



Monitoring of airborne asbestos fibers in an urban ambient air of Shahryar City, Iran: levels, spatial distribution, seasonal variations, and health risk assessment

Farhad Taghizadeh^{1,2} · Ahmad Jonidi Jafari^{1,2} · Mitra Gholami^{1,2} · Majid Kermani^{1,2} · Hossein Arfaeinia³ · Saeid Mohammadi^{2,4} · Mohsen Dowlati¹ · Abbas Shahsavani^{5,6}

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Abstract

Asbestos, as with other pollutants in the air, has adverse effects on the health of human beings and animals. Today, the relationship between presence of asbestos fibers in the air breathed by humans and developing serious diseases such as lung cancer (asbestosis) and mesothelioma has been proven. This study was designed and conducted within the time period of August 2017 and June 2018 to determine the concentration of asbestos fiber in the ambient air of Shahryar City and to evaluate their health effects for the general population of the city. For this purpose, samples were taken from four points, and overall 32 air samples were taken along the year. The samples were then analyzed by the phase contrast microscopy (PCM) method. Also, to investigate the type of asbestos and for more accurate counting of fibers, SEM analysis was utilized. Finally, based on the EPA IRIS method, the health effects resulting from asbestos risks were also evaluated. The results of this study indicated that the mean annual concentration of asbestos fiber in the ambient air of Shahryar City was obtained as 0.0019 f/ml PCM and 0.0072 f/ml SEM. Furthermore, the most polluted point was S1 point (0.0119–0.0026 f/ml, PCM), while the lowest concentration was related to S4 point (0.001 f/ml PCM–0.0021 f/ml SEM). The mean annual risk resulting from airborne asbestos fiber in the ambient air of Shahryar City for all samples was obtained as 1.72×10^{-6} to 2.2×10^{-4} , which was higher than the recommended risk range in some points.

Keywords Air quality · Asbestos fibers · Risk assessment · Shahryar City

Responsible editor: Philippe Garrigues

✉ Farhad Taghizadeh
ftaghizadeh96@gmail.com

✉ Hossein Arfaeinia
arfaeiniah@yahoo.com

Majid Kermani
kermani.m@iums.ac.ir

¹ Research Center for Environmental Health Technology, Iran University of Medical Sciences, Tehran, Iran

² Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

³ Department of Environmental Health Engineering, School of Public Health, Bushehr University of Medical Sciences, Bushehr, Iran

⁴ Department of Cancer Research Center, Tehran, Iran

⁵ Environmental and Occupational Hazards Control Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

⁶ Department of Environmental Health Engineering, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran

Introduction

Asbestos refers to a group of six different types of mineral fibers (amosite, chrysolite, crocidolite, along with fibrous species including tremolite, actinolite, and anthophyllite), which are naturally found in the environment (Wei et al. 2012). The chrysolite belongs to serpentine family, while other types of asbestos belong to the subgroup of amphibole family (Nichols et al. 2002). All forms of asbestos are hazardous and are involved in the development of cancer. However, amphiboles have been more studied compared to chrysolites given their health risks (Perkins et al. 2008; Nichols et al. 2002). Chrysolites are known as white asbestos and are considered as the major form of commercial asbestos, which are used by as much as 35–65% as the raw material in producing brake pads and clutch pads of automobiles (Singh 2013). However, amphiboles are commercially less important. Asbestos fiber has no detectable odor or taste, cannot dissolve in water and do not evaporate, and are heat resistant and are not degraded through biological methods (Kakooei and Normohammadi

2014; Marioryad et al. 2011). Due to these unique characteristics of asbestos, it is widely used in different industries including construction industries as well as abrasion and heat-resistant products (Ghorbani and Hajizadeh 2016).

Generally, there is always the possibility of being exposed to airborne asbestos fiber through respiration (Harding et al. 2009). This fiber can either have natural origin or come from breakdown and abrasion of different asbestos products such as heat insulators, brake pad, clutch pad, tiles, and ceramics used for covering the floor and ceiling, asbestos cement pipes, etc., in whose production asbestos is used (though these products do not always contain asbestos) (Pastuszka 2009; Kakooei and Marioryad 2010; Berman and Crump 2008). According to studies, the content of asbestos fiber per cubic meter of ambient air in rural regions has been reported to be around 10 f/m^3 , which is equivalent to 0.00001 f/ml (Awad 2011). However, the asbestos fiber content in the ambient air of urban regions is about 10 times greater than that of villages (Ghorbani and Hajizadeh 2016). Typically, the concentration of asbestos fiber in urban regions might be higher than the considered standards in places with heavy traffic, close to buildings in which asbestos products have been used, or close to the site for discharging asbestos wastes which are subject to windblow (Mokhtari et al. 2018). According to the report by Iranian Environmental Protection Agency, in 2007, around 55,000 tons of asbestos fibers were introduced into the environment from different sources (Mousavi et al. 2008).

