

Overview of historical occupational exposure to trichloroethylene in China

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Abstract

Objectives: Trichloroethylene (TCE) is a carcinogen that has been causally linked to kidney cancer and possibly other cancer sites including the liver and lymphatic system. Its use in China has increased since the early 1990s due to the growing metal and electronic industries. We aimed to summarize the major sources of occupational exposure to TCE over time in China.

Methods: Occupational TCE exposure assessments were extracted from both the Chinese and English scientific literature, as well as from industrial hygiene surveys performed in Guangdong, Tianjin, and Hong Kong. Weighted mean concentrations were summarized by occupation and industry.

Results: We extracted over 12,412 measurements from 55 industries and 35 occupations across China since 1976, of which at least 201 were from case reports. More than half of the measurements were derived from 4 industries, including “manufacture of footwear” (29%), “manufacture of electronic components and boards” (17%), “manufacture of games and toys” (14%), and “manufacture of fabricated metal products, except machinery and equipment” (13%). Several occupations, including “electronic-equipment assemblers,” “metal-, rubber, and plastic-products assemblers,” “metal finishing-, plating-, and coating-machine operators,” “precision-instrument makers and repairers,” “printing-machine operators,” and “ore and metal furnace operators” were identified as having high risks of TCE exposure, with either pooled weighted mean task-based or full-shift concentrations over 150 mg/m³ over the years. TCE exposure levels varied across different occupations and changed over time. In 1990 and earlier, 1991 to 2000, the exposure levels were at their highest with pooled weighted mean task-based concentrations of 202.8 and 242.9 mg/m³, respectively. Subsequently, the level decreased to 118.7 mg/m³ from 2001 to 2010 before increasing again to 216.0 mg/m³ from 2011 onwards. This overall trend was also observed for “electronic-equipment assemblers” and “metal finishing-, plating-, and coating-machine operators.” However, for “precision-instrument makers and repairers,” the exposure levels consistently declined over the years.

Conclusions: Over the past few decades, degreasing-related occupations, such as “electronic-equipment assemblers” and “metal finishing-, plating-, and coating-machine operators” have been consistently identified as being at high risk of significant TCE exposure and continued to warrant attention. Identifying high-risk industries and occupations can inform the development of targeted interventions and regulations to mitigate TCE exposure. Furthermore, enhancing the quality and coverage of exposure measurement data in occupational settings will advance epidemiological investigations in occupational health.

Key words: China; metal degreasing; occupational exposure; trichloroethylene

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What's Important About This Paper?

This study extracted trichloroethylene (TCE) exposure data for workplaces in China from the Chinese and English language scientific publications and combined with available measurement datasets to summarize exposures over time by industry and occupations. While a downward trend in exposures was seen, this trend has reversed in recent years. These data can be used for epidemiologic research and targeted interventions in high-risk industries and occupations.

Introduction

Trichloroethylene (TCE) is a chlorinated solvent used in various industries. The Global Burden of Diseases, Injuries, and Risk Factors Study for 1990 to 2017 reported a 30.3% increase in occupational TCE exposure worldwide (Li et al. 2021). TCE is a human carcinogen causing kidney cancer according to the International Agency for Research on Cancer monograph working group and also noted to be associated with liver cancer and non-Hodgkin lymphoma (IRAC 2014). There are continuing questions about the full spectrum of disease caused by TCE, and thus understanding TCE exposure patterns in occupational settings should provide valuable information for investigating its adverse health effects.

The numbers of exposed workers and reported concentrations of TCE in workplaces have significantly decreased in Europe and North America, while the levels appear somewhat higher in Asia (IRAC 2014). TCE was widely used as a cleaning agent for metal components and electronic devices in China before 2008, mostly in producing household appliances, such as televisions, refrigerators, and air conditioners, as well as automobiles and precision machinery such as watches (Lin 2013). Alongside the growth of these industries, acute and subacute health effects of TCE exposure in the workplace are being recognized as China has recorded multiple incidents of TCE poisoning among workers in the manufacturing industry (Kamijima et al. 2007; Li et al. 2007).

