



# Spatio-seasonal variation, distribution, levels, and risk assessment of airborne asbestos concentration in the most industrial city of Iran: effect of meteorological factors

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## Abstract

Like other dangerous pollutants in the air, asbestos has negative and adverse effects on human and animal health. The present study is designed to determine the concentration of asbestos in the air of the most industrial city of Iran (Karaj) in 2018–2019. For this purpose, 4 samples were taken from different areas of the air of Karaj during a year with an SKC pump and flow of 6 L/min for 8 h and in 45 days, and a total of 68 samples of asbestos fibers were collected. Then, the samples were analyzed by phase-contrast microscope (PCM) and scanning electron microscopy (SEM). Eventually, the health effects of asbestos fibers were evaluated by the IRIS EPA method. The average concentration of asbestos fibers was 1.84 f/L PCM and 18.16 f/L SEM. Also, the results of statistical correlation analysis indicated that asbestos fibers are positively correlated with wind speed but negatively correlated with the other three parameters (temperature, relative humidity, and pressure). On the other hand, the average annual risk of asbestos fiber in the ambient air of Karaj for all samples was in the range of  $4.32 \times 10^{-6}$  to  $1.81 \times 10^{-4}$  which in some places had more danger than the recommended risk range. According to the EPA guidelines, carcinogenicity acceptable levels are in the range of  $10^{-4}$  and  $10^{-6}$ . Values higher than  $10^{-4}$  have more carcinogenic risk and values lower than  $10^{-6}$  have a lower carcinogenic risk.

**Keywords** Air quality · Asbestos fibers · Risk assessment · Traffic · Karaj city

## Introduction

As air pollution is intertwined with all aspects of modern life, air pollutants are very important (Zhang et al. 2018). Asbestos

fibers are one of these pollutants that are of great importance among the particles in the air (Pawelczyk and Božek 2015). Six types of amosite, crocidolite, tremolite, chrysolite, actinolite, and anthophyllite form asbestos groups (Wei et al. 2012). Asbestos fibers themselves are composed of two groups of minerals called amphibole and spiral. These groups, of which only white asbestos (chrysolite), are flexible and have long fibers which belong to the spiral asbestos family, and the rest belong to the amphibole family (Kazan-Allen 2005). Features, such as tastelessness and no odor, durability, high flexibility, non-evaporation and solubility in water, non-degradable fibers, and low conductivity, make them an important group in industries, such as construction (cooling and heating, tile, and ceramic), cement industry, automotive (brakes and clutches of cars), and insulation (floor and ceiling covering) (Perkins et al. 2008). Commercially, white asbestos (chrysolite) are the largest group, and the amphibole groups are less important (Berman 2010). Asbestos fibers are generally a group of particles in the air that humans can be exposed to (Zha et al. 2019). Due to their importance, all asbestos can be dangerous to health and can lead to serious diseases, such

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as lung cancer (asbestos) (Pawełczyk and Bożek 2015). Some studies have shown diseases, such as gastrointestinal tract, kidneys, larynx, and bladder, and colon cancers are also due to exposure to asbestos fibers (Covello and Merkhoher 2013). And, the most important way for them to enter the human body is through the respiratory system (Awad 2011). However, the pathogenicity of asbestos depends on factors, such as the duration of fiber exposure, the type of fiber, and the concentration of asbestos (Harding et al. 2009). Therefore, in places where there is asbestos (cement plant, car factory, etc.), eating and drinking should be avoided, and smoking also increases the risk of asbestos diseases by 30 times (Pastuszka 2009). The International Agency of Research on Cancer (IRAC) has identified it as a carcinogen for humans due to its health impact (Tarone 2018). According to the International Cancer Registry in Iran in 2005, 55 cases of asbestos-related malignant mesothelioma were registered, while in 2004 to 2006, 144, 230, and 10 cases of asbestosis were registered respectively (Mousavi et al. 2009).

Many countries around the world have banned the production and consumption of asbestos (Buck et al. 2013). Many industrialized countries have also banned the use of asbestos not only in large but also in small industries (Arfaenia et al. 2017; Perkins et al. 2008). However, the laws on the use of asbestos are mostly ignored; therefore, in 2007, approximately 55,000 tons of asbestos were consumed in Iran (Kakooei and Normohammadi 2013). There are also 11 large factories producing cement asbestos sheets and pipes in Iran (Panahi et al. 2011). The World Health Organization has declared a concentration of 2.2 f/L PCM as the standard for asbestos in ambient air (Nichols et al. 2002). Also, according to the performed studies, the amount of asbestos fiber per cubic meter of urban air is about 10 times more than their amount in rural areas (10 fiber per cubic meter or equivalent to 0.00001 fiber per milliliter for villages) (Wei et al. 2012). This can be due to reasons, such as traffic in urban areas, or proximity to buildings that use asbestos products (Pastuszka 2009). But in Iran, due to the lack of any reliable data about asbestos that directly show their health risks, we may doubt our management decisions and may make mistakes.

There are several studies around the world on asbestos and its carcinogenicity. In Iran, in Shahryar city, the concentration of asbestos fibers was 0.0019 f/mL PCM and 0.0072 f/mL SEM (Taghizadeh et al. 2019). In Isfahan, the highest type of asbestos tremolite fibers was reported (Mokhtari et al. 2019). In urban areas of Canada, Australia, Germany, and Italy, asbestos fiber concentrations of 2.4, 4.6, 2.5, and 4.11 fiber/mL were reported, respectively (Bourdès et al. 2000). In another study, conducted in Korea in 2004, the concentrations of asbestos fibers in urban and rural areas were 0.60 and 0.3 fibers per liter, respectively (Lim et al. 2004).

Karaj, the capital of Alborz province, is located the west of the capital of Iran. This city is located in the geographical

coordinates of 51° 00' E and 35° 48' N. According to the last census of 2016, its population was approximately 2.5 million people, with an area of about 175.5 km<sup>2</sup> and is located at a length of 16 km and 1300 m above the sea level. Currently, there are about 840 industrial units (large and small) throughout the city, which has made this city one of the most industrial cities in Iran (Fig. 1). As this city is the main road connecting 15 provinces of the country, every day, it faces a high volume of vehicle traffic, as well as, high traffic and finally, high and frequent braking of drivers, and as all around the city is surrounded by mountains that prevent the exit of these types of pollutants produced by vehicles and industries, it can cause very high environmental problems and pollution (Vahidi et al. 2020).