As with other air pollutants, asbestos has adverse effects on human and animal health. According to the report by the International Agency for Research on Cancer, asbestos is considered as a definitive carcinogen for humans, which lies in the IARC Group I (Tarone 2018). The major pathway of exposure to asbestos fiber which causes pathogenicity is through inhalation (Mousavi et al. 2008). Today, the relationship between the presence of asbestos fiber in the air inhaled by humans and developing serious diseases such as lung cancer (asbestosis), pleural plaques, and pleural effusion has been proven (Pawelczyk and Božek 2015; Mullaugh et al. 2015). The extent of risk of developing various diseases resulting from asbestos fiber depends on the duration of exposure, asbestos concentration, the extent of smoking, type of fiber, etc. (Lee and Van Orden 2008). Further, development of disease is significantly different given the different sizes and types of asbestos fiber (Kakooei et al. 2009). Asbestos fiber can change into very tiny and invisible particles (Wagner et al. 1960). These invisible particles which have a diameter of 3–5 μm penetrate the lungs during respiration, and over time these, particles cause disease to develop due to their constant stimulations (Khadem et al. 2018). One of the major types of asbestos fiber which can penetrate the respiratory system due to its special characteristics are the chrysolite type fibers, and as such they can be considered as the most dangerous type of

asbestos fiber (Berman 2010; Wagner et al. 1960; Khadem et al. 2018).

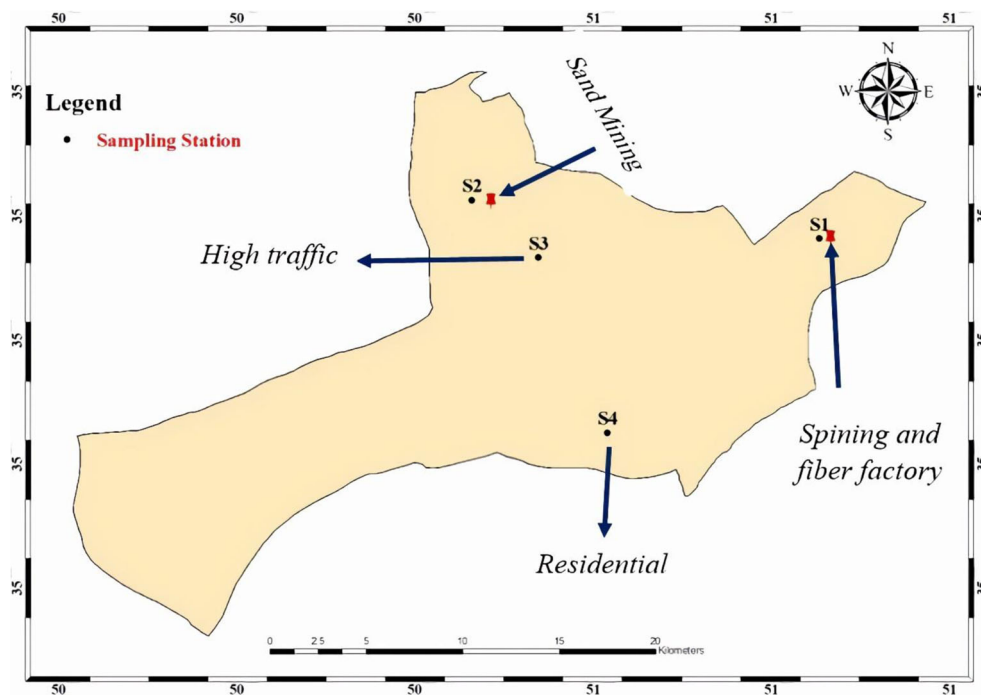
Shahryar City is located west of Tehran Province. This city is located on the geographical coordinates of eastern 51° and $53'$ and northern 35° $33'$. Its population according to the latest census of 2016 is 744,210 inhabitants, which has an area of around 340 km^2 and an altitude above sea level of 160 m. Currently, there are around 1223 industrial units across this city which are active in eight industrial groups (according to Internet search). The major polluting agents in this region are the industries and operations involving extraction and exploration of mines, where air pollutants as smoke and suspended solids claim the largest share. Based on the abovementioned points on the importance of asbestos fiber and since so far no study has been conducted for investigating asbestos concentration and evaluating the health effects of asbestos fiber in the ambient air or exposure of the public in this region, this study was designed and conducted with the three following objectives in mind: (1) determining the levels and spatial distribution of asbestos fiber in the ambient air of Shahryar City; (2) determining the seasonal variations of the asbestos fiber levels in the ambient air of Shahryar City and its relationship with meteorological parameters; and (3) assessing the health effects for the general population of Shahryar City who are exposed to air containing asbestos fiber.