A previous study from Shanghai reported a decreasing trend in TCE concentrations at the workplace based on 932 short-term, area TCE air inspection measurements conducted from 1968 through 2000 (Friesen et al. 2015). Yet no comprehensive description exists of the exposure patterns across different industries, occupations, and time trends across China. Most prior investigations on occupational TCE exposure were limited to case reports, and industrial hygiene surveys, and restricted to a single region. The exposure measurements in case reports are usually conducted by occupational physicians after the occurrence of occupational diseases (Zhang et al. 2010). Industrial hygiene surveys involve systematic measurements conducted in various workplaces within a single region to assess potential risks associated with occupational exposures. However, these surveys typically aimed at all potential hazardous factors, and normally

report the proportions of measured industries exceeding the Occupational Exposure Limit (OEL) for Hazardous Agents in the Workplace (GBZ 2-2002) set by the Chinese government (which should be less than 30 mg/m³ for time-weighted average [TWA] concentration and 60 mg/m³ for short-term exposure level [STEL] and remained in use). Overall, the format and content of case reports and industrial hygiene surveys varied significantly. Therefore, an integrated analysis of diverse data sources across the country is necessary, which could provide a broader view of TCE exposure levels and trends for further investigating its health effects, as well as developing effective occupational health policies to protect workers.

This paper aims to aggregate available data from a wide range of English and Chinese sources, gathering evidence from both published literature and available datasets from industrial hygiene surveys, and give an overview of current and historical occupational exposure to TCE in China.

Methods

To gather as much occupational TCE exposure information as possible, comprehensive searches of electronic databases were conducted in both English and Chinese. In English, PubMed, Embase, and Web of Science were searched. In Chinese, searches were conducted in the China National Knowledge Infrastructure, the China Science and Technology Journal Database (VIP), and the WanFang database. Search methods were adjusted according to the different databases.

To further identify patterns of occupational TCE exposure levels in China, individual measurements were extracted from a measurement dataset that recorded the results of task-based or full-shift air concentrations collected between 1979 and 2018 as part of industrial hygiene surveys in Tianjin and Hong Kong. Another dataset was gathered from a previous study (Lan et al. 2010), which also provided occupational TCE measurements sampled in 2006 in Guangdong. The flow chart of the measurements data extraction is shown in Fig. 1.

Search strategy

Search terms used for the literature review were: ((occupational AND exposure) OR (industrial AND exposure) OR (work AND exposure) OR (workplace

