Chapter

Per- and Trichloroethylene Air Monitoring in Dry Cleaners in the City of Sfax (Tunisia)

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Abstract

The use of chlorinated solvents in dry cleaning poses risks to human health. The occupational health exposure assessment to these volatile chemicals is conducted through quantification of airborne concentrations inside the facilities. Indeed, the lack of such measurements in Tunisia pushed us to conduct the study. After identifying dry cleaners in Sfax city, we conducted door-to-door canvassing in 47 facilities. Then, the levels of perchloroethylene (PCE) and trichloroethylene (TCE) in the indoor air are measured in two sampling positions: fixed and individual. The pollutants are adsorbed with charcoal sorbent tubes where their amounts correspond to given air volumes that are suctioned through the pump. It is later used to calculate their mean concentrations. These solvents are desorbed using carbon disulfide and analyzed by gas chromatography—flame ionization detection. After the analytical validation of the protocol, 19 air samples were quantified. The measured concentrations of TCE are close to the occupational exposure limit value in almost all facilities, whereas the PCE concentrations are about half of the OELV. The overall results showed that the working environment in dry cleaning in Sfax city are concerning and can lead to many adverse health effects up to several types of cancers.

Keywords: air monitoring, trichloroethylene, perchloroethylene, exposure assessment, occupational health

1. Introduction

In the modern world, synthetic chemicals are a big part of the human life. Among these products, the organic solvents represent a group of diverse chemical substances with a generally high volatility and solubilization ability that allow their use in broad range of applications. In this respect, there are about a thousand different solvents involving a hundred common uses, especially in industrial sectors.

Depending on their properties, these organic solvents can be used as degreasers (cleaning textiles and metals), additives and thinners (paints, varnishes, inks, glues, and pesticides), strippers (removal of organic products), and even purifiers (perfumes) [1].

Nevertheless, all these solvents have negative impacts on human health and the environment in case of noncaution. The health effects are variable depending on the solvent and the exposure duration and intensity [1]. Due to their volatility, humans can be typically exposed by the three routes: (i) inhalation; (ii) dermal contact, whatever the state of the skin; and (iii) ingestion through accidental absorption or contaminated water or food.

In occupational settings where organic solvents are used or processed, prevention measures have to be established and followed. Their establishment should obey the general principles of prevention and also be based on chemical risk prevention methods [1].

Among the main chemical substance families of organic solvents, we can distinguish the family of the halogenated hydrocarbon. The latter includes a subgroup named the chlorinated hydrocarbons. Since the 1920s, chlorinated hydrocarbons have been widely used for their stripping property. In fact, because they are nonflammable compounds, chlorinated solvents were used in degreasing, notably in the cleaning of clothes. However, since the 1970s, their use has declined steadily because of the growing awareness of their harmful effect on humans and the environment [2].

Once in the human body, their effects are multiple. Some effects are common to all halogenated solvents, and others are distinct and specific to the solvent depending on toxicological proprieties [2]. The common effects include irritation mainly of the skin and mucous membranes (ocular and respiratory) and neurological disorders especially neurobehavioral difficulties. Many chlorinated solvents cause liver or kidney damages [2]. Ultimately, some of them can even induce cancers.

In addition, the recent literature reports with certainty that several volatile organic solvents including the chlorinated ones are deemed to be harmful to the environment by contributing to the production of tropospheric ozone via photochemical reactions. This is consequently causing respiratory disorders for suffering from asthma or respiratory failure. Besides, due to their low solubility in water and their limited biodegradability, these solvents can also lead to soil pollution and in some cases can lead to groundwater contamination [2].

Due to their potential hazardous properties, in recent years, the use of organic solvents in industry and laboratories has progressed considerably. The precaution instructions, which fall under what is called "green chemistry," led to the suspension or a significant limitation of some solvents (chlorinated solvents, glycol ethers, aromatic solvents, etc.) [3].

The perchloroethylene (PCE) and trichloroethylene (TCE) are considered as the second and the third most used chlorinated solvents, respectively. One of the industrial sectors that are largely using these two solvents is the dry cleaning industry.