In some of the city's industrial towns, there are industries, such as the production of fireproof clothing and brake pads that produce asbestos materials, and the main pollutants in this area are industries and activities related to mining and exploration, in which air pollutants, such as smoke and suspended solids have the largest share (Kermani et al. 2020). According to the abovementioned materials and considering that no study has been done so far on asbestos and evaluation of health in Karaj city and also due to lack of sufficient information about the concentration of asbestos fibers in the ambient air of Karaj city and the health risks due to excessive exposure to asbestos fibers, it is necessary to monitor this harmful pollutant. As a result, the present study is performed in order to (1) determine the level and spatial distribution of asbestos fiber in the urban air of Karaj; (2) determine the seasonal changes in the amount of asbestos fibers in the ambient air of Karaj; (3) health effects assessment for the general population of the city of Karaj who are exposed to air containing asbestos fiber; and (4) the relationship between asbestos fiber concentrations with meteorological parameters (relative humidity, wind speed, pressure, and temperature). It is hoped that the data obtained can provide insights into the level of exposure to asbestos fibers and can be used in traffic management and other control programs.

## Materials and methods

### Study area description

This cross-sectional descriptive study has been performed in Karaj. This city is located in the geographical coordinates of 51° 00' E and 35° 48' N. And also, this city with 175.5 km and 1300 m above the sea level, the weather of the four seasons, the existence of small and large industries, and the population of nearly 2.5 million, is considered the most industrial city in Iran. For this purpose, we selected 17 points in the city of Karaj based on low-traffic, medium-traffic, and high-traffic points, so in this way, these points cover the entire city of Karaj. (Station numbers 1, 12, 13, 14, 15, and 16 have a



**Fig. 1** Examples of sources of asbestos fiber production in the city of Karaj

low-traffic load. Station numbers 2, 3, 4, 9, and 17 have a medium-traffic load. Station numbers 5, 6, 7, 8, 10, and 11 have a high-traffic load). Sampling stations were selected based on collecting representative ambient air samples (based on traffic conditions as well as the area of Karaj city) that would cover the entire city evenly and represent possible contaminant sources. Figure 2 shows the study area and sampling points. Samples were taken from March 21, 2018, to March 20, 2019, for a period of 45 days to assess the impact of seasonal and climatic changes. Totally, 68 asbestos samples were taken from all stations based on traffic load during the study. While sampling asbestos fibers, we also measured temperature, pressure, humidity, and wind speed by PHB318 portable device. For taking samples, asbestos fibers were collected using a high-volume peripheral pump (Leland Legacy (SKC)) with a flow rate of 6 L/min for 8 h on a cellulose filter (MCE) with a pore size of 0.45 microns and a diameter of 25 mm. According to the standard of the US Environmental Protection Agency, sampling devices were installed at a height of 1.5 to 2 m from the ground to prevent the entry of re-suspended dust into the filter (Fig. 3). Also, before sampling, all subject devices and equipment were calibrated.

### Phase-contrast microscope

In this study to determine the level of asbestos fibers, a phase-contrast electron microscope (model: OLYMPUS) method was used, according to NIOSH7400 instructions (Breyse et al. 1994). First, the filters were placed on a glass slide, and for clarity, they were placed under an acetone steamer. Then, 300–350  $\mu\text{L}$  of acetone was

injected into the device to clarify the samples. Note that if the amount of acetone injected for clarification is low, the transparent filter will be removed from the slide within a few minutes, and also, if the amount is more than 350  $\mu\text{L}$ , it will cause the asbestos fibers to be removed from the filter. To count the fibers, the magnification of the microscope was set on 10, and the magnification of the lenses was about 40 to 45 times, and finally, the magnification of the entire contrast phase microscope was set on 400 to 450.

In this method, the particles which had a length of more than 5  $\mu\text{m}$  and a diameter of less than 3  $\mu\text{m}$  and a length to diameter ratio of 1:30 are known as asbestos fibers. Although this method is fast and inexpensive, it is not able to distinguish asbestos fibers from non-asbestos fibers. After counting the number of asbestos fibers, its concentration was calculated based on the following formula:

$$E = \frac{F - B}{A_f \cdot n_b} \quad \text{fiber/mm}^2 \quad (1)$$

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

In this formula, **E** is the fiber density of the filter surface. **nf** is the sampled filter. **AF** is graticule field. **nb** is the control filter. **C** is the fiber concentration. **Ac** is the useful surface area of the filter ( $\text{mm}^2$ ). **F** is the number of fibers counted in each graticule field.

