Assessment of Indoor/outdoor Particulate Matter in Residential Building: Tehran Metropolis, Iran

Balal Oroji[1]*

Abstract

Indoor Air Quality and the prediction of indoor pollution levels have become more important subjects for health risks. This research will be investigated the ratio of the concentration of particles inside and outside residential houses in Tehran. The particulate matter (PM) sampling was performed in four seasons from August 2020 to July 2021. Four stations were selected as fixed sampling stations and sampling time varied from 6 hours to 12 hours. Due to the risk of fine particles and the possibility of their impact on human health, in this study, $PM_{0.4}$ and $PM_{2.5}$ were examined. A multi-stage virtual shock absorber that traps particles on steel plates with a constant airflow was used for sampling. The Scanning Electron Microscope (SEM) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) methods were used to study the size, morphology, and chemical composition and analyze the total concentration of particulate matter (PM). The results showed that in most stations, the penetration of outdoor particles into the building in the cold season was more than in the hot season. Due to the use of natural ventilation in most residential buildings in the study area, the I/O ratio of $PM_{2.5}$ and $PM_{0.4}$ was on average more than 0.752. At some stations in March, April, and May the I/O ratio was over 0.965. According to these results, in the eastern area, the exposure to particulate matter (PM) with a diameter of less than $0.4\,\mu m$ was higher than in other areas.

Also, the results showed that the average effect of the ventilation factor in the studied area for the whole year was about 38.4%. Meanwhile, this amount was 19.4 and 13% for the factors of cooking and activity, respectively. The average effect of factors of building age and smoking were 7.6 and 21.6%, respectively. The results of the SEM method showed that the penetration of pollutants outdoor the building has a great effect on the concentration of particles indoor.

Resumen

La calidad del aire interior y la predicción de los niveles de contaminación interior se han convertido en temas más importantes para los riesgos para la salud. Esta investigación se investigará la proporción de la concentración de partículas dentro y fuera de las casas residenciales en Teherán. El muestreo de material particulado (PM) se realizó en cuatro temporadas desde agosto de 2020 hasta julio de 2021. Se seleccionaron cuatro estaciones como estaciones de muestreo fijas y el tiempo de muestreo varió de 6 horas a 12 horas. Debido al riesgo de partículas finas y la posibilidad de su impacto en la salud humana, en este estudio se examinaron $PM_{0.4}$ y $PM_{2.5}$. Para el muestreo se utilizó un amortiguador virtual de etapas múltiples que atrapa partículas en placas de acero con un flujo de aire constante. Se utilizaron los métodos Microscopio Electrónico de Barrido (SEM) y Espectrometría de Masas de Plasma Acoplado Inductivamente (ICP-MS) para estudiar el tamaño, la morfología y la composición química y analizar la concentración total de material particulado (PM). Los resultados mostraron que en la mayoría de las estaciones, la penetración de partículas exteriores en el edificio en la estación fría fue mayor que en la estación cálida. Debido al uso de ventilación natural en la mayoría de los edificios residenciales del área de estudio, la relación I/O de $PM_{2.5}$ y $PM_{0.4}$ fue en promedio superior a 0.752. En algunas estaciones en marzo, abril y mayo, la relación I/O fue superior a 0.965. De acuerdo con estos resultados, en el área oriente, la exposición a material particulado (PM) con un diámetro menor a $0.4\,\mu m$ fue mayor que en otras áreas. Asimismo, los resultados mostraron que el efecto promedio del factor de ventilación durante el año fue del orden del 38.4%. En tanto, esta cantidad fue de 19.4 y 13% para los factores de cocción y actividad, respectivamente. El efecto promedio de los factores de vida del edificio y tabaquismo fue de 7.6 y 21.6%, respectivamente. Los resultados del método SEM mostraron que la penetración de contaminantes en el exterior del edificio tiene un gran efecto sobre la concentración de partículas en el interior.