Actually, PCE and TCE are currently well-known to induce many adverse health effects [2, 4–7]. However, in Tunisia, dry cleaners generally use them by dint of their important cleaning properties. In case of noncompliance with the standardized prevention and industrial hygiene measures, their consumption may lead to the contamination of the workplaces' atmospheres, especially nearby solvent handlers, which can lead to health quality degradation in case of long-term exposure.

In this context, for the purpose of protection of solvent handlers' health, the control of the occupational exposure is obligatory in Tunisia according to Law 94-28 of 21 February 1994 [8] and Law No. 95-56 of 28 June 1995 [9]. However, the actual indoor air monitoring is almost absent; besides, there is a shortage of specialized laboratories in the field of air and biomonitoring.

In contrast, for instance, in the United States and Japan, PCE is automatically removed if frequent and intense exposure is confirmed in the workplaces. In France, a national project of gradual cessation of its use in dry cleaning industry is ongoing. In 2013, the installation of new PCE dry cleaning machines is prohibited in buildings contiguous to dwellings [5]. In January 2022, the substitution of all PCE machines is going to take place [7].

Actually, the occupational exposure monitoring of chemical pollutants has an important place in today's strategies for chemical risk prevention [10]. Moreover, the technical advances in the analytical chemistry field have allowed the development of sufficiently sensitive techniques in order to detect pollutants in low concentrations.

Therefore, given the absence of occupational air monitoring standards and the lack of industrial hygiene control in our country, we are especially interested in the current study in occupational exposure assessment by means of the indoor air monitoring of PCE and TCE in dry cleaning facilities in Tunisia (case of Sfax City). This study aims also to assess the human health risks associated to the long-term exposure to these solvents.

2. Material and methods

2.1 Selection of the organic solvents

Dry cleaning is clothes and textiles cleaning process that uses a solvent other than water. Most of the time, the conventional and common technique consumes chlorinated hydrocarbons, primarily PCE [7]. In the current study, we decided to also include TCE because it was traditionally used in dry cleaning. Even though TCE is no longer used in France since the 1960s [7], we suspect its presence in dry cleaners as it is not explicitly banned by law in Tunisia. Thus, considering its toxicity and proved carcinogenicity, we decided to monitor it as well.

These solvents incur serious adverse effects threatening the health of workers following chronic exposure [11, 12]. They are also proved to be carcinogenic and probably carcinogenic to humans, for TCE and PCE, respectively [13].

Table shows the main exposure routes of these two solvents and their health effects and carcinogenicity.

2.2 Identification and selection of dry cleaning facilities

In order to explore the exhaustive list of dry cleaning facilities in the city of Sfax, we contacted the Sfax Chamber of Commerce and Industry and the Regional Union of Industry, Commerce and Handicrafts in Sfax. However, they neither had sufficient information about this industrial sector nor an updated list.

Therefore, we decided to carry out a door-to-door canvassing in the study area. We only included facilities on a radius of 5 km from the city center. We excluded facilities using solvents other than TCE and PCE. Besides, we concomitantly requested their acceptance to participate in our study. After that, we randomly selected half number of the facilities who freely and voluntarily accepted to collaborate.

Afterward, information was collected using a questionnaire with the aim of:

i. identifying all the handled substances in the facilities in order to get complete qualitative and quantitative inventories and

ii. describing the working environments and the ventilation quality in each facility.

2.3 Indoor air measurements

There are two sampling methods of gas and vapors: passive and active air monitoring of TCE and PCE [14–18]. In this study, we adopted the active sampling of vapors by pumping onto an activated charcoal tube [19, 20]. This method is suitable for the quantification of high exposure levels of air pollutants and of many chlorinated compounds simultaneously. It has also the advantage of allowing the control of sampling conditions (air flow rate and duration).