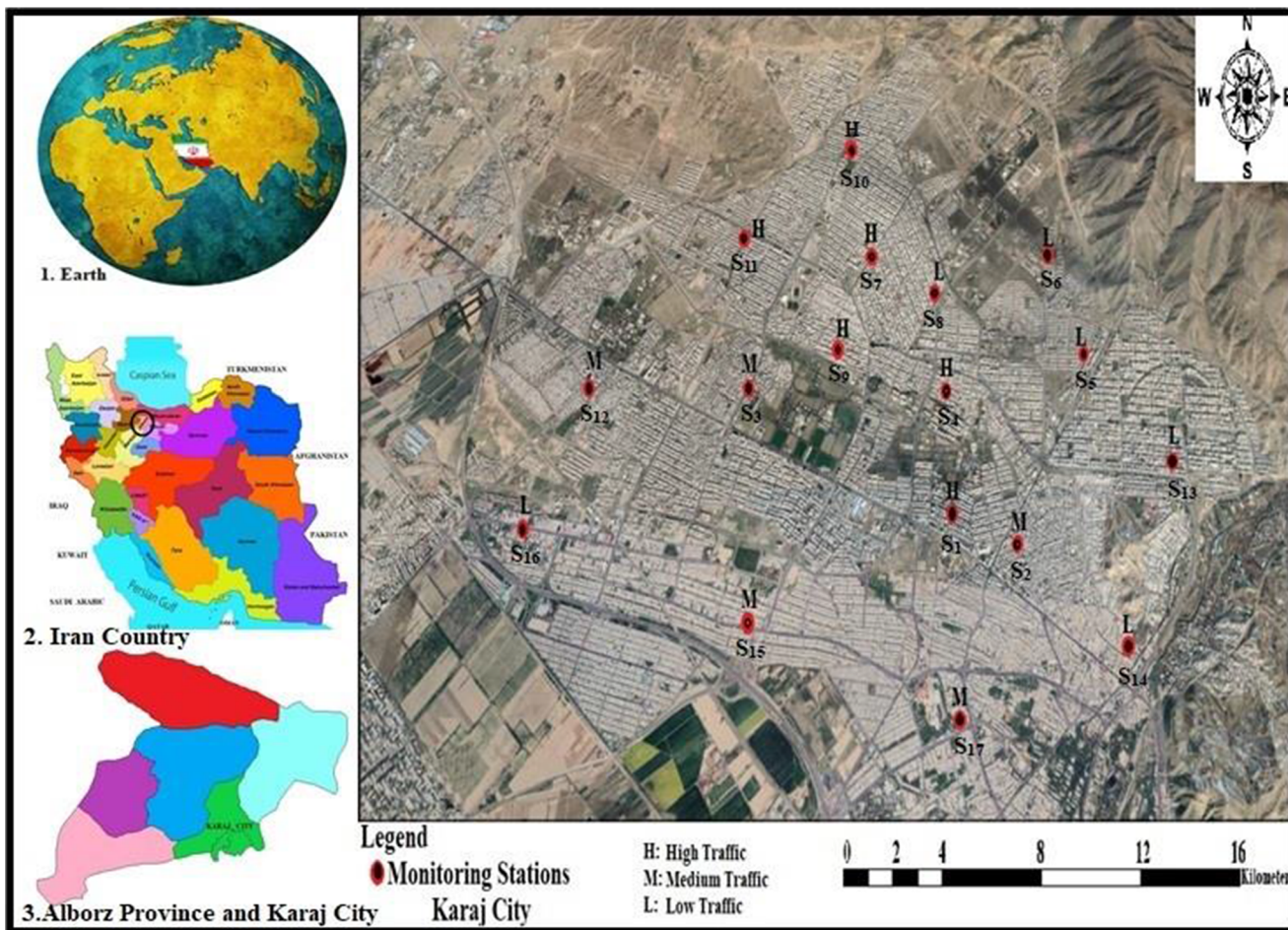


Fig. 2 Geographical location and sampling points of the study area



Fig. 3 Sampling pilot used in this study

### Scanning electron microscopy

Since the PCM method is not able to distinguish asbestos fibers from non-asbestos fibers, and as this method only identifies the fibers with a diameter greater than 0.25 μm, it leads researchers to use a better and higher quality method. One of these methods is the SEM method. In this method, the BS ISO 14966: 2002 standard is used for numerical counting of asbestos fibers (Millette 2006). The asbestos filters are then mounted on a copper sheet and a thin gold coating is applied to it. Then, using SEM, with a magnification of 500–2500, the fibers that have a length to diameter ratio of 1:3, a diameter of less than 3, and a length of more than 5 μm are considered as asbestos. Since the sensitivity of the SEM device is in the range of 0.0001 fiber per milliliter of air, asbestos fibers can be easily identified. Finally, after counting the number of fibers by SEM and its type, the concentration can be calculated based on the following formula:

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

In this relation,  $N$  is the number of observed asbestos fibers,  $r$  represents the filter radius (mm),  $V$  denotes the volume of an air sample taken, and  $a$  shows the area of calibration of each image ( $\text{mm}^2$ ).

### Spatial distribution of asbestos fibers

In this study, Arc GIS10.3 was used to show the spatial distribution of asbestos concentrations in the ambient air of Karaj. A geographic information system (GIS) is a computer-based information system that studies geographic phenomena and events that occur on the surface of the earth. The reason for using GIS software is the surety of proper management and fast and optimal achievement of the specified goals by this software. The reverse weighting method (IDW) was also used for interpolation or zoning of asbestos fiber concentrations. This is a common method for zoning and distribution of air pollution. IDW is one of the simplest and most popular methods of interpolation. This type of interpolation is a correct and robust interpolation method that estimates the required unknown values by weighting the average values of the sample data points with weighting factors proportional to the inverse distance. This method considers a weight for each measuring point based on the distance between those points and the position of the unknown points. These weights are then controlled by the weighting power, so that larger powers reduce the effects of these points more than the estimated point, and the smaller powers distribute weights more evenly among the adjacent points. Of course, regardless of the position and arrangement of points, this method only considers their distance (Hajizadeh et al. 2020; Karbasdehi et al. 2016). It is indeed a non-statistical method which is typically used for predicting the concentration of pollutants in unmeasured points through optimal special prediction technique. The weight factor is calculated using the following equation:

$$\lambda_i = (D_i - \alpha) / \sum_{i=1}^n D_i - \alpha \quad (4)$$

In this formula,  $\lambda_i$  is the station weight,  $D$  is the station distance ( $i$ ) to an unknown point, and  $\alpha$  is the weighting power.

### Assessing the health effects

Generally, the extent of exposure to asbestos fiber in the ambient air depends on the concentration of its fibers in the air for risk assessment. In order to risk assessment the asbestos, it can be calculated either for the general people or for workers. The difference of these is the duration of exposure, which is considered as 8 and 24 h for workers and general people exposures, respectively. Also, in workers, there is no distinction

between different age groups. In this work, risk assessment of asbestos was performed based on the data obtained from the PCM method based on the IRIS EPA references. For this purpose, the excess lifetime cancer risk (ELCR) was estimated for the residents of Karaj. ELCR was calculated through modifying exposure concentration (EC) by a unit factor (URF) (Eqs. (5) and (6)). Indeed, this parameter determines the extent of developing cancer given the concentration of asbestos to which a person has been exposed throughout their lifetime (Benner 2004; Dodson and Hammar 2011).

$$EC = Ca \times ET \times EF \times ED / AT \quad (5)$$

$$ELCR = EC \times URF \quad (6)$$

In this formula,  $EC$  is the chronic exposure concentration (averaged over a 70-year lifetime) ( $f/\text{cm}^3$ ).  $Ca$  is the asbestos concentration in fibers per cubic centimeter ( $f/\text{cm}^3$ ).  $ET$  is the exposure time in hours per day (24 h a day).  $EF$  is the exposure frequency in days per year (it is 365 days a year).  $ED$  is the exposure duration in years.  $AT$  is the averaging time.  $URF$  is the unit risk factor for asbestos inhalation ( $(f/\text{cm}^3)^{-1}$ ) (= 0.23).

### Statistical analysis

In this study, meteorological parameter data were processed by using Excel software. In the next step, after calculating the concentration of the asbestos fibers by PCM and SEM methods, the Pearson statistical test with SPSS software was used to correlate asbestos fibers with meteorological parameters. The normality of the data was also checked by the Kolmogorov-Smirnov test, and following it, Arc GIS software was used to zone the concentration of asbestos fibers.