Editorial responsibility: Dra.Ofelia Morton-Vermea

* Corresponding author: Balal Oroji
[1] Water, Energy and Environment Center, Faculty and Research Institute of Civil Engineering, Water and Energy, Imam Hossein Comprehensive University, Tehran, Iran. E-mail: Balaloroji@yahoo.com Tel: +98 918 819 0443 Fax: +98 21 741 685 25

Introduction

$PM_{2.5}$ emission is known as a major challenge to environmental health and is the cause of approximately 7 million deaths annually (Alikhani *et al.* 2021). Epidemiological research has shown that $PM_{2.5}$ will be a serious threat to human health (Ortega-Rosas *et al.* 2021; Thangavel *et al.* 2022). Based on this research, $PM_{2.5}$ has been shown to damage the cardiovascular system, nervous system, respiratory system and immune system and so on (Du *et al.* 2016; Yang *et al.* 2020). This can seriously affect long-term economic, social, welfare and national health development (Ranft *et al.* 2009; Lim *et al.* 2011; Meza-Figueroa *et al.* 2022). PM is one of the primary air pollutants that pose a constant threat to health, well-being and quality of life. These compounds are composed of a complex mixture of chemical, physical and biological components (Schneider *et al.* 2015; Schneider *et al.* 2016; Ramirez *et al.* 2020; Rojas *et al.* 2019; Hu *et al.* 2020; Mellouki *et al.* 2020; Silva *et al.* 2020a; Silva *et al.* 2020b; Zamberlan *et al.* 2020; Schiavo *et al.* 2021). The fine particles stay in the atmosphere longer than coarse particles, so these can enter the respiratory system very quickly (Juginović *et al.* 2021). Due to their aerodynamic properties, these particles can be easily removed during the wet and dry deposition process. The fine particles are also able to be easily transported through the respiratory system by penetrating the pulmonary alveoli and thus lead to pulmonary deposition and systemic displacement (Schiavo *et al.* 2021).

The results of studies in this field have shown that long-time exposure to atmospheric particles leads to complications and various respiratory and lung diseases (Xiao *et al.* 2016; Bourdrel *et al.* 2017; Liu *et al.* 2020; Moller *et al.* 2020; Gao and Sang 2020; Nho 2020; Schiavo *et al.* 2021; Zhao *et al.* 2022; Voss *et al.* 2022). Also, recent studies show that fine particles (diameter less than 2.5 µm) and ultrafine particles (diameter less than 0.1 µm) are the most toxic airborne particles (Xiao *et al.* 2016; Soppa *et al.* 2019). Depending on the source of the contamination, the PM varies in size and composition. Major sources of primary particles are industrial processes, traffic characteristics (i.e. traffic volume and percentage of gasoline and diesel vehicles) and topography, biomass burning (as agricultural products incineration, forest and range fires and Garbage disposal), road traffic, power plants, domestic burning (coal, wood, etc.), incineration, and resuspension of road and construction dust. (Dias *et al.* 2014; Goel and Kumar 2015; Dalmora *et al.* 2016; Kecorius *et al.* 2016; Abramesko and Tartakovsky 2017; Chen *et al.* 2017; Habre *et al.* 2018; Islam *et al.* 2019; Stacey 2019; Moller *et al.* 2020; Agudelo-Castaneda *et al.* 2019; Li *et al.* 2021). Due to the differences in air quality in different regions (like some cities in Europe, North America and China), many studies inside and outside the country have examined

factors that are closely related to changes in air quality, such as meteorological conditions, changes in surface coverage, urbanization and economic development, transportation methods and urbanization (Oroji *et al.* 2018b; Oroji *et al.* 2019; Zhao *et al.* 2020; Isaev *et al.* 2022; Domhagan *et al.* 2022). Therefore, further investigations into the impacts on health effects of short-term and long-term exposures to urban air pollution are warranted. One of the indicators which are widely used for evaluating the impacts of indoor pollution resulting from outdoor pollution is the ratio of indoor to outdoor (I/O ratio) air pollution (I/O ratio) (Meng *et al.* 2005; Brunekreef *et al.* 2005).