Solvents	Trichloroethylene (TCE)	Perchloroethylene (PCE)
Main exposure route [11, 12]	General population: inhalation, ingestion, and dermal contact: depending on the exposure media Occupational exposure: inhalation and/or dermal contact depending on the job process	General population: inhalation and ingestion: depending on the exposure media Occupational exposure: inhalation
Reported effects: chronic exposure via inhalation [11, 12, 25, 26]	• Neurological effects: ○ Neuropsychic disorders ○ Neuromotor function alteration ○ Cranial nerve damage ○ Risk of Parkinson's disease • Developmental effects: • Risk of congenital heart defects • Hepatic effects: ○ Liver damage and diseases • Immunological and lymphoreticular effects: ○ TCE hypersensitivity syndrome ○ Immune system alterations ○ Autoimmune disease: Scleroderma • Gastrointestinal effects: ○ Anorexia, nausea, and vomiting	• Neurological effects: ○ Neurobehavioral difficulties ○ Visual alterations • Ocular effects ○ Irritation • Respiratory effects ○ Respiratory hypersensitivity and pulmonary edema ○ Respiratory irritation • Hepatic effects ○ Subclinical liver effects • Renal effects ○ Risk of hypertensive end-stage renal disease ○ Increase in kidney markers
IARC classification: cancer site [13, 38]	• Group 1: ○ Carcinogenic to humans (kidney) • Limited evidence in humans: leukemia and/or lymphoma and liver	• Group 2A: ○ Probably carcinogenic to humans: urinary bladder

IARC: International agency for research on cancer.

Table 1.
The main exposure routes of trichloroethylene and perchloroethylene, and their adverse health effects due to chronic inhalation and carcinogenicity.

In order to assess the exposure level of the workers, we chose the sampling mode according to the workers' mobility inside the workplace. A fixed monitoring station characterizing the workplace atmosphere was carried out when employees are working in a steady position. The sampling device is fixed near employees and at the level of their airways in order to measure the exposure level (**Figures 1** and **2**) [14, 21]. Elsewhere, a personal air sampling was carried out in the worker's breathing zone in order to quantify the individual exposure when the job task requires the worker's mobility (**Figure 3**) [14, 21]. Samples were taken in the middle of the week for each facility (from Wednesday to Friday).

The sampling device consists of an activated charcoal sorbent tube with two sorbent sections (SKC® tube 226-16) [22]. The tube is connected by a flexible hose to a sampling pump: pocket pump (SKC® 210-1002 TX). The sampling takes place at a regular rate of 100 (±5%) cm^3/min for a 4-h shift (**Figures 1** and **2**). So, the indoor air is pumped out through two sorbent layers that are separated with foam and glass wool (800 and 200 mg). The first one is the sampling section and the second is a backup section that detects sample breakthrough [21].

After sampling, the sorbent tubes were stored in unpolluted areas at 4°C. Even though it is possible to store them at ambient temperature [20, 21] (limited to 8 days for PCE [19]), we preferred to avoid any minimal loss [17].

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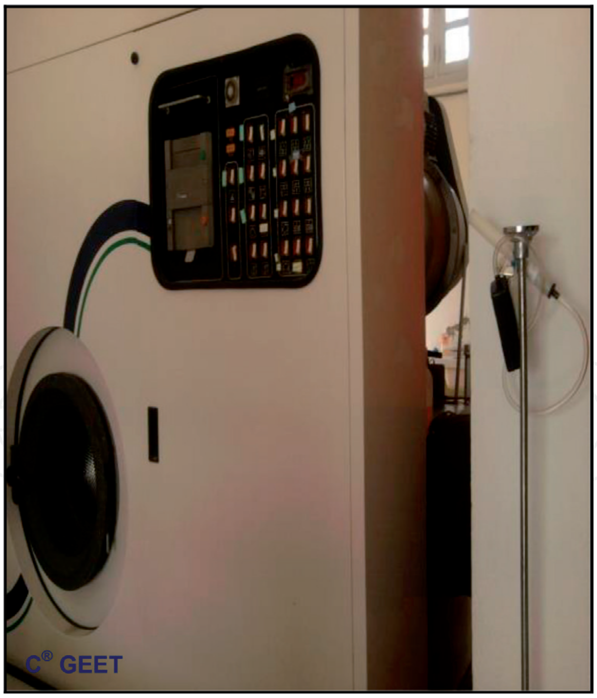

Figure 1.
Active air monitoring using fixed sampling station.

Figure 2.
Active air monitoring using personal sampling.

2.4 Sample analysis

Desorption of both solvents from activated charcoal was achieved using carbon disulfide. In fact, after breaking the tube glass tips, the content was put in a glass flask already placed in an ice bath to avoid any vaporization. Then, the content was stirred for 30 min to promote desorption [19, 20].

