatic if complaints exceeded 50% of the questionnaire items, and (2) asymptomatic if complaints were less than 50%. Neurological symptoms were measured using the standardized Q18 questionnaire and the Romberg Test for balance disorders. Environmental exposure was assessed through the measurement of Cr and PM. Levels of PM10 and PM2.5 were measured using a portable dust sampler (Haz Dust Environmental Particle Air Monitor, Model EPAM-5000) during working hours (3-4 hours), with reference to Government Regulation No. 22 of 2021 on Environmental Protection and Management, which specifies threshold limits for particulate matter. Total chromium (Cr) concentrations in wastewater samples were analyzed using UV-VIS spectrophotometry, following the SM 3111 B (23rd Edition, 2017) method, with reference to the Ministry of Environment and Forestry Regulation No. 5/2014, which establishes permissible Cr limits.

Univariate analysis was conducted to describe respondent characteristics, exposure factors, PPE use, and reported symptoms. Bivariate analysis was performed using the chi-square test to examine the association between independent variables and respiratory also neurological symptoms. A p-value < 0.05 was considered statistically significant. Prevalence ratios (PR) were calculated with 95% confidence intervals (CI). This study received ethical approval from the Ethics Committee of the Faculty of Public Health, Diponegoro University (Ref. No. 283/EA/KEPK-FKM/2024).

RESULT AND DISCUSSION

Environmental Exposure (Cr and PM Levels)

The process of making Troso weaving includes the process of spinning thread, designing motifs, designing motif patterns, printing motif patterns, collecting threads, drawing motifs, tying threads, dyeing threads, drying, only after that the weaving process can be carried out. In the process of making Troso weaving, worker contact with chromium dye can occur during the dyeing stage. Cr exposure can also occur during weaving process takes place, especially at the stage of using threads that have been previously exposed to chromium dye, and there is the potential for direct contact of workers with the dye particles (Kumie et al., 2020).

Table 1.
Data of Chromium (Cr) Concentration in Wastewater of Troso Woven Fabric Home Industry, Jepara

No	Sampling Site	Result (mg/L)	Testing Method	Reference
1	Site 1	< 0.010	SM 3111 B (23rd Edition, 2017)	Highest total Cr levels for the textile industry: 1.0 mg/L (Ministry of Environment and Forestry Regulation No. 5/2014)
2	Site 2	< 0.010		
3	Site 3	0.046		
4	Site 4	0.104		

Table 1 shows the chromium levels measured in wastewater at several points at Troso. In addition to the production process, liquid waste from production by-products contains hazardous chemicals that can pollute water and soil (Tumolo et al., 2020). Based on the Ministry of Environment and Forestry Regulation No. 5/2014 concerning Wastewater Quality Standard, the permissible limit for total Cr content in the textile industry is 1.0 mg/L (Ministry of Environment and Forestry Indonesia, 2014). The concentrations of Cr detected in the Troso weaving sites were below this threshold (table 1), which at first glance may indicate compliance with regulatory requirements. However, this interpretation requires caution, as the Troso weaving industry operates at a household scale and lacks wastewater treatment facilities. In this context, effluents are discharged directly into the surrounding environment without any prior processing. The mere presence of Cr, even at concentrations below the regulatory limit, signifies that the production process involves chromium-containing materials, reflecting a continuous input of this contaminant into the local environment.

Chromium, as a toxic contaminant, can persist and accumulate in environmental media over time, through industrial processes such as papermaking, wood processing, and dye production (Yan et al., 2023). Evidence from Benoa Bay, Bali confirms this risk. Cr from the textile and screen-printing industry was absent in surface water but detected in plankton and sediments, indicating bioaccumulation (Suteja et al., 2020), while studies in chromium-related industries also identified Cr(VI) and SO_4^{2-} as primary groundwater contaminants (Xia et al., 2025). Research in the Zarqa River Basin, Jordan, further showed that industrial activities, including textiles, contributed to Cr pollution up to 250 µg/L, but improvements such as relocation of industries and construction of effluent treatment plants reduced contamination, underscoring the importance of treatment infrastructure and regulatory enforcement (Shammout et al., 2022). Thus, even though Cr concentrations in Troso remain below the effluent quality standard, the absence of wastewater treatment and the continuous direct discharge into the environment pose cumulative ecological risks, leading to potential contamination of surface water, soil, and irrigation channels closely connected to community activities.