Method

The site of study and sampling

The present study has been conducted in Shahryar City located in Tehran Province, Iran. For this purpose, four different stations were chosen across different points of the city. The samples were taken from the ambient air within the period of August 2017 until June 2018. Figure 1 demonstrates the studied zone and the sampling points. As stated previously, relatively numerous industries and mines have been established around and inside the city. Therefore, to investigate the effect of each pollution source on the levels of asbestos fiber in the ambient air, the sampling points were chosen close to the sites of extraction and exploration of mines, industrial town, high-traffic points of the city, and residential areas. Furthermore, to investigate the effects of seasonal variations and changes of climatic conditions, the sampling was conducted during four seasons with 45-day intervals. In total, 32 samples were taken from all stations throughout the study. The equipment utilized for sampling consisted of a high-volume peripheral pump (SKC, Leland Legacy, USA), cellulose ester filter (MCE, pore size $0.45 \mu\text{m}$; diameter 25 m), and a cassette holder. The sampling was conducted for 8 h at a flow rate of 6 l/min. The equipment for taking samples from the ambient air was installed 3 m above the ground level. Note that all of the

Fig. 1 Study area and sampling stations



equipment used for the sampling were calibrated before initiating the task.

Preparation and analysis of the samples

PCM analysis

Determination of asbestos fiber levels was performed by phase contrast microscopy (PCM) method and based on NIOSH 7400 instructions (Breyse et al. 1994). To prepare the samples, the filters including control and sampled ones were separately placed on a glass slide and cleared using acetone vaporizer device. The level of acetone injected for clearance of the acetone vaporizing device according to guidelines can be within the range of 200–350 μl. Nevertheless, it should be noted that if the level of acetone injected is low, it causes the filter to detach from the slide within less than a few minutes. On the other hand, if it is too high, it causes clearance of fibers. After the clearing process, using a PCM with a green filter and with the possibility of adjusting the diaphragm and a Walton and Beckett graticule with a diameter of 100 field model (G-22), the fibers were counted. According to NIOSH instructions, to count the number of fibers, the microscope lenses should have special adjustments. For this purpose, its optical lens was adjusted at × 10 magnification, its optical lens was adjusted at × 40 or × 45 magnification (the total magnification of the microscope was equal to 400), and the lens hole was adjusted on 65–75. The Walton and Beckett graticule was placed on the optical lens, and then by scanning the entire surface of the filter, the fibers were counted. Note that in order

to ensure absence of fiber on the surface of the utilized filters, before analyzing the samples, one non-sampled filter was analyzed as the control filter. After the counting, asbestos fiber level in the volume of sampled air was obtained by Formulas (1) and (2).

$$E = \frac{F - B}{nf - nb} \text{ fiber/mm}^2 \tag{1}$$

$$C = \frac{Ac \times E}{V \times 1000} \text{ fiber/cc} \tag{2}$$

- E* The fiber density of the filter surface
- E/nf* The number of fibers counted in each graticule field in the sampled filter
- B/nb* The number of fibers counted in each graticule field in the control filter
- Af* Graticule field
- C* Fiber concentration
- Ac* The useful surface area of the filter (mm²)

SEM analysis

PCM method only detects fibers with a diameter above 0.25 μm, which is one of the optical limitations of optical microscopy methods. This method is also unable to separate other fiber-like non-asbestos particles from asbestos fiber. Therefore, these issues drove researchers toward application or improvement or development of other methods such as

scanning electron microscopy (SEM). Accordingly, BS ISO 14966:2002 standard has been developed to measure the numerical concentration of inorganic fiber-like particles through SEM (Millette 2006). For this purpose, to detect the type of asbestos fiber and differentiate between asbestos and non-asbestos fibers, the samples in which fiber was observed using the PCM method were analyzed by SEM coupled with EDAX. The asbestos fiber concentration by SEM method was calculated according to Formula (3).

$$C = 100 N \pi r^2 / V \times n \times a \tag{3}$$

In this relation, *N* is the number of observed asbestos fibers, *r* represents the filter radius (mm), *V* denotes the volume of air sample taken (l), and *a* shows the area of calibration of each image (mm²).

Spatial distribution of asbestos

In order to investigate the spatial distribution of asbestos fiber in the ambient air of Shahryar City, ArcGIS 10.5 developed by ESRI Company was used. In this study, to manage spatial data and for the analyses, environmental ArcObjects tool was used along with spatial and due statistical add-ons. Further, for the interpolation, inverse distance weighting (IDW) method was used which is a common method for zoning and distribution of air pollution (it has been used in different studies for mapping the distribution of environmental pollutants including particulate matters, heavy metals, ozone, PAHs, PCBs, and other pollutants) (Karbadehi et al. 2016; Raeisi et al. 2016; Arfaeinia et al. 2017). All interpolation methods have been developed based on this hypothesis suggesting that the closer points are more correlated and similar compared to farther points. In IDW, the main assumption is that the extent of correlation and similarity between adjacent points is in line with the distance between them, which can be defined as a function with an inverse of the distance of each point from its adjacent point. This technique is very useful when the distribution of the estimated parameters is abnormal (Jafari et al. 2018). IDW model seems that the predictions are in a linear function of the available data. Formula (4) represents the IDW model.

$$i = \frac{Di^{-\alpha}}{\sum_{i=1}^n Di^{-\alpha}} \tag{4}$$

In this formula, *i* represents their weight of each sampling point, *Di* shows the distance between the sampling point *i* and an unknown point, *α* denotes the weighting power, and *n* represents the number of specific points for interpolation. In this model, higher weighting powers belong to closer interpolated points, while for farther points, the weighting power diminishes.