After the separation of the organic phase using filtration, it was directly injected (1 μL) and analyzed by gas chromatography with flame ionization detector (GC-FID). The used instrument is a SHIMADZU® chromatograph GC-2014. The capillary

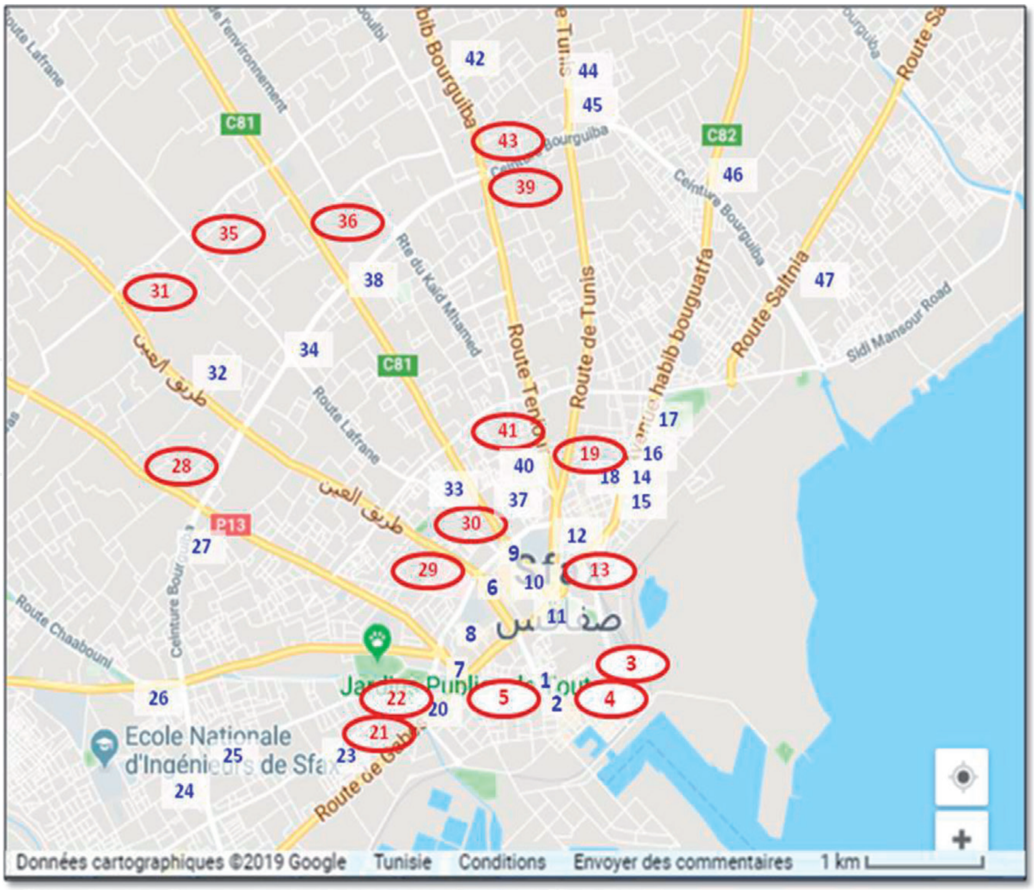

Figure 3.
Location of dry cleaning facilities in a radius of 5 km from the city center of Sfax. The facilities that profited from indoor air monitoring are encircled in red.

	Solvents			
OELV	TCE		PCE	
	(mg/m³)	(ppm)	(mg/m³)	(ppm)
France (INRS, ANSES) [17, 18, 25–27]	405	75	138	20
Europe (SCOEL) [17, 18, 27, 28]	55	10	138	20
USA (ACGIH) [25, 26]	55	10	170	25
Selected for this study	55	10	138	20

Table 2.
Occupational exposure limit values developed from different countries for trichloroethylene and perchloroethylene.

column (DB-23) features are length = 60 m, inner diameter = 0.32 mm, and film thickness = 0.25 μm. The temperature of injection is 200°C and the oven program is the following: 35°C (3 min), 7.5°C/min, 115°C (0 min), 15°C/min, 200°C (2 min). The vector gas is nitrogen with a flow rate of 2 ml/min. We adopted external calibration using the same solvent as for the samples [19, 20, 23]. Then, the air concentrations of both solvents were calculated using the airflow rates and sampling durations [24].