Table 2.
Data of PM2.5 and PM10 Concentration in Troso Woven Fabric Home Industry, Jepara

No	Sampling Site	Parameter	Mean (µg/m³)	Reference
1	Site 1	PM 2.5	19	Government Regulation No. 22/2021
		PM 10	71	
2	Site 2	PM 2.5	131	
		PM 10	190	
3	Site 3	PM 2.5	107	
		PM 10	61	
4	Site 4	PM 2.5	178	
		PM 10	149	
Average from 4 sites		PM 2.5	108.75	≤ 55 µg/m³
		PM 10	117.75	≤ 75 µg/m³

Table 2 shows the PM10 and PM2.5 level, measured at four points where Troso weaving was performed. Workers in this setting are potentially exposed to these fine and coarse particulates during various production stages such as thread tying, dyeing, and finishing (Kumie et al., 2020). The results of the descriptive analysis revealed that the mean concentration of PM 2.5 across the four sampling locations was 108.75 µg/m³, while the mean concentration of PM 10 was 117.75 µg/m³ (Table 2). Both values exceeded the national air quality standards stipulated in Government Regulation No. 22/2021 concerning Environmental Protection and Management, which set the permissible limits at 55 µg/m³ for PM2.5 and 75 µg/m³ for PM10 (Government of Indonesia, 2021).

The relatively high standard deviations, namely 66.68 for PM2.5 and 56.84 for PM10, highlight substantial variability between sites, suggesting that pollution levels

are not uniformly distributed across the area. Some sites, such as Site 4 with PM2.5 reaching 178 µg/m³, recorded concentrations more than three times the regulatory threshold, reflecting localized hotspots of intense pollution likely associated with specific weaving or dyeing activities. Conversely, sites with lower values still exceeded the permissible limits, reinforcing that even the least polluted areas remain unsafe in terms of air quality. Such findings underscore the urgency of implementing dust control measures and local exhaust ventilation in weaving facilities

Respondent Characteristics

Table 3 presents the characteristics of respondents working in the Troso weaving industry. The majority of workers were aged ≥ 40 years (55.4%) with an average age of 41.04 years, indicating that this sector is still dominated by older individuals who have been engaged in weaving for a long time. Male workers accounted for 68.3%, showing that men still form the largest share of the workforce, although women also contributed significantly (31.7%). In terms of education level, 75.2% of respondents had a low education status (≤ senior high school), suggesting that weaving remains a labor-intensive activity managed largely by individuals with limited formal education. This aligns with the traditional, family-based nature of Troso weaving, where skills are inherited across generations rather than obtained through formal schooling.

Table 3.
Frequency Distribution of Respondent Characteristics Among Troso Workers, Jepara

No	Variable	n	%	Min	Max	Mean
1	**Age**			22	65	41.04
	> 40 years	56	55.4			
	≤ 40 years	45	44.6			
2	**Gender**					
	Male	69	68.3			
	Female	32	31.7			
3	**Education Level**					
	Low (< senior high school)	76	75.2			
	High (≥ senior high school)	25	24.8			
4	**Exposure Duration**					
	≥ 40 hours/week	66	65.3	20	59	42.5
	< 40 hours/week	35	34.7			
5	**Working Period**			2	35	15.97
	> 5 years	82	81.2			
	≤ 5 years	19	18.8			
6	**Coloring Type**					
	Contain Chromium	73	72.3			
	Other Chemicals (Copper (Cu), Cadmium (Cd), Lead (Pb), Silica (Si) and Chloride Ion (Cl^-)	28	27.7			
7	**Coloring Frequency**			1	4	2.13
	> 2 times/day	33	32.7			
	≤ 2 times/day	68	67.3			
8	**Personal Protective Equipment (PPE)**					
	Incomplete	74	73.3			
	Complete	27	26.7			