## Results and discussion

### Concentration and spatial distribution of asbestos fiber

In this study, to assess the risk of exposure to asbestos fibers and to examine the trend of monthly and seasonal changes, air samples were collected from 17 areas of Karaj based on traffic load from March 21, 2018, to March 20, 2019, in a 45-day interval. The results obtained from the analysis of asbestos samples are presented in Table 1.

As can be seen, the average of four-season concentration of asbestos fibers in the ambient air of Karaj is equal to 1.84 f/L PCM and 18.16 f/L SEM, which is higher than the determined guide values; also, it is considered higher than the recommended values for the average exposure in the lifespan. Therefore, due to the carcinogenic risk of this type of particle, necessary measurements should be taken to reduce and

**Table 1** Averages of airborne asbestos fiber concentrations in different sampling points analyzed by PCM and SEM methods

Monitoring stations	Number of samples	Asbestos fibers concentrations (fiber/liter)			
		PCM	SD	SEM	SD
S <sub>1</sub>	4	1.36	0.31	13.98	1.89
S <sub>2</sub>	4	1.74	0.35	16.97	1.05
S <sub>3</sub>	4	1.36	0.93	13.98	1.89
S <sub>4</sub>	4	1.57	0.61	15.76	2.05
S <sub>5</sub>	4	3.31	0.52	29.60	4.47
S <sub>6</sub>	4	1.72	0.51	16.85	2.93
S <sub>7</sub>	4	1.95	0.58	19.04	1.65
S <sub>8</sub>	4	3.23	0.50	27.8	4.25
S <sub>9</sub>	4	1.72	0.66	16.81	1.05
S <sub>10</sub>	4	2.42	0.25	25.15	3.47
S <sub>11</sub>	4	2.35	0.27	23.15	3.06
S <sub>12</sub>	4	1.66	0.34	16.32	0.89
S <sub>13</sub>	4	1.06	0.71	8.71	0.78
S <sub>14</sub>	4	1.40	0.61	14.23	0.86
S <sub>15</sub>	4	1.27	0.98	12.42	1.63
S <sub>16</sub>	4	1.36	0.84	19.98	1.30
S <sub>17</sub>	4	1.83	0.43	18.03	1.38

maintain the health of the inhabitants of this area. In a study by Fernandez, 444 women and 976 men died from exposure to asbestos fibers over a period of 30 years (Fernandes et al. 2019). Therefore, taking the required measurements to reduce asbestos pollution has become a global issue.

In a study conducted by Taghizadeh et al., the average concentration of asbestos fibers during a year was obtained about 1.9 f/L PCM and 7.2 f/L SEM, which is very similar to the results of our study (Taghizadeh et al. 2019). Hajizadeh et al. also showed that in Shiraz the mean concentration of asbestos fibers during the study period of 1 year was 1.11 f/L PCM and 12.21 f/L SEM (Fathi Fathabadi et al. 2017). The results of this study differed from the results of our study. One of the reasons was that in Shiraz, 8 points were selected for pollution monitoring. Also, the average concentration of asbestos fibers in 2008 and 2013 in Tehran was higher than the WHO standard (Kakooei and Normohammadi 2013; Kakooei et al. 2009). In another study by Mokhtari et al., the average concentration of asbestos fibers was 8.48 f/L SEM, which is much higher than the WHO guidelines (Mokhtari et al. 2019). The subject city is one of the most industrial cities in Iran, so the inhabitants of that city are exposed to a high concentration of asbestos fibers daily. On the other hand, in the Gualtieri study, the average annual concentration in three cities of Italy was about 0.56 f/L PCM, which is less than the standard (Gualtieri et al. 2009), because the use of asbestos equipment in those cities has decreased over a planned 10-year period. In Sobue's study, in Japan, the average fiber concentration of asbestos was about 2.67 f/L PCM. Also, the evaluation of

health effects showed that in this city, men are more exposed to asbestos fibers than women (Zha et al. 2019).

According to the information obtained from the analysis, it was found that station number 5 had the highest average concentration of asbestos fibers during the four seasons (3.31 f/L PCM, 29.60 f/L SEM). Following it, station number 8 is ranked second in terms of asbestos pollution (3.23 f/L PCM, 27.8 f/L SEM). This is in case that station 13 had the least average annual concentration of asbestos (1.06 f/L PCM, 8.71 f/L SEM).

Since the largest hospital in Karaj and even Alborz province is located in station number 5, it can be claimed that the high congestion and traffic load is one of the reasons for the high concentration of asbestos fibers in this station. Other factors which may have a role in the high concentration of asbestos fibers in this station include in-hospital construction due to the repair of the cardiac angiography department, where the building materials themselves release asbestos fibers. Moreover, this station is located on the busiest street of this city. These results were similar to the results of the study of Taghizadeh et al. They showed that areas with higher traffic load had higher concentrations of asbestos fibers, which were due to mining and exploration operations in these areas, and the construction materials and vehicles and their parts in this area. On the other hand, due to the existence of 3 hospitals next to each other and new buildings around it, as well as the proximity of station number 8 to the East Karaj Health Center and high number of visitors to this center, it can be claimed that station number 8 was one of the areas with a high

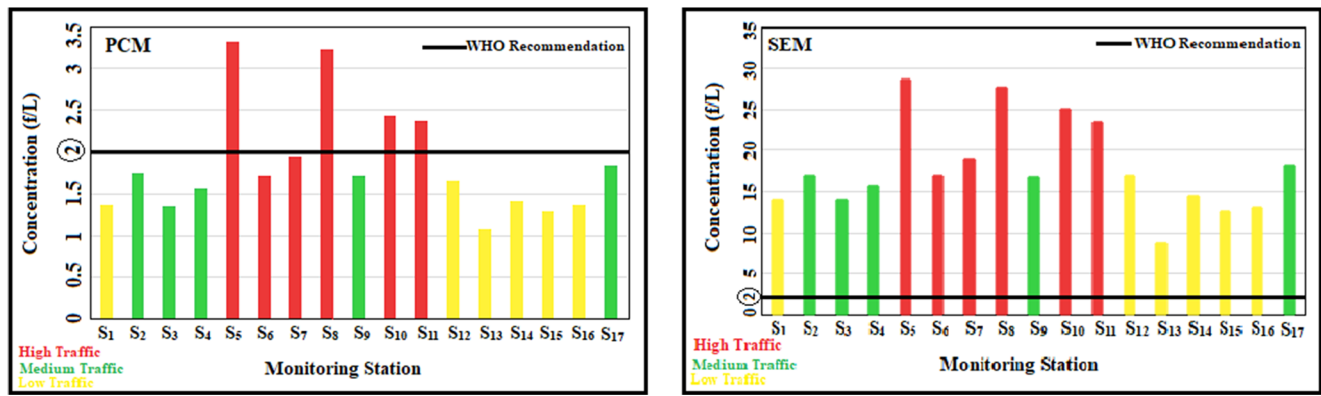


Fig. 4 Mean concentration of asbestos fibers based on traffic load by SEM and PCM method and its comparison with standard