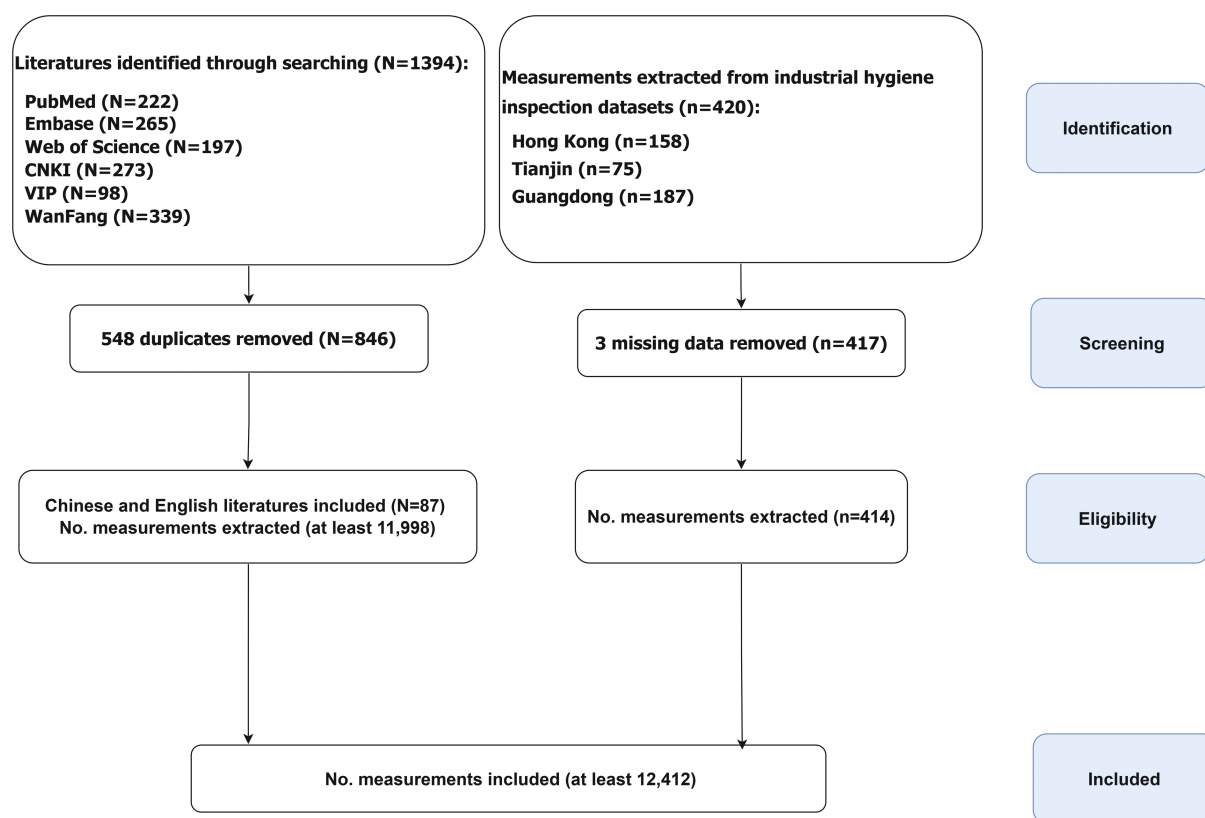


Fig. 1. Flow chart of the measurements extraction process.

AND air concentration) OR (Occupational hazard) OR (occupational health) OR (industrial hygiene)) AND (Trichloroethylene OR TCE OR Chlorinated solvents) AND (China OR Chinese OR Hong Kong). The search strings in Chinese used in different Chinese databases are adjusted and listed in [Supplementary Material 1](#) and the search was conducted April 3, 2024.

Eligibility criteria

Any study reporting occupational TCE exposures in China was considered. We restricted our inclusion to publications in the English or Chinese language. We had no restriction on the time period. The most complete publication was included when multiple publications were based on the same measurement dataset. Publications based on the Guangdong dataset, for which we had the raw data, were excluded.

Data extraction and synthesis

From each paper or measurement dataset, the relevant information was extracted wherever available ([Table 1](#)). Different types of area or personal concentrations were further categorized as full-shift, task-based, and other non-specified.

Analysis

For each extracted (summary) measurement, the arithmetic means (AM) were taken for summarization. If only a single value of formaldehyde concentration was reported, then it was taken as an individual measurement. If the authors only provided a range of values, the AM of minimum and maximum reported values was taken as the average. If only a maximum value was provided, the analysis was based on AM of the maximum and zero. If only the minimum was given, then the observation was considered missing ([Liu et al. 2009](#)). The same rules were applied to the industrial hygiene survey data and we summarized measurements from publications of case reports separately.

The pooled mean concentrations per occupation and industry were then weighted by the number of samples or the estimated smallest number of samples measured for each (summary) measurement, which was calculated by the multiplication of the number of sites measured and the number of measurements taken per site. In circumstances where only one of these metrics was provided (either the number of sites measured or the number of measurements taken per site), it was considered as at least that number of samples were taken. In

Table 1. Information extracted from publications.

Information extracted	Description
Industry	The company name or the type of industry or products they made.
Job/task	Job titles. Job tasks were extracted if job titles were not reported and then coded by occupational epidemiology researchers.
Location	The province or city.
Sample reason	Type of study for scientific publications. Industrial hygiene surveys, occupational hazard assessments, or other types.
Sample year	Year of sampling. When the sample year was not provided, the year of publication was used.
Type of sample	Area or personal sampling.
Number of measurements	The number of measurements or samples taken per site.
Number of sites measured	The number of sites selected per industry or job.
Number of samples	The number of samples tested per industry or job.
Sampling and analytic method	Description of sampling and analytic methods.
Summary statistics	For concentrations reported as TWA, STEL, or non-specified mean concentrations in literature, we further categorized them as full-shift concentration, task-based concentration, or other, respectively. AM, SD, median (minimum-maximum), GM, and GSD were extracted wherever possible. Concentrations in the unit of ppm were transferred to mg/m ³ (25 °C, 1 ppm = 5.374 mg/m ³)
Working conditions	The description of the availability of ventilation systems and other related protective procedures.

Abbreviations: TWA=time weighted average, STEL=short term exposure level, AM=arithmetic mean, SD=standard deviation, GM=geometric mean, GSD=geometric standard deviation.

circumstances where none of the aforementioned sampling information was given, we assigned “at least 1” for a single concentration value and “at least 2” for a range of concentrations or a mean value with standard deviation (SD). The pooled weighted mean TCE occupational exposure concentrations were then grouped based on coded industries and jobs according to the International Standard Industrial Classification of All Economic Activities (ISIC4) (United Nations 2008) and the International Standard Classification of Occupations (ISCO88) (International Labour Organization 2010), respectively.