2.5 Occupational exposure limit values

The fixed amount on a sorbent tube over a work shift corresponds to average concentrations of solvents and subsequently will be compared with occupational exposure limit values OELVs that are time-weighted averages on the basis of 8 h a day.

In the absence of Tunisian guide values [8, 9], several OELVs are available internationally, for instance in France [17, 18, 25–27], Europe [27, 28], and the United States of America [25, 26]. The values are presented in **Table 2** OELVs are fixed for the purpose of helping employers to protect workers from occupational diseases and adverse health effects due to the exposure to hazardous chemicals within their job tasks.

In this study, we chose to select the most protective values among the explored ones.

3. Results

Following the door-to-door canvassing, 47 dry cleaning facilities were located in the city of Sfax within a radius of 5 km. **Figure 3** shows the locations of facilities in each major road using the map of Sfax city from "Google Maps." The facilities' locations on the map show their congestion in the city center with 19 dry cleaners which represents more than 40%. No facility has been identified in the medina quarter or the Sidi Mansour road.

After the meetings with the facilities' managers, only 33 dry cleaning companies accepted to participate to our study. Thus, we had an agreement with them about the confidentiality of their names, contacts and any personal specific data. The identification questionnaire was carried out for all of them. Then, we randomly selected 16 facilities. The selected ones are highlighted on the map in **Figure 3**.

It was noticed that the majority of dry cleaning establishments are located next to habitation. Moreover, they are exclusively naturally ventilated through open doors/windows. The 33 explored facilities have small surfaces with a mean value of 31.3 m^2 (95% CI [25.6-37]) where there are one or two machines. Despite all these exposure circumstances, we highlighted the almost total lack of personal protective equipment (PPE). In fact, employees never use masks even when they are directly manipulating the solvents, only one facility provides gloves, and three facilities use protective clothing.

The work activity is semiindustrial and the dry cleaners reported that they are solely using PCE with a mean quantity of 177.6 L/year (95% CI [159.9-195.3]). The number of workers in the facilities varied from 1 to 6, yet about 70% of them were women.

The chromatograms of our analysis show sharp, narrow, and well-separated peaks of both solvents. Interestingly, TCE is detected in all samples (fixed and personal), whereas the PCE is detected only in 6 workplaces among the 16 (**Table 3**).

TCE concentrations in the workplaces' atmospheres are almost equal in all facilities except for F3 (coefficient of variation (CV) is equal to 12.5%). In fact, their mean value is nearly the same as their median: ~43.2 mg/m^3 (95% CI [40.4-46]). Only in F3, the TCE concentration in the workplace's atmosphere is 40% lower than the mean concentration in all facilities. This could be due to the large surface of F3 compared to the other workplaces, which is 43% higher than the mean surface value. Moreover, we noticed that dry cleaners in F3 are using the lowest quantity of solvents, which is 60% lower than the mean quantity used in all facilities.

As for PCE concentrations in the workplaces' atmospheres, they are remarkably variable with a CV higher than 100%, which is significantly higher than the CV of TCE concentrations in the workplaces' atmospheres. PCE concentrations in the workplaces' atmospheres have no relationship with the used quantity of solvents. This may be explained by the differences in the working behaviors between the facilities, since all of them are not following the same standard prevention measures.

As for the personal sampling, TCE concentrations are almost the same as the workplace atmosphere levels, except for F3 where it increased by about 25%. However,

	Fixed monitoring				Personal sampling			
	TCE		PCE		TCE		PCE	
F	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm
F3	26.35	4.98	12.60	1.89	35.38	6.69	25.08	3.76
F4	40.58	7.67	7.86	1.17	—	—	—	—
F5	44.67	8.45	ND	ND	—	—	—	—
F13	42.06	7.95	ND	ND	41.60	7.87	—	—
F19	49.61	9.38	ND	ND	—	—	—	—
F21	43.57	8.24	ND	ND	—	—	—	—
F22	49.72	9.40	ND	ND	—	—	—	—
F28	42.22	7.98	ND	ND	—	—	—	—
F29	41.10	7.77	54.34	8.14	44.06	8.33	65.40	9.80
F30	41.45	7.84	ND	ND	—	—	—	—
F31	48.89	9.25	7.98	1.19	—	—	—	—
F35	43.21	8.17	8.47	1.27	—	—	—	—
F36	45.86	8.67	ND	ND	—	—	—	—
F39	46.21	8.74	ND	ND	—	—	—	—
F41	43.74	8.27	12.27	1.84	—	—	—	—
F43	42.27	7.99	ND	ND	—	—	—	—

ND, not detected; F, dry cleaning facility.