concentration of asbestos fibers. In station number 10, due to the frequent use of clutch pedals and vehicle brakes (origin of asbestos), the location of this station in a high-traffic area, it is ranked third in terms of pollution. In the study of Hajizadeh et al., the second-most polluted point of asbestos is due to the existence of densely populated and commercial and marketing area of location (Fathi Fathabadi et al. 2017). Station 11 for reasons such as (1) the location of several bus stations in their vicinity, (2) a completely commercial and marketing area, (3) and also because of the narrow streets that lead to traffic in terms of asbestos fiber concentration in the city of Karaj has the fourth rank. This area is also somewhat affected by wind. The prevailing winds that encompass this area from Douro industrial towns are not ineffective in the high concentration of asbestos fibers in this area, which is consistent with the results of the study of Hajizadeh et al. and showed that

asbestos fibers from building materials can be the main reasons for the higher level of asbestos in the air in that area (Ghorbani and Hajizadeh 2016). Actually, wind could be an important factor in the dispersion and dilution of air pollutants (i.e., asbestosis) in the ambient air of cities. Although an area with moderate traffic, station 17 contained high asbestos fiber concentration that could be due to reasons, such as new buildings in the area and the activities of the city’s residents during the day, which was consistent with the Buck study. They showed that despite the low traffic, they observed high concentrations of asbestos fibers due to high construction activities and proximity to the electronics industry, which use asbestos to produce insulation and electronic materials (Buck et al. 2013). But, station 13 has a lower concentration compared to other areas of asbestos fiber sensors due to its relatively smooth traffic.

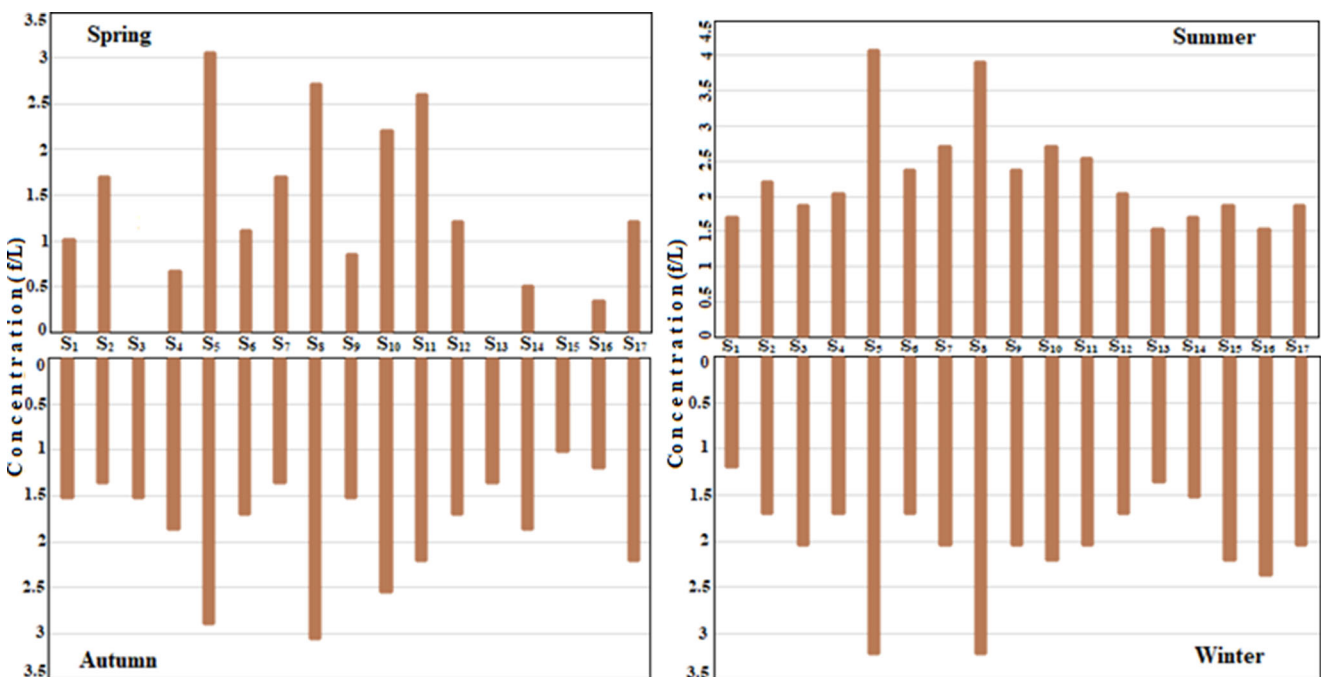
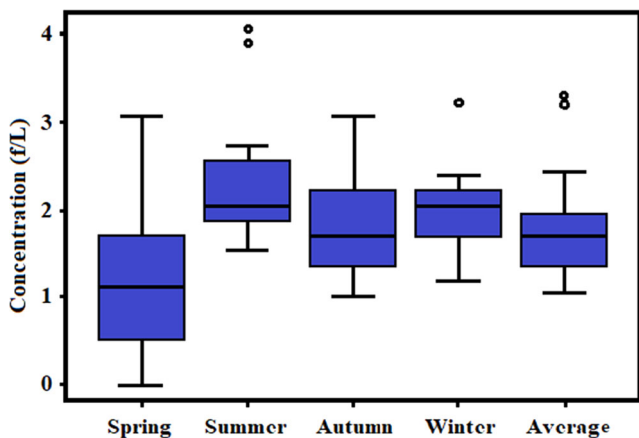