Results

After excluding publications without assessments specific to an industry or occupation, 87 publications (Supplementary Material 2) with over 11,998 individual measurements of occupational TCE exposure conducted from 1976 to 2022 were included. Additionally, a sum of 414 individual measurements was gathered from the industrial hygiene surveys conducted in Hong Kong, Tianjin, and another series of measurements in Guangdong. The measurements from Hong Kong were conducted around 1990 while those from Guangdong and Tianjin were taken after 2000. In total, over 12,412 measurements from 55 industries and 35 occupations were extracted, as shown in Table 2, Tables S1 and S2, respectively. The pooled weighted mean task-based TCE air concentrations at Chinese workplaces were higher than that of the full-

shift concentrations for most occupations and industries. More than half of the pooled concentrations for various occupations over time exceeded the OEL.

The majority of the data (73%) were obtained from 4 industries: “manufacture of footwear,” “manufacture of electronic components and boards,” “manufacture of games and toys,” and “manufacture of fabricated metal products, except machinery and equipment.” Six occupations were identified as having higher levels of TCE exposure over time, with a pooled weighted mean concentration of 150 mg/m³ or higher of at least 100 individual measurements. The pooled weighted mean (range) values of task-based and full-shift concentrations for “metal-, rubber-, and plastic-products assemblers” were 190.5 (1.1 to 205.8) and 4.8 (0.0 to 13.1) mg/m³; for “electronic-equipment assemblers” were 171.8 (0.0 to 660.2) and 127.5 (0.1 to 3,255.3) mg/m³; for “metal finishing-, plating-, and coating-machine operators” were 310.0 (0.0 to 2,148.0) and 398.0 (0.6 to 2,005.5) mg/m³; for “printing-machine operators” were 195.3 (1.5 to 2,792.4) and 94.7 (0.1 to 639.0) mg/m³; for “precision-instrument makers and repairers” were 236.0 (0.0 to 2,685.0) and 65.6 (0.1 to 361.2) mg/m³; and the pooled weighted mean (range) task-based concentration for “Ore and metal furnace operators” was 220.0 (220.0 to 220.0) mg/m³. The occupation with the highest TCE exposure level at workplaces caught in the current review was “Incinerator, water-treatment and related plant operators.” A case report study reported the measurements taken after a case occurred and the task-based concentration was 5,484 mg/m³.

Table 2. TCE concentrations (mg/m³) by occupations in China, 1976 to 2022.

Job title (ISCO88)	Task-based		Full-shift		Others	
	Concentrations	No.ˆ	Concentrations	No.ˆ	Concentrations	No.ˆ
Mechanical engineers (2145)	45.0 (45.0–45.0)	62				
Physical and Engineering Science Technicians (311)	22.7 (5.5–27.0)	10	9.2 (9.2–9.2)	2		
Painters and related workers (7141)	399.6 (26.9–1,342.5)	5			0.0	1
Varnishers and related painters (7142)	9.5 (6.0–107.4)	43				
Welders and flamecutters (7212)	47.3 (3.0–145.0)	6				
Agricultural- or industrial-machinery mechanics and fitters (7233)	16.7 (1.5–25.0)	53				
Electrical mechanics and fitters (7241)			9.7	1		
Precision-instrument makers and repairers (7311)*	182.7 (103.2–341.5)	6	474.3 (5.0–1,428.0)	19	41.8 (41.8–41.8)	4
Precision-instrument makers and repairers (7311)	236.0 (0.0–2,685.0)	61	65.6 (0.1–361.2)	118	69.4 (0.6–322.0)	98
Jewellery and precious-metal workers (7313)	325.9 (53.7–805.5)	9				
Glass makers, cutters, grinders, and finishers (7322)	344	1				
Shoe-makers and related workers (7442)	2.2 (1.8–12.1)	214	41.7 (0.0–84.0)	109	1.6 (0.8–12.1)	4,018
Ore and metal furnace operators (8121)	220.0 (220.0–220.0)	475				
Metal melters, casters, and rolling-mill operators (8122)*			93.9 (93.9–93.9)	6		
Metal-heat-treating-plant operators (8123)	240.0 (240.0–240.0)	4				
Glass and ceramics kiln and related machine operators (8131)	510.0 (510.0–510.0)	20				
Chemical-processing-plant operators (815)					37.0 (37.0–37.0)	10
Incinerator, water-treatment, and related plant operators (8163)*	2,742.0	1				
Incinerator, water-treatment, and related plant operators (8163)	16.6 (0.1–30.0)	20	15.0 (15.0–15.0)	11		
Machine-tool operators (8211)*	113.7 (46.0–164.0)	3				
Machine-tool operators (8211)	68.4 (0.3–582.7)	22	0.7 (0.7–0.7)	12		
Chemical-product machine operators (822)*					56.4	1
Chemical-products machine operators (8220)*					369.3	1
Chemical-products machine operators (8220)	70.0 (70.0–70.0)	11				
Metal finishing-, plating- and coating-machine operators (8223)*	364.2 (102.0–917.5)	22	124.3 (98.5–137.2)	4	377.1	1
Metal finishing-, plating-, and coating-machine operators (8223)	310.0 (0.0–2,148.0)	134	398.0 (0.6–2,005.5)	412	356.4 (17.0–415.2)	81
Chemical-products machine operators not elsewhere classified (8229)*			145.0	1		