Table 3.
Indoor air measured concentrations of TCE and PCE in dry cleaning facilities.

it still is 18% lower than the mean value of TCE concentrations in the workplaces' atmospheres, which confirms its connection with the lowest consumed quantity.

Regarding PCE, the personal sampling concentrations are higher than workplaces' atmospheres, particularly in P3 where the PCE level has doubled. Thus, the employees who are carrying personal sampling devices (particularly in F3 and F29) are exposed to greater levels of solvents. This is obviously due to their specific movement patterns where they could be moving closer to the emission sources. This consequently justifies our judgment to use the personal sampling in these job tasks.

As we can notice in **Table 3**, almost all TCE concentrations are close to the selected OELV (**Table 2**). These results are quite surprising because all facilities have declared to only use PCE. In fact, we suspected to have found TCE in trace amounts as impurity content. But, these high concentrations are an alarming finding. Thus, even though all PCE concentrations are lower than one-tenth of the OELV (except for both measurements in F29 and for F3 personal sampling level), we believe that urgent corrective actions should be carried out in all facilities.

4. Discussion

4.1 Location of dry cleaning facilities in Sfax and residential exposure

First of all, since there was no list of dry cleaning facilities in Sfax city, we encountered some difficulties during the identification and location steps. That is why, it was decided to conduct a door-to-door canvassing in the study area.

The lack of dry cleaners in the medina quarter may be explained by its transformation into a commercial zone with plenty of stores. However, this is not the case in the Sidi Mansour road, which is predominantly an industrial zone. It is a less populated area and seems like its inhabitants did not see the need for dry cleaning, which could be explained by their relatively low standard of living. Finally, we noticed that the facilities are generally located in densely populated areas of Sfax city. Indeed, the downtown area that includes 40% of the total number has a high demographic density. Actually, this could represent a major issue for the health of people living close to the dry cleaning facilities. In fact, they could be exposed to higher concentrations of solvents in comparison with the rest of the general populations [12].

Several studies have explored many adverse health effects related to the exposure of people residing near dry cleaning facilities and TCE- or PCE-emitting sites. A study showed that the maternal age increased the risk of fetal heart defects when mothers were living around a trichloroethylene-emitting site [11, 18]. Many epidemiological studies have reported that visual functions, such as contrast sensitivity, were reduced when residents were exposed to low perchloroethylene levels from dry cleaning facilities in their neighborhood [12, 29, 30]. This association was also confirmed in children in further studies but with even lower levels [12]. These Visual alterations are rather considered as neurological effects [12, 29]. Actually, other studies showed the increase of neurobehavioral difficulties, such as memory, cognitive, and attention impairments, in people living in residential buildings that include a dry cleaning facility [12, 29]. These neurological effects were also noticed in occupationally exposed populations, but according to a meta-analysis study, they were more significant in the general population [12]. This could be explained by the fact that the general populations include all ages and genders, which increases the worry about them.

On the other hand, a study conducted in North Carolina demonstrated that the dry cleaning facility was the main source of drinking water contamination with trichloroethylene [11]. Since many Sfaxians are using rainwater harvesting, this could induce a great concern about possible supplementary adverse health effects related to other routes of exposure through water.

4.2 Occupational exposure limit values and threshold effects

OELVs are established to prevent occupational illnesses in general but they are not specific to a health effect or target organ. Thus, even though the TCE and PCE concentrations are below the OELVs, some serious adverse health effects may occur [31]. Furthermore, since the general population is also involved, people, including the occupationally exposed ones, are more effectively protected if the air concentrations are below the toxicological reference values (TRV). These TRVs are exclusively established based on scientific considerations [31]. In this section, we are only discussing TRVs that are protecting populations from threshold effects.