Fig. 5 Averages of airborne asbestos fiber concentrations at different seasons

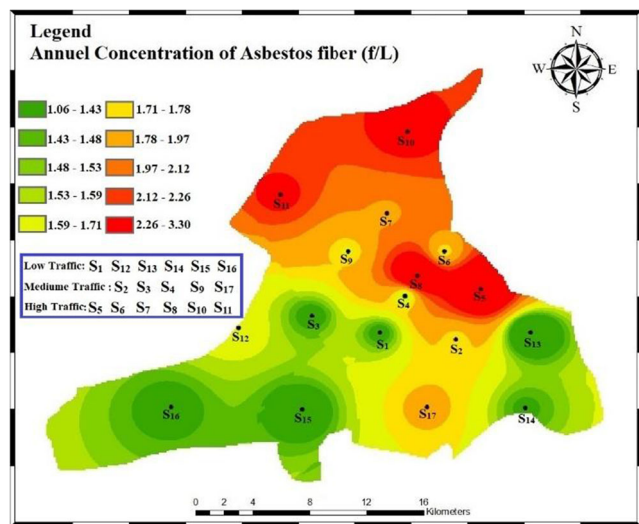


**Fig. 6** Box plot of the average concentration of asbestos fibers in different seasons of the year 2018–2019

Asbestos fiber could be released into the urban atmosphere through various other sources such as cement asbestos pipes, brake pads and clutch, roofing sheets, building pipes, façade panels, floor tiles, building insulators, glue, flooring, and ventilation canals. Asbestos is also used in industries as a strength factor as well as durability and for prevention from abrasion and combustion (Pawelczyk and Bożek 2015).

Figure 4 shows the concentration of asbestos fibers in the city of Karaj based on the traffic load by SEM and PCM methods.

As can be seen, although station 12 is located in an area with low traffic, it has a higher concentration of asbestos fibers than stations 3 and 4, which are in the areas with moderate traffic. Due to its 3-km distance from the petrochemical plant in this area, it can be one of the reasons for the high concentration of asbestos fibers. In the study of Kakooei et al. in Tehran, it was found that the areas with moderate traffic have a concentration of asbestos fibers of 1.81 f/L PCM on some days of the year (Kakooei et al. 2013).



**Fig. 7** Spatial distribution of annual asbestos fiber concentration (f/L)

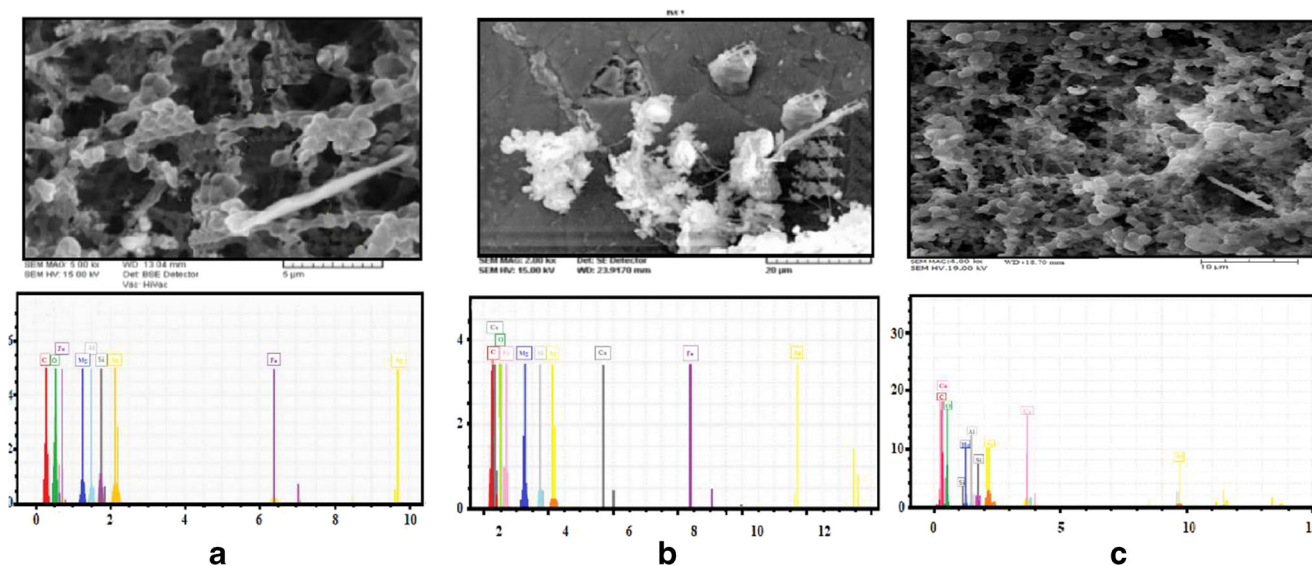
The concentration of asbestos fibers in the city of Karaj in different seasons in 2018–2019 was also different. As it is shown in Fig. 5, during the 4 seasons, the highest concentration in spring, summer, and winter is equal to (3.06, 4.08, and 3.23 f/L PCM), respectively, for station 5, and in autumn, the highest concentration for station no. 8 is 3.06 f/L PCM. This shows that station 5 (the location of the largest hospital in Karaj) is facing a serious health risk. On the other hand, the average of four seasons of asbestos fiber evaluation stations shows that in spring and summer, station number 16 with concentrations of 0.34 and 1.53 f/L PCM, in autumn, station number 15 with a concentration of 1.02 f/L PCM, and, in winter, the station number 1 with a concentration of 1.19 f/L PCM had the least concentration of asbestos fibers.

In the study of Hajizadeh et al., the highest concentration of asbestos fibers was observed in winter (Ghorbani et al. 2020). In the study of Taghizadeh et al., maximum concentration was observed in autumn (Taghizadeh et al. 2019). Moreover, the results of Fig. 5 show that no asbestos was observed in stations 3–13 and 15 in spring. Based on this figure, it could be also seen that the values of asbestos concentration in the air of Karaj in winter, summer, and autumn in 25, 75, 30, and 70% of the measuring stations were higher than the allowable value recommended by EPA (2 f/L PCM), respectively. This shows that in summer due to hot weather and the use of air conditioners in vehicles, and as a result more fuel consumption, and in winter due to the use of heating equipment and insulations, higher concentrations are observed in these two seasons, which is clearly shown in Fig. 6.

This figure also shows that in summer, there was the highest asbestos fiber pollution and following it, the winter season was the second season of pollution, and the least contamination was observed in spring, which is similar to Belanger’s study, and the maximum concentration was observed in summer and then in winter. In the study of Gholami et al. in Tehran, it was found that the cold season had a higher concentration of asbestos fibers than the warm season (1.46 f/L PCM in the warm season and 2.31 f/L PCM in the cold season) (Maleki et al. 2020). In the study of Abdolahnejad et al. in Yazd, it was found that the concentration of asbestos fibers in winter was the highest and in summer was in the second rank (Mokhtari et al. 2019). The subject city studied in this article is one of the most industrial cities in Iran, which is due to the presence of brick kilns and the automotive industries; the concentration of asbestos fibers during the year is much higher than the guidelines of the WHO.