Table 2. Continued

Job title (ISCO88)	Task-based		Full-shift		Others	
	Concentrations	No. ^{`</sup>	Concentrations	No. <sup>`}	Concentrations	No. [`]
Chemical-products machine operators not elsewhere classified (8229)	1.1	1				
Rubber-products machine operators (8231)	0.3 (0.3–0.3)	2	0.3 (0.3–0.3)	2		
Plastic-products machine operators (8232)	136.0 (1.4–840.8)	43	0.5 (0.3–2.9)	10		
Printing-machine operators (8251)	195.3 (1.5–2,792.4)	87	94.7 (0.1–639.0)	40	5.2 (5.2–5.2)	239
Textile, fur, and leather product machine operators (826)	630.0 (630.0–630.0)	12				
Weaving- and knitting-machine operators (8262)	79.0 (60.0–98.0)	6				
Bleaching-, dyeing-, and cleaning-machine operators (8264)	720.7 (710.0–770.0)	28				
Electrical-equipment assemblers (8282)*	108.0 (34.0–145.0)	3				
Electrical-equipment assemblers (8282)			2.3	1		
Electronic-equipment assemblers (8283)*	118.6 (0.1–591.4)	38	281.2 (6.7–677.0)	66	148.2 (3.8–340.5)	11
Electronic-equipment assemblers (8283)	171.8 (0.0–660.2)	201	127.5 (0.1–3,255.3)	640	15.0 (7.7–673.0)	1,385
Metal-, rubber-, and plastic-products assemblers (8284)*			94.0 (39.0–107.8)	5		
Metal-, rubber-, and plastic-products assemblers (8284)	190.5 (1.1–205.8)	479	4.8 (0.0–13.1)	321	3.0 (0.8–7.6)	2,449
Wood and related products assemblers (8285)	3.0 (3.0–3.0)	32	0.2 (0.2–0.2)	12	2.3 (2.3–2.3)	300
Other machine operators and assemblers (8290)*					107.6 (89.8–125.5)	2
Helpers and cleaners (9132)	11.0 (11.0–11.0)	10				
Freight handlers (9333)*			35.0 (9.7–60.3)	4		
Freight handlers (9333)	39.6 (0.5–41.0)	111	80.1	1		
Unknown (NA)*	106.1 (77.2–164.0)	3	66.4 (66.4–66.4)	2		
Unknown (NA)	1,015.0	1	380.5	1		

Weighted mean concentrations (range) were calculated from all measurements of both literature (except case report) and representative industrial hygiene surveys, and the minimum and maximum of the reported summary concentrations were shown in brackets.

*Measurements were extracted from the case report.

[`]No.: Estimated number of measurements. The smallest number of measurements were taken if we only know at least how many measurements were taken per summary measurements.

General characteristics

The collected data covered more than 13 provinces, municipalities, and autonomous regions, representing 38% of the 34 administrative regions in China. A subgroup analysis of exposure levels for different regions is shown in Table S3. Guangdong and Shanghai were regions with the most exposure assessments and the pooled weighted mean (range) task-based concentrations extracted from publications were 133.8 (0.1 to

1,964.8) and 183.3 (0.1 to 770.0) mg/m³, respectively. Assessments from Hong Kong were all extracted from the industrial hygiene survey dataset and the pooled weighted mean (range) task-based concentration was 359.8 (0.0 to 2,792.4) mg/m³.