The exposure patterns also reveal a high intensity of work. Most workers (65.3%) were exposed for ≥ 40 hours per week, with an average exposure time of 42.5 hours, reflecting the dependence of household-based industries on continuous production to meet demand. Furthermore, 81.2% of respondents had worked in the industry for more than five years, with an average of 15.97 years, emphasizing the long-term engagement of workers in this occupation. In terms of raw materials, a considerable proportion (72.3%) reported using dyes containing chromium, while the rest (27.7%) used other chemicals such as copper (Cu), cadmium (Cd), lead (Pb), silica (Si), and chloride ion (Cl^-). Coloring activities were mostly carried out at relatively low frequency, with 67.3% performing coloring ≤ 2 times per day, suggesting variability in workload intensity depending on production cycles. However, protective measures were minimal, as 73.3% of workers reported incomplete or no use of personal protective equipment (PPE), reflecting limited awareness, resources, or enforcement regarding occupational safety in the home industry context. Taken together, these characteristics illustrate that Troso

weaving remains a traditional, family-driven, and high-exposure activity with limited modernization in both production and occupational safety and health practices.

The Relationship Between Independent Variables and Respiratory Disorders

The bivariate analysis (Table 4) showed a significant association between exposure duration and working period with respiratory disorders (p = 0.001; PR = 7.333; 95%CI=3.01-17.85 and PR = 20.935; 95%CI=7.34-59.6). Workers exposed for ≥ 40 hours/week had a higher prevalence of respiratory disorders (78.6%) compared to those working < 40 hours/week (33.3%). Similarly, workers with a working period of > 5 years experienced more respiratory complaints (82.5%) than those with ≤ 5 years of service (18.4%).

Table 4.
Bivariate Analysis Between Independent Variables and Respiratory Disorders Among Troso Workers, Jepara

Variable	Having respiratory disorders		Not having respiratory disorders		p-value	PR (95%CI)
	f	%	f	%		
Exposure Duration						
≥ 40 hours/week	44	78.6%	12	21.4%	0.001*	7.333 (3.01-17.85)
< 40 hours/week	15	33.3%	30	66.7%		
Working Period					0.001*	20.935 (7.34-59.6)
> 5 years	52	82.5%	11	17.5%		
≤ 5 years	7	18.4%	31	81.6%		
Coloring Type					0.082	2.410 (0.99-5.86)
Contain Chromium	47	64.4%	26	35.6%		
Other Chemicals	12	42.9%	16	57.1%		
Coloring Frequency					0.295	1.688 (0.74-3.83)
> 2 times/day	27	65.9%	14	34.1%		
≤ 2 times/day	32	53.3%	28	46.7%		
Personal Protective Equipment (PPE)					1.000	0.954 (0.38-2.33)
Incomplete	43	58.1%	31	41.9%		
Complete	16	59.3%	11	40.7%		

* = significant; PR = Prevalence Ratio

Inhaled particulate matter (PM10 and PM2.5) deposits along the respiratory tract according to particle size, with PM10 retained in the upper airways and PM2.5 reaching the alveoli. Both generate oxidative stress and reactive oxygen species (ROS), activating transcription factors (NF-κB, AP-1) that drive pro-inflammatory cytokine release, epithelial injury, barrier dysfunction, and cell death via ferroptosis and pyroptosis. Prolonged exposure sustains inflammation and oxidative damage, leading to airway remodeling, fibrosis, and chronic diseases such as asthma and chronic obstructive pulmonary disease (COPD). Moreover, PM10 and PM2.5 can induce DNA damage and epigenetic modifications, disrupting gene expression and promoting long-term pathological outcomes (Kalmatov et al., 2025; Leikauf et al., 2020; Taylor-Blair et al., 2024). Meanwhile, Cr exposure, especially in occupational settings, poses significant risks to respiratory health, including inflammation, lung function decline, and cancer. The mechanisms involve oxidative stress, DNA damage, and chronic inflammation (Zhang et al., 2023).