On the other hand, Fig. 7 shows the distribution of asbestos fiber concentration based on the annual average in the ambient air of Karaj city. According to this figure, the closer we get to the north of the city, the higher the concentration of asbestos fibers is due to the existence of the main highways of this city to other cities and provinces of the country and the existence of factories, such as glassmaking, concrete, and polyethylene





**Fig. 8** SEM images of asbestos fiber observed in the air sample and EDXA spectrum (a crocidolite, b chrysotile, c tremolite)

pipes. On the other hand, in the east of the city, due to the existence of the largest hospital and the creation of consecutive traffic, there is a higher concentration. Also, the further we go to the south area, the less is the concentration of asbestos fibers. In some places in mid of the city, such as points 1 and 2, less concentrations of asbestos have been observed. In the study of Taghizadeh et al., it was shown that the closer we got to the source of asbestos fiber production, the higher the concentration of that point was (Taghizadeh et al. 2019).

As mentioned before, the PCM method has some limitations; the most important of which is that it is not able to detect the type of asbestos fibers. Also, the fibers smaller than 0.25  $\mu\text{m}$  are not visible by PCM. For this reason, to evaluate the asbestos fibers and their morphological analysis in the air of Karaj, we analyzed the samples taken by SEM and EDX. SEM and EDX photos were taken from all three types of tremolite, crocidolite, and chrysotile fibers, and their results are shown in Fig. 8 a, b, and c. The SEM method detects fibers with a diameter of even less than 0.01  $\mu\text{m}$ .

Based on the results of SEM analysis, it was found that the concentration of asbestos fibers in the outputs obtained from PCM is 10 times higher. This has also been reported in the study of Kakooei and Normohammadi (2013). In the present study, the SEM-EDX method showed that approximately 35% of the observed asbestos fibers were non-asbestos. The same was shown in the study of Hajizadeh et al. that 25% of the counted fibers were non-asbestos (Mokhtari et al. 2016). According to Fig. 8, the spectra with Fe-Mg-Si peaks generally belong to crocidolite and the fibers that do not have iron peaks of tremolite. Crocidolite fibers are mostly used in asbestos cement press pipes for cladding and insulation. On the other hand, more tremolite fibers are found in brake liners and new buildings, which is mostly seen in commercial (Clinkenbeard et al. 2002), newly built and high-traffic areas,

including points S<sub>10</sub>-S<sub>5</sub>-S<sub>8</sub>. As shown in Fig. 7, there is a white spot on the emitted fiber, which is determined to be barite (BaSO<sub>4</sub>) based on EDX analysis. In fact, this situation is more common in high-traffic areas of the city, because barium sulfate is one of the mineral fillers (friction reducer) that uses friction-reducing materials in the brake pads to stabilize the heat. Based on the images obtained from SEM, it was found that in the air of Karaj, due to the traffic in most parts of the city and the industrial nature of this city and the existence of too many factories, tremolite is the highest used type of fiber. The Dodson study also found that the highest percentage of asbestos fibers was tremolite (Dodson and Hammar 2011).

### Correlation between asbestos fiber concentration and meteorological parameters

In the present study, we measured the meteorological parameters (including temperature, pressure, humidity, and wind speed) during the sampling period to evaluate their effect on the concentration of asbestos fibers by the PHB-318 portable device. However, other factors, such as rainfall, dew point, and ultraviolet rays, should not be overlooked. As shown in Fig. 9, the lowest temperature was in December (3.82 °C) and the highest in June (28.1 °C); the lowest and highest relative humidity was in May (33.82%) and November (64.51%) respectively; the lowest pressure was in July (627.56 mmHg) and the highest was in November (633.15 mmHg); and the lowest wind speed was in December (3.82 m/s) and most wind speed was in June (28.1 m/s).

The Pearson correlation test was used to correlate these parameters with the concentration of asbestos fibers. As can be seen in Table 2, asbestos fibers have a weak and negative relation with pressure, relative humidity, and temperature, while they have a positive relationship with the wind speed.