The number of assessments reported by publications started increasing with the beginning of the economic reform in the late 1980s. It peaked between the mid-1990s and early 2000s, when the demand for electronics

Table 3. TCE concentrations (mg/m³) at workplaces in China for different historical periods.

Job Title (ISCO-88)	Year group	Task-based		Task-based*		Full-shift		Full-shift*	
		Concentrations	No.	Concentrations	No.	Concentrations	No.	Concentrations	No.
All	1990 and before	202.8 (0.0–2,792.4)	907			168.1 (32.0–415.2)	64		
	1991–2000	242.9 (8.1–1,772.1)	147	2,742.0	1	387.1 (11.6–3,255.3)	105	213.5 (5.0–340.5)	9
	2001–2010	118.7 (0.6–1,015.0)	947	203.9 (0.1–917.5)	70	66.3 (0.0–1,887.4)	998	296.0 (9.7–1,428.0)	91
	2011 and after	216.0 (0.1–1,964.8)	162	65.5 (0.3–108.9)	5	278.0 (0.0–2,005.5)	526	94.4 (6.7–124.2)	7
	1990 and before	103.7 (0.0–375.9)	84						
Electronic- equipment assemblers (8283)	1991–2000	186.2 (21.5–402.8)	3			499.4 (71.7–3,255.3)	67	239.6 (43.0–340.5)	8
	2001–2010	121.1 (25.7–505.3)	73	125.1 (0.1–591.4)	36	88.3 (3.1–729.2)	491	291.9 (30.8–677.0)	57
	2011 and after	400.3 (0.1–660.2)	41	0.3 (0.3–0.3)	2	58.4 (0.1–370.0)	82	6.7	1
	1990 and before	350.7 (0.0–2,148.0)	38			168.1 (32.0–415.2)	64		
Metal finishing, plating- and coating-machine operators (8223)	1991–2000	423.1 (107.4–1,342.5)	24			205.8 (205.8–205.8)	16		
	2001–2010	161.8 (5.5–756.0)	46	404.5 (102.0–917.5)	19	136.2 (0.6–1,887.4)	99	137.2 (137.2–137.2)	2
	2011 and after	408.1 (1.7–1,964.8)	26	108.9 (108.9–108.9)	3	585.5 (0.7–2,005.5)	233	111.4 (98.5–124.2)	2
	1990 and before	454.7 (0.0–2,685.0)	25						
Precision- instrument makers and repairers (7311)	1991–2000	170.1 (26.9–268.5)	3					5.0	1
	2001–2010	135.6 (0.6–161.2)	16	182.7 (103.2–341.5)	6	69.8 (5.6–361.2)	109	500.4 (12.2–1,428.0)	18
	2011 and after	20.7 (0.1–64.5)	17			15.2 (0.1–27.5)	9		

Weighted mean concentrations (range) were calculated from all measurements of both literature (except case report) and representative industrial hygiene surveys, and the minimum and maximum of the reported summary concentrations were shown in brackets.

* Measurements were extracted from the case report.

No.: Estimated number of measurements. The smallest number of measurements were taken if we only know at least how many measurements were taken per summary measurements.

manufacturing and metal degreasing was at its highest (Table S4). Measurements extracted from industrial hygiene survey datasets were mostly conducted in 2001 to 2010. Most assessments extracted from publications were industrial hygiene survey reports (91%) and occupational hazard assessment reports (3%). The rest comprised case reports and other studies (6%), including case-control and cohort studies.

Some source reports, especially those extracted from publications, did not include details related to the number of samples, or factors that could potentially influence occupational TCE exposure, such as ventilation and other protective procedures. Information on the accuracy and precision of the sampling and analytical methods were also limited, instead, the Chinese Standard *Specifications of Air Sampling for Hazardous Substances Monitoring in the Workplace* (GBZ 159 - 2004) was often mentioned. Detailed information on sampling and analysis used in China can be found in [Supplementary Material 3](#).