This biological mechanism is consistent with the symptoms reported by Troso weaving workers during interviews, where 26 respondents (25.7%) frequently experienced coughing either during the day or at night, and 24 respondents (24.8%) reported recurrent coughing after waking up. Meanwhile, the least common symptoms were recognizing that their breathing was not normal (8 respondents, 8%) and needing to stop to breathe when walking at a normal speed on flat ground (9 respondents, 8.9%). These patterns reflect the progressive nature of chronic respiratory impairment, where mild symptoms such as persistent cough occur earlier and more frequently, while more severe manifestations like activity-limiting dyspnea appear in a smaller proportion of workers.

These findings are consistent with the research (Berlian et al., 2023), who reported that workers in the textile industry in Semarang with > 5 years of service had significantly higher respiratory complaints (p = 0.037). Particulates such as PM2.5 and PM10 have a direct impact on respiratory health, especially for workers and communities living around traditional weaving industries. Processes such as spinning, weaving, and processing of textile materials produce fine dust that is easily inhaled. Maksuk et al. (2022) in Palembang also found that PM2.5 and PM10 concentrations in weaving environments exceeded air quality thresholds, thereby increasing non-carcinogenic risks to the respiratory system if exposure persists (Maksuk et al., 2022). Both studies reinforce that cumulative exposure, both in terms of working hours and

years of service, is a key determinant of respiratory disorders.

Meanwhile, variables such as type of dye, frequency of dyeing, and PPE use were not significantly associated with respiratory disorders. The non-significant relationship with dye type (p = 0.082) may be explained by the fact that Cr exposure tends to exert more systemic effects (e.g., neurotoxicity) rather than direct respiratory outcomes, especially when airborne Cr concentrations are not sufficiently high. Moreover, some weaving workshops had natural ventilation, reducing the inhalation exposure from the dyeing process. Dyeing frequency also did not show a significant relationship (p = 0.295). This may be because although many workers performed dyeing ≤ 2 times/day, the main source of respiratory exposure was continuous dust (PM2.5 and PM10) generated during spinning and weaving, rather than the dyeing process itself (Kumie et al., 2020). In other words, dust exposure was constant and chronic, which overshadowed the contribution of dyeing frequency to respiratory outcomes.

Similarly, PPE use showed no significant association with respiratory disorders (p = 1.000). Although the majority of workers did not use complete PPE (73.3%), those who did mainly wore thin cloth masks, which are ineffective against PM2.5 or chromium vapors exposure. With such low protection efficacy, the presence or absence of PPE did not create a significant difference in respiratory risk. Overall, these findings emphasize that cumulative exposure (long working hours and prolonged service years) is the most influential factor in respiratory disorders among Troso weaving workers. The biological plausibility lies in chronic inflammation, oxidative stress, and airway remodeling due to fine particulate and heavy metal exposure. In contrast, variables such as dyeing types and PPE were not significant due to lower exposure levels or ineffective protection, which failed to meaningfully affect respiratory outcomes in this worker population.

The Relationship Between Independent Variables and Neurological Disorders

Bivariate analysis showed a significant association between neurological disorders and exposure duration, working period, type of dye, frequency of dyeing, and use of PPE (Table 5). Chromium (VI) readily penetrates cell membranes, where it elevates reactive oxygen species (ROS) production and induces oxidative stress that damages neuronal DNA and proteins. With prolonged exposure, this stress disrupts essential enzymes such as acetylcholinesterase (AChE), impairing its ability to regulate nerve impulse transmission. As AChE activity declines, acetylcholine accumulates at synapses, which can manifest as neurological symptoms including tremors, memory deficits, and impaired concentration. Inhalation or direct contact further allows Cr(VI) to cross the blood–brain barrier, amplifying oxidative stress, inflammation, and molecular injury. Together, these mechanisms demonstrate how Cr(VI) exposure contributes to severe neurological disorders (Zendehdel et al., 2019); (Xu et al., 2023). Meanwhile, particulate matter (PM) enters the human body primarily through inhalation. Once inside, it can affect neurological health through multiple mechanisms, including translocation along transport pathways, induction of neuroinflammation and oxidative stress, disruption of the blood–brain barrier (BBB), epigenetic modifications, metabolic disturbances, and specific cellular processes such as ferroptosis and microglia-derived extracellular vesicle (EV)-mediated neurotoxicity (Thangavel et al., 2025).