Since there are no Tunisian values, we are checking TRVs that are conceived from French and American agencies. The French values are constructed by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) [32]. The TCE chronic TRV via inhalation is constructed based on noncarcinogenic renal effect because of a well-established nephrotoxicity mechanism [33]. The TRV is fixed on 3.2 mg/m^3. The mean value of all TCE concentrations is 13.4 times the French TRV, which means that there is a great risk of nephrotoxicity for workers. Among the American TRVs, we can mention, for instance, the ones that are established by the Environmental Protection Agency (US EPA) [34]. The TCE chronic Reference concentration (RfC) is fixed on 2 10^{-3} mg/m^3 [35] based on both developmental and immune effects. The mean value of all TCE concentrations is 21,385 times the RfC, which means that there is also an enormous risk related to the increase of congenital cardiac malformations and a decrease of thymus weight [36]. This developmental effect could be also alarming because 70% of the workers are women.

Regarding PCE, the chronic French TRV via inhalation is developed based on neurological effects. Among them, the ANSES distinguished the visual alterations as the most sensitive effect toward the lowest exposure levels [30]. The TRV is fixed on 0.4 mg/m^3 [30, 32], which is over 60 times the mean value of all PCE concentrations. Since the PCE concentration distribution is highly dispersed, the ratio, and consequently the risk, is even higher (108 times) if we use the upper bound of the 95% confidence interval for mean. As for the RfC, it is set at the tenth of the French TRV (0.04 mg/m^3 [37]) based also on neurological effects, notably neurobehavioral effects and color vision impairment induced by neurotoxicity [29]. Thus, the risk of neurotoxicity could be even 10 times higher for workers. It is worth to note that these risks maybe also extrapolated to the general population with lower intensity, but with great significance and likely adverse consequences.

4.3 Carcinogenic effects

Chronic exposure can also induce carcinogenic effects. Thus, there are non-threshold TRVs as well. Each value is established for a specific tumor site or sites based on a lifetime exposure.

As shown in **Table 1**, according to World Health Organization (WHO) [13, 38], TCE was proved to cause kidney cancer to humans. Indeed, the French carcinogen TRV via inhalation, established by ANSES, is the ERU "excès de risque unitaire," and is equal to 10^{-6} (μg.m^{-3})$^{-1}$ [32]. It was constructed based on kidney cancer, specifically the renal cell carcinoma [33].

Yet, other solid scientific evidences indicate other potential carcinogenic effects of TCE. In fact, the US EPA established the Inhalation Unit Risk for three different cancer sites: the hematologic, liver, and kidney cancers. Its value is more protective and equal to 4.1 10^{-6} (μg/m^3)$^{-1}$ [35, 36]. According to the latter value, the lifetime cancer risk, which is defined as the product of multiplying the carcinogen TRV by the exposure concentration, is equal to 17.5 10^{-2}, when compared with the mean value of all TCE concentrations. This means that, more than 17 additional cases of hematologic, hepatic, and renal cancers are estimated to occur during a lifetime exposure to TCE in a population of 100 people. This value is considerably high even for an occupationally exposed population.

Furthermore, other international agencies have also demonstrated the carcinogenic effect of TCE for other target organs, such as in testes or in lungs [33].

As for PCE, according to WHO [38], it is probably inducing urinary bladder cancer to humans.

Elsewhere, ERU established by ANSES is based on liver cancer (hepatocellular adenoma and carcinoma) [30] and is equal to 2.6 × 10^{-7} (μg/m^3)$^{-1}$ [32]. Additionally, the Inhalation Unit Risk by US EPA has the same value, but only for the hepatic cancer. According to this carcinogen TRV, the lifetime cancer risk is 6.3 × 10^{-3}. It means that six additional cases of liver cancer are expected to take place during a lifetime exposure in a population of 1000 people. Due to the high variability of PCE concentrations, this value could be even higher (more than 11 cases if the upper bound of the 95% confidence interval for mean is used) in some cases. Although these findings are slightly better than those for the TCE, they are still high and troubling. In fact, the inhalation cancer risk could be worse if we consider a total cancer risk due to the cumulative exposure to both solvents, especially when the target organ is the same.

4.4 Health risk assessment and chemical risk prevention

In Tunisia, chemical risk assessment studies have started in many industrial sectors that are handling solvents, such as adhesive [39] and shoe manufacturing [40] industries. Yet, the occupational exposure in dry cleaning industry is not explored. The exposure assessment was achieved using questionnaires and indoor air measurements. In fact, air samplings were carried out for the first time in the region of Sfax. We consider that this study will help for better understanding the dry cleaning industrial sector in Tunisia, which will lead to further improvement in health risk assessment studies in this sector.