Assessing the health effects

According to USEPA IRIS references (Benner 2004), evaluation of the risk of asbestos is performed based on the fibers counted by the PCM method (Dodson and Hammar 2011). To evaluate the health effects of asbestos, the excess lifetime cancer risk (ELCR) resulting from inhaling asbestos fibers in the ambient air of Shahryar City was estimated. For this purpose, ELCR was calculated through modifying exposure concentration (EC) by unit factor (URF) (Eq. 5). Indeed, this parameter determines the extent of developing cancer given the concentration of asbestos to which a person has been exposed to throughout their lifetime. EC was also calculated using Eqs. (4) and (5) (Dodson and Hammar 2011).

$$EC = Ca \times ET \times EF \times ED / AT \tag{5}$$

$$ELCR = EC \times URF \tag{6}$$

In these formulas,

- EC Chronic exposure concentration (averaged over a 70-year lifetime) (f/cm³)
- URF Unit risk factor for asbestos inhalation ((f/cm³)⁻¹)
- Ca Asbestos concentration in fibers per cubic centimeter (f/cm³)
- ET Exposure time in hours per day (it is 24 h a day in the case of the residents' scenario)
- EF Exposure frequency in days per year (in the resident scenario, it is 365 days a year)
- ED Exposure duration in years (the value of ED depends on the age group)
- AT Averaging time

To evaluate the risk by this method, URF value was considered as 0.23 (Pawelczyk and Bożek 2015).

There are also other methods for assessing their asbestos risk including calculating lifetime average daily dose (LADD) and cancer slope factor (CSF). It can be stated that the results are similar to those of ELCR (Pawelczyk and Bożek 2015).

Statistical analysis

To perform the statistical analyses, R software (3.5.0) and Microsoft Excel (2013, v15.0) were used. To evaluate the data normality, the Shapiro-Wilk test was used. In order to investigate the relationship between the variables of asbestos fiber concentration, temperature, and air humidity, given the normality of data distribution, Spearman correlation coefficient method was used.

Results and discussion

The concentration and spatial distribution of asbestos fiber

The results obtained from the analysis of the sample to determine the concentration of asbestos fiber across the sampled points in Shahryar are presented in Table 1. The mean annual concentration of asbestos fiber in Shahryar ambient air was 0.0018 f/ml PCM and 0.0089 f/ml SEM, which is far higher than the guideline values determined based on SEM (0.0022 f/ml), as well as the values recommended for the average exposure to asbestos throughout the lifetime (0.0005 f/ml). For this reason, the necessary measures should be taken to reduce asbestos fiber concentration in the ambient air of this city. As presented in Table 1, it is observed that S1 (0.0026 f/ml PCM–0.0119 f/ml) followed by S3 (0.0023 f/ml PCM–0.0012 f/ml SEM) has had the largest concentration, while the minimum concentration was related to S4 point (0.001 f/ml PCM–0.0021 f/ml SEM). At S1, which claimed the largest asbestos concentration, with a high probability, it can be stated that this high concentration is a result of activity of the fiber and spinning production factory, which is located close to the site of sampling. Since S3 is situated in the most high-traffic point of the city, the high concentration of asbestos fibers can be attributed to vehicles and their pieces (brake pad, clutch pad, washer, and glues), which have an asbestos origin. At S2, which has a higher asbestos fiber concentration compared to S4, the difference can be attributed to the effects of mining extraction and exploration operations, which are close to the S2 point. Nevertheless, across all of these points, there are other factors that can contribute to elevated concentration of asbestos fiber. For example, asbestos has been extensively used in construction materials, including thermal insulation, fireproofing, decorative surfacing, pipe insulation, floor tiles, acoustical products, ventilation ducts, and chimney pipes. Since Shahryar is a newly built city (with numerous construction operations), asbestos fibers can be released into the atmosphere during the construction of residential or commercial structures. Therefore, these issues can claim a significant portion of the asbestos present in the ambient air of Shahryar City.