Some factors, such as distance from polluting resources, smoking, cooking, climate, the life of the building, and its architectural characteristics can affect indoor air pollution which is resulted from outdoor air pollution (Ji *et al.* 2015; Parajuli *et al.* 2016; Zhou *et al.* 2018). Several studies have been conducted to measure the PM concentration and levels of exposure to particle in indoor air. Branis and Šafránek (2005), investigated the mass concentration, mineral composition, and morphology of suspended particles re-emitted by children during scheduled physical exercise in urban, suburban, and rural elementary school gymnasiums in Prague (Czech Republic). Oroji *et al.* (2021) investigated the penetration and deposition of indoor particles and found that the penetration of indoor particles is determined by particle size and air tightness. Bhangar *et al.* (2011) investigated the sources of and daily exposure to indoor and outdoor particle by measuring ultrafine particles in houses in California. This research revealed that residential exposure to particle was determined by indoor sources and the infiltration factor. Mullen *et al.* (2011) measured the ultrafine particles in elementary schools in California and found that the main cause of particle exposure was outdoor sources.

The metropolis of Tehran, the capital of Iran, is one of the most polluted cities in the region and the world, and increasing the concentration of PM is one of the biggest challenges for its inhabitants. A significant volume of atmospheric particle concentrations in Tehran is related to human resources, which are produced by motor vehicles, industrial factories, and home heating systems. Another part of the source of atmospheric particles in Tehran is local storms (Heger and Sarraf 2018). In recent years increased personal vehicle traffic in the city and the construction of high-rise buildings have raised the concentration of atmospheric particles in the area to dangerous levels and drastically reduced the air quality (Oroji 2018a; Oroji 2021). In this study, we intend to determine the I/O ratio in residential houses by examining the concentration of particles inside and outside. Because so far, the amount of exposure of people living in homes in Tehran with suspended particles has not been calculated. Study and research in the field of physical and chemical

properties of suspended particles, identifying their behavior in different climatic conditions and recognizing the sources that produce them can improve decisions about air pollution control and management.

Methods and Materials

Area of study

The city of Teheran (capital of Iran), located on the southern slops of the Alborz Mountains with and area of about $73\,km^2$, is one of the most populous metropolises in the world with a population of about 15 million people (Arhami *et al.* 2018). The geographical location of the study area is shown in Figure 1. Population growth, land cover, land-use change and, most importantly, a significant increase in the number of moving pollutants (motor vehicles) have led to an increase in air pollution, which has posed significant risks to the ecosystem and human health and safety (Alizadeh Choobari *et al.* 2016). In the last decade, air pollution, including the presence of PM, are recognized as the most important environmental problem in Tehran. Local storms, industries (such as manufacturing industries, electricity generation with fossil fuels and sand mines), urban transport (such as motor vehicle) and soil erosion are the most are the most important sources of pollution in Tehran. The geographic location and prevailing wind direction (specify wind direction in Teheran) limits natural ventilation, increase Temperature inversions in wet seasons and the effects of local dust storms (Halek *et al.* 2010a; Halek *et al.* 2010b).

Sampling method

Atmospheric PM sampling was performed in four seasons from August 2020 to July 2021. Due to the area, four fixed