All the 33 dry cleaning facilities in Sfax have announced to use PCE as a dry cleaning product; however, due to the high TCE concentrations, we assume the following:

- The dry cleaning products are contaminated by TCE but in significant amounts, so either the product manufacturers did not inform their customers about TCE or solvent handlers are mixing PCE with TCE to reduce cost since it is cheaper.

- TCE could be coming from a different emission source, as it could be used as a degreaser in maintenance operations.

- Both managers and workers are not aware of the chemical risks and the adverse health effects of both solvents, especially TCE.

It is worth to note that in our study, the air monitoring was conducted during the warm season (in June and the temperature was ~30°C) when the workplaces were relatively highly ventilated; doors and windows were open. However, in winter season, they are rather closed. So, we suppose that the exposure levels will be even higher in poor ventilation conditions.

The suggested corrective measures could start with the substitution. It consists of eliminating the use of the hazardous products by replacing them with less dangerous ones, especially because they are suspected to contain a high amount of TCE or by switching to a different process. Among the substitution processes, there are the (i) wet cleaning that consists of using a mixture of water, detergents, and surfactants whose risks are little or currently unknown, (ii) hydrocarbon dry cleaning that involves solvents that are less volatile than PCE, and (iii) siloxane D5 dry cleaning that are using the latter product as a liquid solvent that is barely volatile. These alternative machines may be quite costly; however, other easier corrective actions could be carried out.

For the second level of the corrective actions, we highly recommend the implementation of collective protection measures (CPM). In every facility, general mechanical ventilation ought to be installed immediately, with fume extraction systems positioned toward every job task. It should be noted that the polluted air needs to be rejected after purification [7]. In addition, the mechanical ventilation has to be supplied by outdoor fresh air and the reuse of the same air after gas scrubbing is interdicted [7].

The third level of the corrective actions involves the mandatory use of PPE in some job tasks. The wearing of protective clothing is advisable for every worker. Elsewhere, we noticed that the loading of solvents in the cleaning machines is generally introduced by manual pouring on the back or through the porthole, which increases the risk of exposure by direct contact with solvents. Thus, in such job tasks where workers are directly handling solvents for short duration, the use of gloves, safety glasses, and appropriate respiratory protective device is compulsory. The used gloves have to be made of polyvinyl alcohol or Viton® or Téflon® [25, 26]. Latex, butyl rubber, and polyethylene gloves are not suitable to be used for PCE [26]. The respiratory equipment should be equipped with gas filter type A [25, 26].

5. Conclusion

The current study is the first one in Tunisia and Sfax city that aimed to assess the occupational exposure and health risks of PCE and TCE in the dry cleaning industry.

The exposure assessment was achieved by means of the quantification of airborne concentrations of the chlorinated solvents via active air monitoring and their chemical analyses.

Our results revealed and responded to many interrogations and suspicions about the qualitative and quantitative exposure conditions and consequently the health status of dry cleaning workers in Sfax. In fact, all facilities are not following the standardized prevention and industrial hygiene measures. Moreover, they have declared to exclusively work with PCE products; however, TCE was detected in all facilities, and its concentrations were high and concerning.

Due to the inhalation exposure levels, many adverse effects are probably threatening the occupationally exposed population and even the general one, because of the location of all facilities in residential settings.

Among the threshold effects, we can distinguish high risks of neurological, nephrotoxic, developmental, and immune effects.

As for the carcinogenic effects, considerably high cancer risks were noticed if the lifetime exposure to these solvents would have the current average levels. Actually, 17 additional cases of hematologic, liver, and kidney cancers are expected to take place in population of 100 people.

Taking this into account, PCE and TCE air concentrations have to be reduced. Thus, some corrective measures were suggested in order to improve the working conditions.

We believe that the implementation of this study is very significant, at the Tunisian level, for better understanding of the dry cleaning industrial sector and for the improvement of future risk assessment studies in this field. Indeed, this pilot study provides the first occupational exposure data to TCE and PCE emissions from randomly selected dry cleaning facilities in Sfax city.

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Conflict of interest

The authors declare that there is no conflict of interest.

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