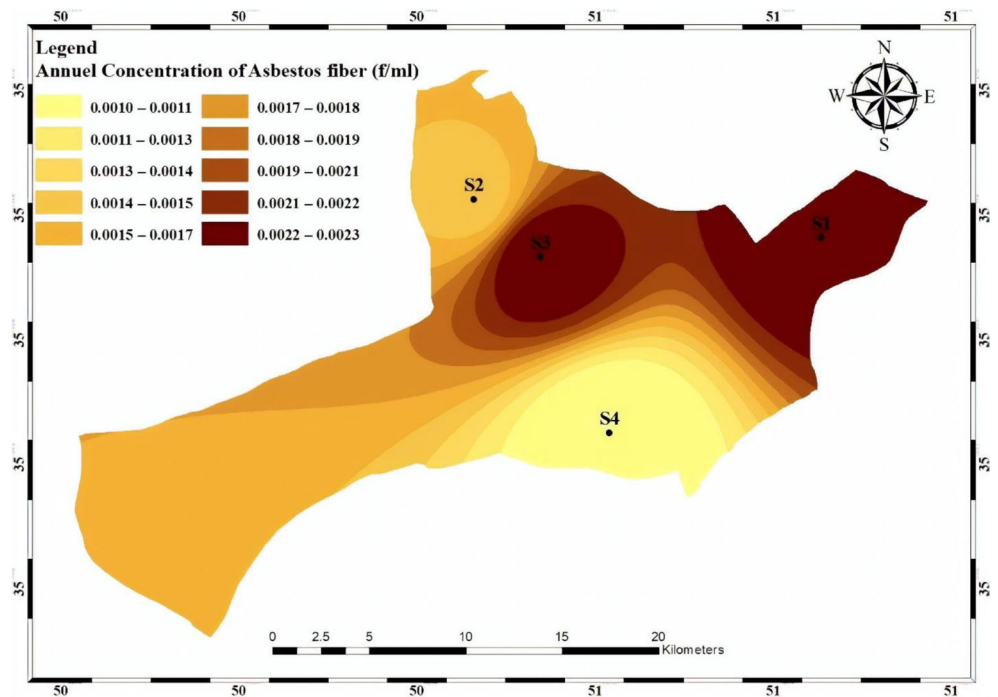
Table 1 Descriptive statistics for annual concentration of asbestos fiber

Asbestos fiber concentration (f/ml)					
PCM			SEM		
Annual average	Max	Min	Annual average	Max	Min
0.0026 ± 0.0012	0.0048	0.0010	0.0119 ± 0.089	0.0126	0.0102
0.0016 ± 0.001	0.0030	0.0007	0.0038 ± 0.021	0.0061	0.002
0.0023 ± 0.0011	0.0040	0.0010	0.0112 ± 0.067	0.0117	0.0106
0.0010 ± 0.0006	0.0016	0.0003	0.0021 ± 0.013	0.0033	ND

Furthermore, Fig. 2 demonstrates the distribution of asbestos fiber concentration in the ambient air of Shahryar City based on the annual mean. Based on this figure, the more we move away from S1 point which is located close to the pollutant source, the asbestos fiber concentration gradually declines, until S3, which is another source of this air pollutant, where the concentration has increased again. However, considering S2 and S4 points, it should be stated that as we approach these points, asbestos fiber concentration shows a descending trend.

As mentioned above, PCM analysis can determine the total asbestos fiber concentration in the air, but it is not able to detect the type of asbestos fiber. Therefore, for proper assessment of the status of asbestos level in the ambient air of Shahryar and to identify the type of asbestos fiber, the samples taken were also read by SEM analysis coupled with EDX, with its results presented in Table 1 as well as Fig. 3 (a, b, c). Based on SEM analysis, the concentrations obtained for asbestos are larger than what have been reported by PCM. This finding is congruent with the cases reported for the air of other cities in similar studies. It has been found that the results of counting by SEM method are 14–15 times as large as the values reported by PCM for the same air sample (Kakooei et al. 2013). The reason of this overestimation is that PCM is not able to detect the fibers smaller than 0.25 μm, while SEM with its excellent resolution is able to detect fibers with diameters even less than 0.01 μm. According to Fig. 3, based on EDX spectra, the chemical composition of each fiber can be detected and the type of asbestos fiber can be specified. Generally, the spectra with Fe, Mg, and Si peaks belong to chrysolite (Fig. 3c), while those lacking Fe peak belong to tremolites (part b). The results of the study on investigating the type of asbestos fiber were completely congruent with what have been expected. This means that considering the proximity of S1 point to weaving and spinning industries, the type of fiber observed at this point was mostly chrysolite fiber. Note that one of the raw materials utilized in weaving and spinning industries are long fibers of chrysolite type. Crocidolite and tremolite fibers are utilized in fabricating brake pad and production of building insulators (Clinkenbeard 2005), which were mostly observed in residential areas and high-traffic regions of the city such as S4 and S3. However, according to Fig. 3c, it is observed that there is a white spot on the emitted fiber, which based on EDX analysis was found to be barite (BaSO₄). Indeed, this situation can be observed mostly in high-traffic areas of the city, since barium sulfate is one of the mineral fillers (friction-reducing compounds) which is used for heat stability of friction reducer materials in brake pad. These compounds, in response to excessive temperature rise of the pad due to frequent braking, can be emitted to the air alongside the fibers used in the structure of pads. Observing them, with a high probability, it can be claimed that the origin of the observed asbestos fiber is the brake pad (Dodson and Hammar 2011; Covello and Merkhoher 2013).