Table 5.
Bivariat Analysis Between Independent Variables and Neurogical Disorders Among Troso Weaving Workers, Jepara

Variable	Having neurological disorders		No symptoms of neurological disorders		p-value	PR (95% CI)
	f	%	f	%		
Exposure Duration						
Duration ≥ 40 hours/week	30	53.6%	26	46.4%	0.001*	5.536
Duration < 40 hours/week	12	26.7%	33	73.3%		(1.36-7.37)
Working Period						
Long (> 5 years)	35	55.6%	28	44.4%	0.001*	5.536
Short (≤ 5 years)	7	18.4%	31	81.6%		(2.12-14.44)
Coloring Type						
Contain Chromium	39	64.4%	34	46.6%	0.001*	9.559
Other Chemicals	3	42.9%	25	89.3%		(2.65-34.47)
Coloring Frequency						
Frequent (> 2 times/day)	23	56.1%	18	43.9%	0.025*	2.757
Rare (≤ 2 times/day)	19	31.7%	41	68.3%		(1.21-6.27)
Personal Protective Equipment (PPE)					0.001*	8.914
Incomplete	39	52.7%	35	47.3%		(2.46-32.19)
Complete	3	11.1%	24	88.9%		

* = significant; PR = Prevalence Ratio

Exposure duration ≥ 40 hours/week and working period > 5 years significantly increased the risk of neurological disorders (PR = 5.536; 95%CI=1.36-7.37 and PR = 5.536; 95%CI=2.12-14.44, respectively). This is consistent with Berlian et al. (2023), who reported that textile workers with longer working hours and extended employment were more vulnerable to health problems due to the accumulation of particulate and chemical exposures (Berlian et al., 2023). In the Troso context, poor ventilation, the absence of wastewater treatment facilities, and the extensive use of hazardous chemicals accelerate the accumulation of such risks.

The use of chromium-based dyes showed a strong association with neurological disorders (p = 0.001; PR = 9.559; 95%CI=2.65-34.47). Although chromium dyes also pose respiratory risks, statistical analysis for respiratory variables was not significant. This discrepancy may be explained by additional factors, such as natural ventilation in home-based weaving sites that disperses some airborne particles, or worker adaptation to respiratory irritation over time. However, the neurotoxic properties of Cr(VI), which can enter not only through inhalation but also via dermal absorption and ingestion, make it more consistently associated with chronic neurological impacts than with respiratory outcomes.

Dyeing frequency > 2 times/day also significantly increased the risk of neurological disorders (PR = 2.757; 95%CI=1.21-6.27). Although the majority of workers reported dyeing ≤ 2 times/day, repeated daily exposures still contributed to cumulative neurological risks. Health impacts from chemical exposure may appear after years of repeated low-intensity exposures. The results of interviews and field observations showed that workers prefer to use chromium dyes for several reasons, namely, the color is more stable, the resulting color tends to last longer and does not fade easily, giving a more attractive final result, more varied color variations, and chromium is also considered more resistant to weather and washing, making it a suitable choice for textile products that will be washed frequently. The dye most widely used by respondents in this study was a dye containing chromium of the naphthol type. The dyeing process is a process in which more chromium vapor appears because this process does not require a short time.

Considering the dangers of chromium-containing dyes for weaving workers and the environment, some weaving sites and other researchers have developed natural dyes. Research in Bima, Indonesia, and Gabes, Tunisia, shows the utilization of natural dyes as an environmentally friendly alternative to synthetic dyes in the textile industry. In Bima, dyes are derived from local plants such as indigo leaves, noni, bark and seaweed for traditional weaving threads (Wiraningtyas et al., 2021). Meanwhile, a study in Tunisia used date palm frond waste (fibrillium) to dye wool and nylon fabrics with strong and durable dyeing results (Baaka et al., 2023). Both studies confirmed that natural dyes have the potential to replace chemical dyes while improving aesthetic value, supporting local economies and reducing the impact of environmental pollution.