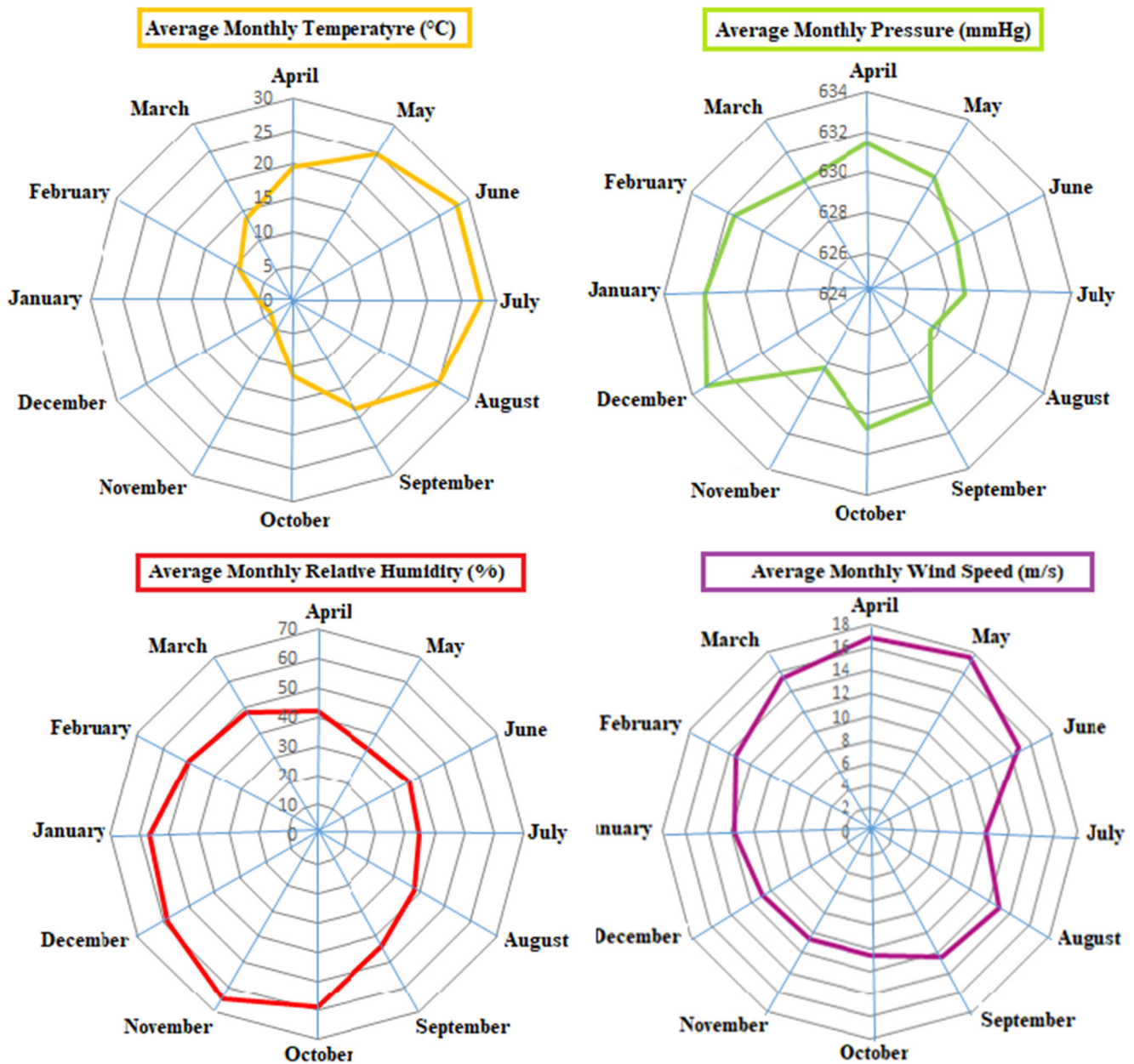


Fig. 9 Average monthly temperature, pressure, relative humidity, and wind speed in Karaj city (2018–2019)

Winds move the particles around the necks of the particles and scatter them in the air, which can be one of the factors that increase the concentration of asbestos fibers. The results of our study were similar to the Taghizadeh study, which showed that asbestos fibers had a negative relationship with humidity

and temperature. Also, in the Hajizadeh study, no relationship was observed between meteorological parameters (Hajizadeh et al. 2020; Taghizadeh et al. 2019).

### Evaluating the health effects of asbestos fibers

In general, people who are more exposed to asbestos fibers have an increased chance of developing two types of cancers, mesothelioma, and lung cancer. Studies also show that people who inhale asbestos fibers have an increased chance of developing cancer in other parts of their body (Fernandes et al. 2019). Ordinary people in contact with low concentrations of asbestos may also be more likely to develop cancer, but

**Table 2** Bivariate correlations between asbestos with meteorological parameter in Karaj from 2019–2020

	Temperature	Wind speed	Relative humidity	Pressure
<i>R</i>	− 0.324	0.34	− 0.147	− 0.179
<i>P</i> <sub>val</sub>	0.016	0.017	0.012	0.324

**Table 3** The chronic exposure concentrations (EC) and excess lifetime cancer risk (ELCR), using maximum and minimum fiber counts

The chronic exposure concentration (EC)							
EC <sub>0–2</sub>		EC <sub>2–6</sub>		EC <sub>6–16</sub>		EC <sub>16–30</sub>	
Min	Max	Min	Max	Min	Max	Min	Max
1.76E-05	4.65E-04	1.05E-05	5.21E-04	1.22E-05	3.27E-04	1.4E-04	7.06E-04
Excess life cancer risk (ELCR)							
ELCR <sub>0–2</sub>		ELCR <sub>2–6</sub>		ELCR <sub>6–16</sub>		ELCR <sub>16–30</sub>	
Min	Max	Min	Max	Min	Max	Min	Max
4.32E-06	2.57E-05	5.68E-06	3.87E-05	3.21E-05	1.81E-04	5.045E-05	3.54E-04

the risk is usually small and difficult to diagnose directly. Several government agencies and regulatory agencies are currently studying evidence of carcinogenicity in asbestos. The Department of Health and Human Services has confirmed that asbestos has been identified as a human carcinogen. The US Environmental Protection Agency (UE EPA) and the International Agency for Research on Cancer (IRAC) have also identified asbestos as a human carcinogen (Fischer and Meyer 1983; Tarone 2018).

In this study, according to IRIS EPA guidelines, the risk assessment of asbestos fibers was calculated based on the concentrations obtained by the PCM method. Risk assessment was analyzed in 4 groups of 0–2, 2–6, 6–16, and 16 to 30 years old, and the ELCR was calculated. On the other hand, to calculate the impact assessment, both the general public and the people working in industries who were exposed to asbestos fibers were considered. The difference in the time of exposure to asbestos fibers, which is 8 h for jobs and 24 h for people in the community, was also considered. The age groups were similar in both community members and people working in the same industries.

According to Table 3, with increasing ELCR, the EC value will be higher. The maximum EC and ELCR rates in all areas are related to the age group of 16 to 30 years, which had the highest amount of contact with asbestos fiber compared to other age groups. Based on the EPA guideline values, the carcinogenic risk range of airborne compounds was considered to be  $1 \times 10^{-6}$  to  $1 \times 10^{-4}$  as the target level. The findings of the present study were similar to Taghizadeh's and Gholami studies (Maleki et al. 2020; Taghizadeh et al. 2019).

## Conclusion

In this study, seasonal concentrations and the effect of meteorological parameters on them, spatial distribution, and risk assessment of asbestos fibers in the air of the most industrial cities of Iran in 2018–2019 were analyzed. The results of this study showed that the city of Karaj has very high

concentrations of asbestos fibers, even higher than the guidelines of the World Health Organization. This has made the city of Karaj, one of the six most polluted cities in Iran. The spatial distribution of asbestos fibers shows that the further we go to the north of the city, the higher the concentration of asbestos fibers are due to high-traffic and commercial centers and central routes. Also, the location of this city (48 km away from the capital of Iran) is also one of the reasons for the high concentration of asbestos fibers.

In terms of the health effects of asbestos fibers for the general public, the ELCR calculated for all age ranges is from  $4.32 \times 10^{-6}$  to  $1.81 \times 10^{-4}$ , which is much higher than the recommended values. Therefore, the residents of Karaj are facing a serious health risk. By having asbestos fiber concentration information for Karaj city, monitor measurements can be taken to decrease the concentrations. It can also be said that future extensive research is very important to determine and control the source of asbestos fiber emissions and reduce their levels. To this end, by taking measurements, such as banning the use of asbestos in industry, raising the standards of vehicles and fuels, developing public transportation systems, and moving industries to the areas out of the cities, the level of asbestos emissions can be significantly controlled.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The authors of this article have covered all the ethical points including non-plagiarism, duplicate publishing, data distortion, and data creation in this article. This project has been registered in Iran University of Medical Sciences with the code of ethics of IR.IUMS.REC.1397.312.

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