Fig. 2 Spatial distribution of annual asbestos fiber concentration (f/ml)



Seasonal variations of asbestos fiber concentration

Along the sampling period, meteorological parameters including the temperature and humidity were recorded from the closest meteorological stations available in the zone. Due to data abnormality, the relationship between asbestos concentration and the meteorological parameters was examined by the Pearson test, with its results provided in Fig. 4. According to this figure, it is observed that statistically, there is no significant relationship between asbestos concentration and temperature or humidity. This means that across all of the samples taken, with a confidence level of 95%, it can be stated that the changes in the concentration of asbestos fiber have not been dependent on temperature and humidity variations. These

results have been congruent with the findings obtained from similar studies (Gualtieri et al. 2009). Also, Fig. 5 illustrates the trend of asbestos fiber variations over the four seasons. Based on this figure, it is observed that the maximum seasonal mean is related to fall. The reason is that Shahryar City due to its geographical location and being surrounded by the surrounding mountains experiences different degrees of inversion phenomenon during cold seasons of the year (fall and winter). This phenomenon results in elevated concentration of pollutants including asbestos fiber. Nevertheless, during winter, due to further reduction of temperature, it is expected to observe intensified inversion, but the asbestos fiber concentration was shown to be lower during winter when compared to that during fall. The reason can be due to atmospheric

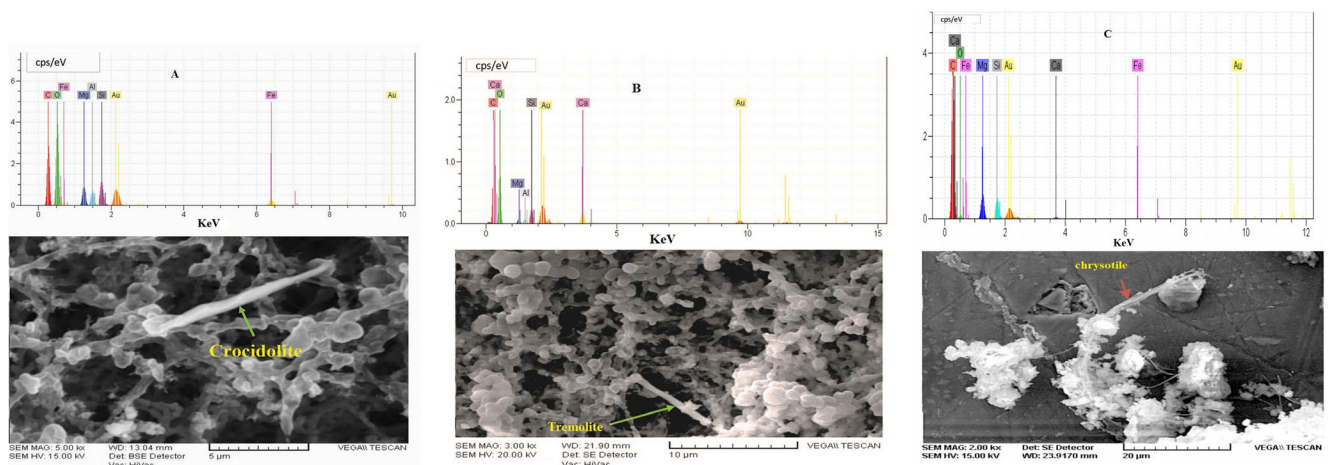


Fig. 3 SEM images of asbestos fiber observed in the air sample and EDXA spectrum (a crocidolite, b tremolite, c chrysotile)

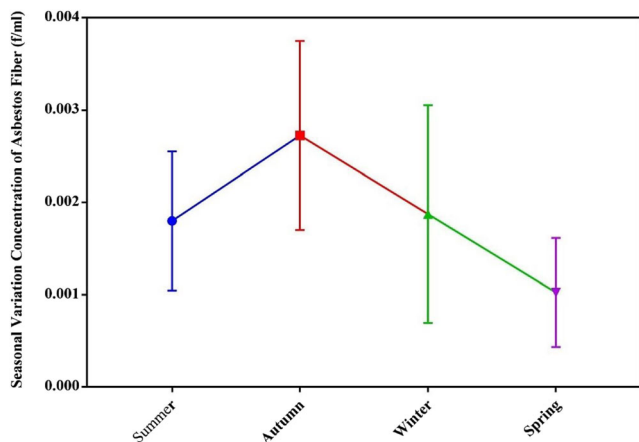


Fig. 4 Seasonal variation of asbestos fiber concentration (f/ml)