The use of PPE was also significantly associated with neurological disorders (p = 0.001; PR = 8.914; 95%CI=2.46-32.19). Most workers (73.3%) do not use complete PPE, and do not even wear adequate clothing, thus providing insufficient protection against chromium and particle absorption. In the weaving industry, the use of comprehensive personal protective equipment (PPE) is key to maintaining worker health. Dust and chemicals present in the work environment can harm the lungs and skin of workers if they are not equipped with appropriate protective equipment. The use of personal protective equipment (PPE) when working aims to minimize the exposure that can enter the body through inhalation or skin contact (Ashwini et al., 2024). Although the use of PPE does not completely protect against chromium exposure, it can reduce the severity of the possible impacts. For example, using a mask protects oneself from exposure to pollutant vapors so that the vapors are not inhaled and do not accumulate in the respiratory tract, which can cause respiratory problems. Therefore, the correct use of PPE is important to protect workers' respiratory systems from the negative impacts of exposure to hazardous chemicals. While no significant association was found between PPE and respiratory disorders, this may be explained by the fact that workers could still experience respiratory symptoms even with simple PPE. In contrast, neurological symptoms arise after chronic accumulation, making the differences more evident among those without complete PPE over the long term.

The implications of these findings extend beyond immediate health concerns, pointing to a looming crisis of chronic health problems among Troso weavers if left unaddressed. The combination of prolonged exposure to occupational hazards and insufficient protective measures creates a perfect storm for the development of long-term health issues. This situation calls for a multi-faceted approach to worker protection, including comprehensive health education programs tailored to the specific risks of the weaving industry, stringent enforcement of existing safety regulations, and widespread distribution and proper use of PPE. Additionally, implementing regular health screenings and monitoring programs could help in early detection and intervention of occupational illnesses, potentially mitigating the progression to chronic conditions. The urgency of these preventive measures cannot be overstated, as they are crucial for safeguarding the health and longevity of the workforce in the Troso weaving industry.

CONCLUSION

This study demonstrates that workers in the Troso weaving industry are continuously exposed to chromium-containing dyes and fine particulate matter (PM2.5 and PM10), largely due to the absence of wastewater treatment, poor ventilation, and inadequate use of PPE. Although measured chromium levels in wastewater remained below the regulatory threshold, their presence

confirms the use of chromium-based materials in production, and continuous direct discharge into the environment heightens the risk of long-term accumulation in water, soil, and air. Bivariate analysis revealed significant associations between neurological disorders and several exposure-related factors, including duration of exposure, working period, type and frequency of dyeing, and PPE use. In contrast, although respiratory complaints were common, statistical associations with specific variables were weaker, likely due to natural ventilation in household production settings and workers' adaptation to irritant exposures. Taken together, the results highlight that neurological outcomes are more consistently linked with occupational exposures than respiratory disorders, underscoring the nervous system's higher vulnerability to chronic heavy metal and particulate toxicity. These findings underscore the urgent need for improved occupational health and safety measures to mitigate long-term health risks in this home industry.

SUGGESTION

Comprehensive occupational safety and health measures must be implemented immediately to improve occupational safety in the Troso textile industry. The main priorities are the technical control of exposure to chromium and dust particles, making use of natural dyes, provision of PPE at each home industry by business owners, and worker education regarding health risks. In addition, environmental monitoring and regular health checks are essential to prevent long-term effects on workers and the surrounding environment.

REFERENCE

Ashwini, K., Vyshnavi, M., Pachiyappan, K. M., Sathyam, R. D., & Jothi, J. (2024). A study on safety measurements in the textiles industry. *International Research Journal of Engineering and Technology (IRJET)*, *11*(10), 235–239. [Publisher]

Baaka, N., Khiari, R., & Haji, A. (2023). Ecofriendly dyeing of textile materials with natural colorants from date palm fiber fibrillium. *Sustainability*, *15*(2), 1688. [Crossref] [Publisher]

Berlian, A. I., Setiani, O., Sulistiyani, S., Raharjo, M., & Darundiati, Y. H. (2023). The relationship of dust exposure with respiratory disorders symptoms among textile industry workers. *Journal of Ecological Engineering*, *24*(3), 35–46. [Crossref] [Publisher]