Time trends of TCE air concentration in the workplace

The trend of TCE exposure was examined in 4 time periods: (i) 1990 and earlier; (ii) 1991 to 2000; (iii) 2001 to 2010; (iv) 2011 and later. Descriptive statistics for these 4 periods are provided in Table 3 for all occupations together, and for some of the frequently reported occupations separately. For all occupations, earlier use of TCE in Chinese industries exhibited the highest occupational exposure levels among workers across the decades, and the pooled weighted mean (range) task-based concentrations at workplaces until 1990 was 202.8 (0.0 to 2,792.4) mg/m³, and 242.9 (8.1 to 1,772.1) mg/m³ during 1991 to 2000. Then the exposure level significantly decreased to 118.7 (0.6 to 1,015.0) mg/m³ during 2001 to 2010, until again increased to 216.0 (0.1 to 1,964.8) mg/m³ from 2011 onwards. The same trend was seen for pooled weighted mean full-shift concentrations. For those “Metal finishing, plating, and coating machine operators” the trend was more obvious. The pooled weighted mean (range) task-based concentration was 350.7 (0.0 to 2,148.0) mg/m³ before 1990; then increased to 423.1 (107.4 to 1,342.5) mg/m³ in 1991 to 2000; a decrease was seen in the following 10 years of 161.8 (5.5 to 756.0) mg/m³, and a huge increase showed in 2011 and after of 408.1 (1.7 to 1,964.8) mg/m³. A similar trend was also found for “Electronic equipment assemblers.” On the other hand, a stronger downward trend was observed for the “Precision-instrument makers and repairers.” Up until 1990, the pooled weighted mean (range) task-based TCE exposure level for those workers was 454.7 (0.0 to 2,685.0) mg/m³, which decreased significantly over the years, and the concentrations were 170.1 (26.9 to 268.5), 135.6 (0.6 to 161.2),

and 20.7 (0.1 to 64.5) mg/m³ in 1991 to 2000, 2001 to 2010, and 2011 onwards, respectively.

Table S4 summarizes exposure levels extracted from publications and individual measurement datasets separately. Exposure trends over time pooled from measurement datasets were similar to the overall trend summarized from all available measurements. Different patterns were observed for those extracted from publications of case reports. The exposure level extracted from case reports was considerably high in 1991 to 2000 with a limited number of measurements and extreme cases. The level then reduced in the following years, with pooled weighted mean (range) task-based concentrations of 203.9 (0.1 to 917.5) mg/m³ in 2001 to 2010, and 65.5 (0.3 to 108.9) mg/m³ in 2011 and later. For publications of industrial hygiene surveys, a downtrend was observed over the years for task-based concentrations but not for full-shift concentrations.

The subgroup analysis of time trends in Hong Kong is presented in Table S5. The elevated exposure levels observed until 1990 and during 1991 to 2000 were primarily attributed to industries in Hong Kong, with pooled weighted mean (range) task-based concentrations of 382.5 (0.0 to 2,792.4) mg/m³ and 330.4 (8.1 to 1,772.1) mg/m³, respectively. In contrast, other regions of China exhibited lower concentrations during the same periods, with summarized task-based concentrations of 185.6 (1.5 to 770.0) mg/m³ and 180.9 (17.0 to 630.0) mg/m³, respectively. The subgroup analyses of different sample types (area or personal) are shown in Table S6. Despite the limited available information, the same trend for pooled weighted mean task-based and full-shift concentrations was observed for area samples.

Discussion

The summarized data provided a general scope of TCE exposure levels across industries and occupations in China, including Hong Kong, over time. Pooled exposure information for 55 industries and 35 occupations from scientific publications and available measurement datasets reported by local hygienists showed that “electronic-equipment assemblers,” “metal-, rubber-, and plastic-products assemblers,” “metal finishing-, plating-, and coating-machine operators,” “precision-instrument makers and repairers,” “printing-machine operators,” and “Ore and metal furnace operators” were particularly at risk of high TCE exposure with either pooled weighted mean task-based or full-shift concentration over 150 mg/m³.

Degreasing-related occupations were highlighted in the current review as highly exposed, including “electronic-equipment assemblers,” “metal finishing-, plating-, and coating-machine operators,” “metal-, rubber-, and plastic-products assemblers,” and “precision-instrument

makers and repairers.” Notably, this finding aligned with historical data from the United States till 2007 (Bakke *et al.* 2007). Bakke’s systematic literature review also found degreasing-related operations to have the most TCE exposure assessments reported in the US industries, with an average arithmetic mean exposure level of 212.7 mg/m³. Moreover, over half of the pooled concentrations of different occupations over time in our overview exceeded the OEL in China. These findings suggest that many workers may be exposed to TCE levels above the acceptable limits in China during the past decades, particularly for workers involved in metal cleaning and degreasing operations. Moreover, it is important to note that according to the US Occupational Safety and Health Administration (OSHA), the recommended permissible exposure limit (PEL) of TCE is 100 ppm (8-h time-weighted average [TWA], at 25 °C, 1 ppm = 5.374 mg/m³). The recommended exposure limit for TCE is 25 ppm (8-h TWA) (Occupational Safety and Health Administration, 2021).