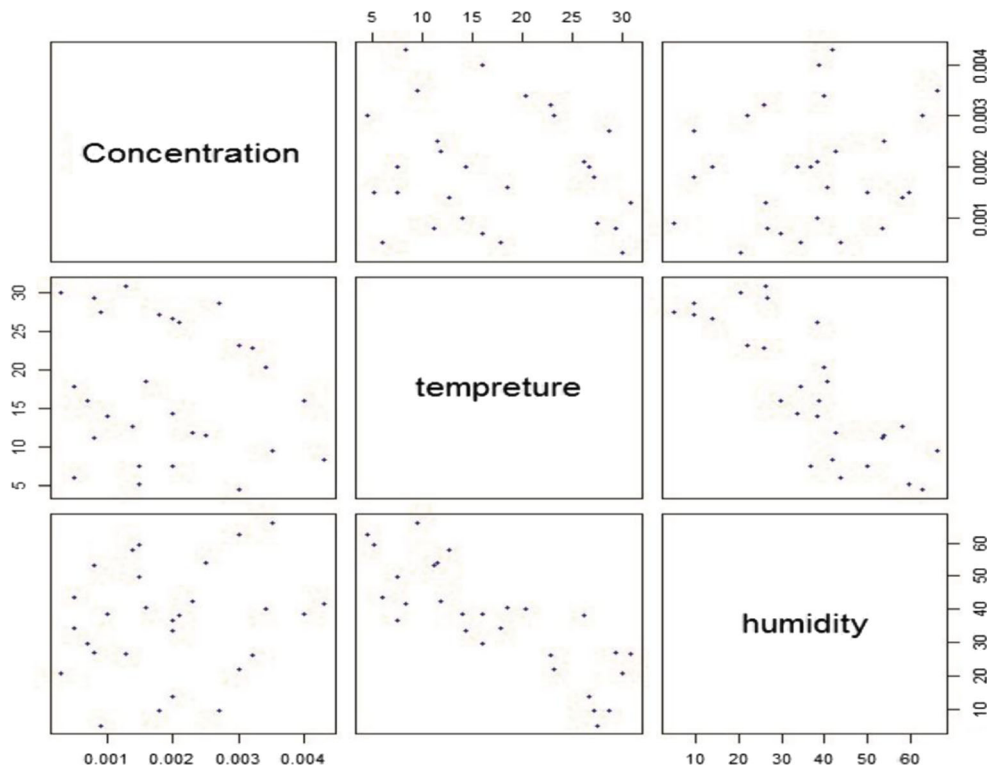
precipitations which mostly occurred during winter days, thereby clearing the air of this city from this fiber. Furthermore, since the mean atmospheric precipitations in this city have been larger during spring than those in winter, the minimum concentration observed in this study is related to spring (Kakooei et al. 2009). Other studies have also reported similar results about the concentration of air pollutants across different seasons of the year (Paustenbach et al. 2003; Awad 2011; Kakooei and Normohammadi 2014).

Assessing the health effects

The non-carcinogenic effects of exposure to asbestos are not as clear as its carcinogenic effects. Therefore, the health

effects estimated by this study are only related to the risk of cancer in the city resulting from exposure to the air polluted with asbestos. According to classification of carcinogenicity, asbestos with the CAS number of 4-21-1332 has been classified as carcinogen group A, human carcinogen, or group 1, carcinogen for humans. In this study, according to IRIS EPA references, evaluation of asbestos risk was performed based on the data obtained from PCM method. According to four age groups (0–2, 2–6, 6–16, and 16–30 years old), ELCR was also calculated and reported as total. Generally, the extent of exposure to asbestos fiber in the ambient air depends on the concentration of its fibers in the air and the type of scenario considered for risk assessment. In order to assess the asbestos risk, there are two different scenarios including occupational scenario and scenario for the public known as residential scenario. The difference of these two scenarios is the duration of exposure, which is considered as 8 and 24 h for occupational and residential exposures, respectively. Further, in the occupational scenario, no distinction is made between different age groups. According to Table 2, it is observed that the higher the concentration and duration of exposure to asbestos fiber, the greater the chronic exposure concentration (EC) will be, thereby increasing ELCR. The maximum EC and ELCR levels across all points are related to the age group of 16–30 years old, which has the maximum extent of exposure to asbestos fiber compared to that of other age groups. According to the US EPA, the range of carcinogenicity risk of the compounds in the air has been considered as 1×10^{-6} to 1×10^{-4} , which is regarded as a target level. Therefore, according to Fig. 6,

Fig. 5 Relationship between asbestos fibers and meteorological variables (Pearson test)



under maximum concentration conditions, it can be stated that across all points, exposure exceeds the allowable risk of asbestos fiber exposure. Nevertheless, the maximum extent of carcinogenicity risk among the points has been related to S1 followed by S3 (2.2×10^{-4} to 1.83×10^{-4}), while the minimum carcinogenicity risk has been related to S4, which almost lies within the allowable range.