Government of Indonesia. (2021). *Government Regulation No. 22/2021 concerning Environmental Protection and Management*. Government of Indonesia. [Publisher]

Islam, S., Jalil, M. A., Belowar, S., Saeed, M. A., Hossain, S., Rahamatolla, M., & Ali, S. (2024). Role of mordants in natural fabric dyeing and their environmental impacts. *Environmental Science and Pollution Research International*, *32*(2), 452–468. [Crossref] [Publisher]

Islam, S., Parvin, F., Urmy, Z., Ahmed, S., & Saiful Islam, A. K. M. (2020). A study on the solutions of environment pollutions and worker's health problems caused by textile manufacturing operations. *Biomedical Journal of Scientific & Technical Research*, *28*(4), 21831–21842. [Crossref] [Publisher]

Iyer, M., Anand, U., Thiruvenkataswamy, S., Babu, H. W. S., Narayanasamy, A., Prajapati, V. K., Tiwari, C. K., Gopalakrishnan, A. V, Bontempi, E., Sonne, C., Barceló, D., & Vellingiri, B. (2023). A review of chromium (Cr) epigenetic toxicity and health hazards. *Science of The Total Environment*, *882*, 163483. [Crossref] [Publisher]

Kalmatov, R., Ismailov, I., Azhibaev, D., Abdiraiimov, I., & Chaurasia, J. K. (2025). The role of high levels of air pollution among human populations with predisposition to respiratory diseases. *Journal of Experimental Zoology India*, *28*(2), 1211–1224. [Crossref] [Publisher]

Kishor, R., Purchase, D., Ferreira, L. F. R., Mulla, S. I., Bilal, M., & Bharagava, R. N. (2020). Environmental and health hazards of textile industry wastewater pollutants and its treatment approaches. In C. M. Hussain (Ed.), *Handbook of Environmental Materials Management* (pp. 1–25). Springer. [Crossref] [Publisher]

Kumie, A., Bråtveit, M., Deressa, W., Wakuma, S., & Moen, B. E. (2020). Personal cotton dust exposure in spinning and weaving sections of a textile factory, north Ethiopia. *Ethiopian Journal of Health Development*, *34*(2), 97–105. [Publisher]

Leikauf, G. D., Kim, S.-H., & Jang, A.-S. (2020). Mechanisms of ultrafine particle-induced respiratory health effects. *Experimental and Molecular Medicine*, *52*(3), 329–337. [Crossref] [Publisher]

Maksuk, M., Kumalasari, I., & Shobur, S. (2022). Health risk assessment of human exposure to dust exposure on communities around weaving industry in Palembang, Indonesia. *International Journal of Advanced Health Science and Technology*, *2*(4), 274–281. [Crossref] [Publisher]

Ministry of Environment and Forestry Indonesia. (2014). *Regulation No. 5/2014 concerning Wastewater Quality Standard*. Ministry of Environment and Forestry, Republic of Indonesia. [Publisher]

Ramadan, W. A., Elkafas, E., Shalaby, S., & Elsallamy, R. (2024). Occupational health disorders among workers in textile dyeing industry. *Egyptian Journal of Occupational Medicine*, *48*(3), 95–111. [Crossref] [Publisher]

Regency, D. J. (2023). *Data of Industry Potention in Jepara Regency, 2022*. Disperindag Jepara. [Publisher]

Sarasi, V., Primiana, I., Harsanto, B., & Satyakti, Y. (2023). Sustainable supply chain of Indonesia's textile & apparel industry: Opportunities and challenges. *Research Journal of Textile and Apparel*, *3*(2), 128–138. [Crossref] [Publisher]

Sarwono, S., Prameswari, N. S., Darwoto, D., Akhmad, Z., & Hassan, H. (2023). The experiment of Jepara

Troso woven in local wisdom. *Harmonia: Journal of Arts Research and Education*, *23*(1), 28–39. [Crossref] [Publisher]

Saxena, R., & al., et. (2022). Mixed metals exposure and cognitive function in Bangladeshi adolescents. *Ecotoxicology and Environmental Safety*, *232*, 113229. [Crossref] [Publisher]