The overall TCE exposure levels at workplaces first increased in 1991 to 2000 and then decreased in 2001 to 2010, and later on a significant increase was seen in 2011 and after. These trends show a slightly different picture compared with the previous study conducted in Shanghai workplaces from 1968 through 2000, where TCE workplace air concentrations appeared to have dropped over time (Friesen *et al.* 2015). The study of Friesen *et al.* was also included in this overview. However, combining these measurements from Shanghai with other reports and measurement datasets with a wider scope of industries and occupations across China over time indicates that TCE exposure levels were high before 2000 and noticeably decreased after the newly announced Law of the People’s Republic of China on the Prevention and Control of Occupational Diseases (2002). New provisions specifically for regulatory enforcement, may partly explain the decrease in exposure levels in the following years (Yongming *et al.* 2011). On the other hand, a rise in exposure levels was seen from 2011 onwards. With the advancement of industrialization in China, there has been an expansion of small-scale industries and crudely converted workshops. Occupational exposure in some of these industries and workshops remains of major concern, as the OEL has not been effectively implemented by health authorities in rural areas (Wong, 2003). Different exposure trends were observed for the “precision-instrument makers and repairers” (Table 3), since their assessments of TCE exposure before 2000 were predominantly conducted in Hong Kong (Table S5), where the development of the industry was more advanced than that in Mainland China, leading to a higher level of exposure in 1990 and before. Furthermore, the replacement of TCE with less hazardous cleaning agents may also have led to lower exposure levels (Lin 2013).

Variations in exposure levels of over 35-fold by industry were reported by Friesen *et al.* with the highest air concentrations observed in the ship and aircraft industries. Our study further revealed the variation of TCE concentrations across different occupations and industries, with the highest concentration reaching 5,484 mg/m³ for “incinerator, water-treatment and related plant operators.”

The number of measurements across time and place were related to economic development and industrialization. Besides measurement datasets reported by local hygienists, most of the extracted assessments pooled from the literature originated in more developed industrial areas in the southeastern coastal regions of China, including Hong Kong, Guangdong, and Shanghai. Similarly, the number of publications also increased over time with economic development and industrialization until 2010.

The current study has several strengths. It is the first systematic review of the Chinese and English scientific publications on TCE exposure in occupational settings across China over time. Second, our overview combined information from both scientific publications with individual measurement datasets. This comprehensive overview of TCE concentrations is important for assessing occupational exposures in epidemiological studies, which presents significant challenges. Chronic diseases, such as cancer and neurodegenerative diseases, require examining exposure periods that often occurred several decades ago, making it difficult to obtain accurate exposure levels for the relevant periods. Therefore, our overview of data containing detailed historical quantitative exposure levels will support the accuracy and consistency of TCE exposure assessment in future studies.

There were also limitations to our study. First, different sampling and analytical methods were employed over the decades covered. For example, The pooled TCE exposure levels combined area and personal sampling assessments because the original reports often lacked clarity on the sampling types. As a result, these concentrations might not fully reflect workers’ actual exposures. Moreover, the assessments included both individual measurements and summary estimates such as means, median, or ranges, and assigning the average of minimum and maximum levels may introduce uncertainty. Although we weighted the concentrations by the estimated number of samples taken, there remains the possibility of inaccurate exposure estimation in some occupations.

Conclusion

With this summarization of TCE air concentrations at workplaces from both the published literature and datasets of industrial hygiene surveys in China during the past few decades, we found that “electronic-equipment

assemblers,” “metal-, rubber-, and plastic-products assemblers,” “metal finishing-, plating-, and coating-machine operators,” “precision-instrument makers and repairers,” “printing-machine operators,” and “Ore and metal furnace operators” were at particularly risk of high TCE exposure. We further observed that the overall TCE exposure levels at workplaces decreased from 1990 to 2010, but an increase was seen from 2011 onwards. Identifying high-risk industries and occupations may provide insights into specific interventions and regulations to reduce TCE exposure and protect workers’ health. Furthermore, enhancing the quality and coverage of exposure measurement data in occupational settings will advance epidemiological investigations in occupational health.

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Conflict of interest

The authors report no conflict of interest.

Data availability

The data underlying this article will be shared on request to the corresponding author.

Supplementary material

Supplementary material is available at *Annals of Work Exposures and Health* online.

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