The limitations of the risk assessment method used in this study

As the limitations of this study, one can say that the method of assessing the health risks which was used in this study to investigate the carcinogenicity risks for asbestos-exposed individuals was simple. Indeed, it creates some ambiguity, and thus its results cannot be considered as definitive and absolute. In other words, the presented method is based on a conservative approach for risk assessment, which mostly tends to overestimate, causing a series of uncertainties for the assessment which are mentioned below. First, the exposure parameters in these risk calculations (hour/day, day/year) were based on the assumption that the residents live full-time in the place (Shahryar). It is also clear that the exposed individuals spend a considerable time inside their houses, bearing in mind that asbestos fiber concentration is different between the indoor air and outdoor air. Secondly, it is evident that the asbestos fiber concentration in the air will not remain at a constant level throughout the lifetime of a person, and it would change daily and even hourly. Thirdly, in risk assessment calculations, the minimum and maximum values of fiber concentration were used, and thus the real risks should lie between these two values. Furthermore, the risk assessment calculations were based on PCM analysis results, which are according to the

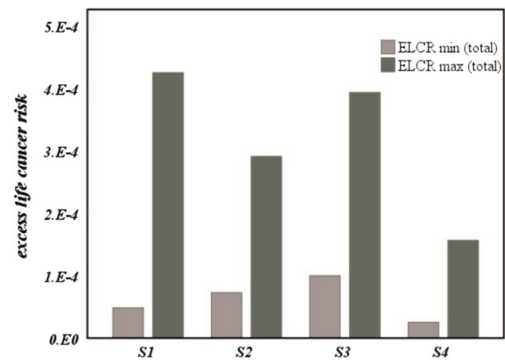


Fig. 6 Comparison of total ELCR based on maximum and minimum fiber counts (f/ml) in four stations

total asbestos content, and no distinction has been made between the type of asbestos fiber (chrysolite, crocidolite, etc.). Finally, confounding factors including smoking habits and diet of the exposed individuals have not been considered in the calculations.

Conclusion

This study has presented the data related to concentration levels, spatial distribution, seasonal variations, and risk assessment of airborne asbestos fiber in the ambient air of Shahryar City. The results of this study showed that Shahryar City is very polluted in terms of asbestos fiber concentration, i.e., the concentrations are higher than the values recommended for exposure throughout the lifetime. The findings also suggested that high asbestos concentration levels in the ambient air of this city are mostly due to industrial activities, traffic, exploration mines and extraction of sand and gravel, meteorological conditions, and geographical location. It was also observed

Table. 2 The chronic exposure concentrations (EC) and excess life cancer risk, using maximum and minimum fiber counts (f/ml)

The chronic exposure concentrations (EC)								
Station	EC 0–2		EC 2–6		EC 6–16		EC 16–30	
	Min	Max	Min	Max	Min	Max	Min	Max
S1	1.43E-05	1.38E-04	2.86E-05	2.75E-04	7.14E-05	6.88E-04	1.13E-04	9.62E-04
S2	2.11E-05	8.43E-04	4.21E-05	1.68E-04	1.15E-04	4.21E-04	1.47E-04	5.90E-04
S3	2.90E-05	1.14E-04	5.80E-05	2.28E-04	1.45E-04	5.70E-04	2.03E-04	7.90E-04
S4	7.45E-06	4.54E-05	1.49E-05	9.08E-05	3.73E-05	2.27E-04	5.22E-05	3.17E-04
Excess life cancer risk (ELCR)								
Station	ELCR 0–2		ELCR 2–6		ELCR 6–16		ELCR 16–30	
	Min	Max	Min	Max	Min	Max	Min	Max
S1	3.29E-06	3.16E-05	6.57E-06	6.33E-05	1.64E-05	1.58E-04	2.30E-05	2.20E-04
S2	4.85E-06	1.94E-05	9.69E-06	3.88E-05	2.42E-05	9.7E-05	3.39E-05	1.35E-04
S3	6.67E-06	2.63E-05	1.33E-05	5.25E-05	3.34E-05	1.31E-04	4.67E-05	1.83E-04
S4	1.72E-06	1.04E-05	3.43E-06	2.09E-05	8.58E-06	5.22E-05	1.20E-05	7.39E-05

that asbestos fiber concentration was significantly higher during fall when compared to that during other seasons. In terms of health effects resulting from asbestos fiber for the public, ELCR calculated for all samples lies within the range of 1.72×10^{-6} to 2.2×10^{-4} , which is larger than the recommended value according to standards. Generally, these findings highlight the importance of controlling asbestos fiber in urban regions with a high traffic and industrial regions. It can be stated that conducting extensive research in the future is crucial to determine and control the origin of asbestos fiber emission and to reduce their levels. For this purpose, by taking measures such as prohibiting use of asbestos in industries, augmenting the standards of vehicles and fuels, developing public transportation systems, and relocating industries to outside cities, it is possible to significantly control the level of emission of asbestos.

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