Shammout, M. W., Shatanawi, M., & Awwad, A. M. (2022). Fate and management of pollution of hexavalent chromium Cr(VI) and heavy metals in the Zarqa River Basin in Jordan. *Journal of Ecological Engineering*, *23*(2), 108–115. [Crossref] [Publisher]

Suteja, Y., Dirgayusa, I. G. N. P., & Purwiyanto, A. I. S. (2020). Chromium in Benoa Bay, Bali – Indonesia. *Marine Pollution Bulletin*, *153*, 111017. [Crossref] [Publisher]

Taylor-Blair, H. C., Siu, A. C. W., Haysom-McDowell, A., Kokkinis, S., Bani Saeid, A., Chellappan, D. K., Oliver, B. G. G., Paudel, K. R., De Rubis, G., & Dua, K. (2024). The impact of airborne particulate matter-based pollution on the cellular and molecular mechanisms in chronic obstructive pulmonary disease (COPD). *Science of the Total Environment*, *954*, 176413. [Crossref] [Publisher]

Thangavel, P., Park, D., & Lee, Y.-C. (2025). Neurotoxic effects of airborne particulate matter: Mechanisms and health implications. *Journal of Biochemical and Molecular Toxicology*, *39*(6), e70322. [Crossref] [Publisher]

Tumolo, M., Ancona, V., De Paola, D., Losacco, D., Campanale, C., Massarelli, C., & Uricchio, V. F. (2020). Chromium pollution in European water, sources, health risk, and remediation strategies: An overview. *International Journal of Environmental Research and Public Health*, *17*(15), 5438. [Crossref] [Publisher]

Wilson, A. M., Ogunseye, O., Fingesi, T., McClelland, D. J., Gerald, L. B., Harber, P., Beamer, P. I., & Jones, R. M. (2023). Exposure frequency, intensity, and duration: What we know about work-related asthma risks for healthcare workers from cleaning and disinfection. *Journal of Occupational and Environmental Hygiene*, *20*(8), 350–363. [Crossref] [Publisher]

Wiraningtyas, A., Ruslan, R., Sandi, A., & Nasir, M. (2021). Development of the weaving home industry through the use of natural dyes in the East Rabadompu Village of Bima City. *Journal of Physics: Conference Series*, *1833*, 12061. [Crossref] [Publisher]

Xia, Y., Wen, Y., Yang, Y., Song, X., Wang, Y., & Zhang, Z. (2025). Exploring bio-remediation strategies by a novel bacteria Micrococcus sp. strain HX in Cr(VI)-contaminated groundwater from long-term industrial polluted sites. *Ecotoxicology and Environmental Safety*, *289*, 117474. [Crossref] [Publisher]

Xu, Y., Tang, X., Xie, Q., Lyu, X., Wang, Z., & Jiang, J. (2023). Chromium contamination and health risk assessment of soil and agricultural products in a rural area in southern China. *Toxics*, *11*(1), 27. [Crossref] [Publisher]

Yan, X., Yang, B., He, E., Peijnenburg, W. J. G. M., Zhao, L., Xu, X., Cao, X., Romero-Freire, A., & Qiu, H. (2023). Fate and transport of chromium in industrial sites: Dynamic simulation on soil profile. *Science of The Total Environment*, *858*. [Crossref] [Publisher]

Zendehdel, R., Fazli, Z., & Rezazadeh Azari, M. (2019). Neurological risk assessment of co-exposure to heavy metals (chromium and nickel) in chromium-electroplating workers. *WORK*, *63*(3), 355–360. [Crossref] [Publisher]

Zeviani, M., & Viscomi, C. (2022). Mitochondrial Neurodegeneration. *Cells*, *11*, 1–45. [Crossref] [Publisher]

Zhang, Y., Hong, S., Zhang, Q., Su, Z., Hu, G., Wang, T., Yu, S., Yuan, F., Zhu, X., & Jia, G. (2023). Relationship between systemic inflammation and lung injury induced by chromate exposure: A cross-sectional study in workers. *Journal of Hazardous Materials*, *452*, 131294. [Crossref] [Publisher]