sampling station were used. Sampling time varied from 6 to 12 hours. The sampling process was performed to determine the concentration of particles inside while people were at home. Sampling stations were between 250 and 600 meters from the first huge traffic street. Also, the age of the buildings at the sampling stations was between 12 and 19 years. More than 98% of the particles are less than 1 μm. They can advance far more deeply into the human organism and even pass alveoli and cellular membranes. In this way, they reach the blood circulation directly, where they are frequently triggering cardiovascular illnesses. They arise mostly in the case of combustion processes (e.g., traffic, heating systems) and with industrial processes (e.g., production, power generation) and are not visible to the human eye (Juginović *et al.* 2021). Due to the risk of fine particles and the possibility of their impact on human health, in this study, $PM_{0.4}$ and $PM_{2.5}$ were examined. A multi-stage virtual shock absorber that traps particles on steel plates with a constant airflow was used for sampling. The sampling airflow in this collector was 28.3 liters per minute. The fiberglass filters were used to collect suspended particles. The collected samples were prepared for chemical analysis. Also, the Scanning Electron Microscope (SEM) method was used to study the size and morphology of suspended particles. In this method, particle surfaces with magnifications of 5000x, 10000x, 20000x and 50000x were studied. The particles were imaged a Zeiss EV050XP SEM, and also, X-ray energy spectra were measured using a Bruker Quantax 200 EDS system with a Peltier-cooled X Flash silicon detector. The Inductively coupled plasma-mass spectrometry (ICP-MS) method was used to study the chemical composition of PM.
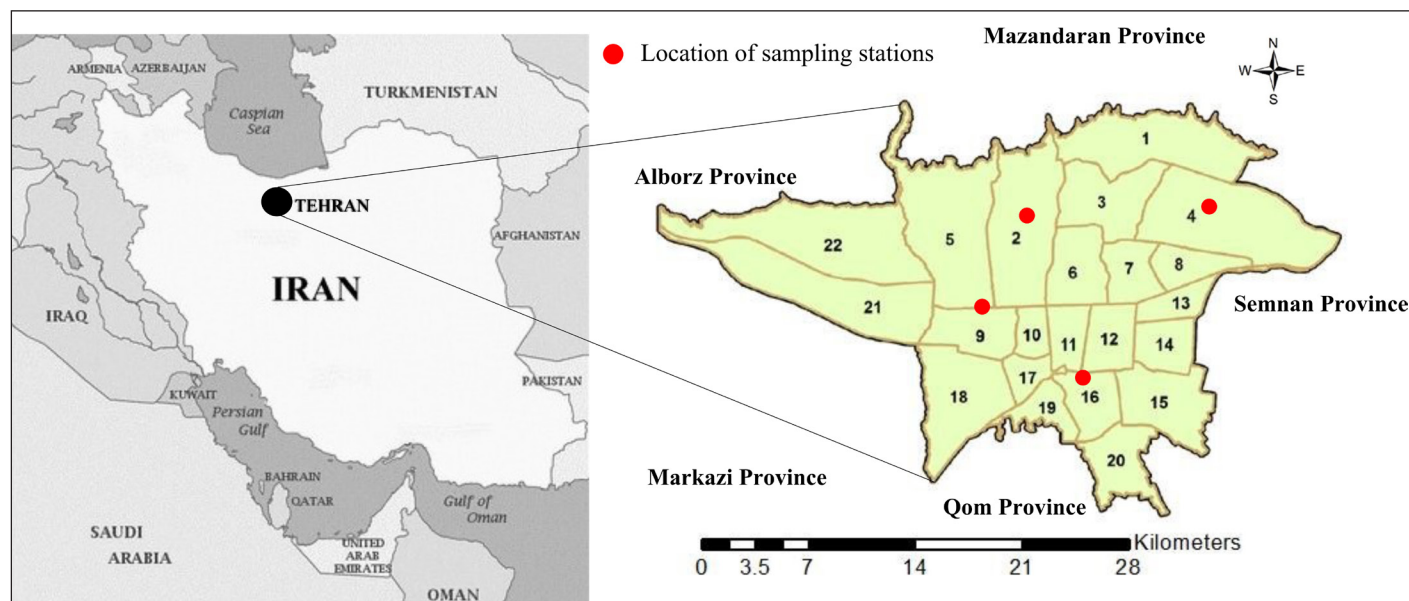

Figure 1. Geographical location of the study area.

Results and Discussion

Outdoor Particle Concentration

Table 1 shows the monthly report of PM concentrations in stations in the study area. According to the measurement results in the Velenjak station, the highest concentration of $PM_{2.5}$ was $161\pm24.6\,\mu g/m^3$ that recorded in October. Also, the lowest concentration was recorded at $25\pm4.3\,\mu g/m^3$, in November. The average of $PM_{2.5}$ in this area was 75 ± 11.1 and $69.9\pm12.6\,\mu g/m^3$ for the dry months (June to November) and wet months (December to May), respectively. The results of the aerodynamic distribution of particles in this area showed that in hot and dry months (such as August and September), the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 11.2 ± 1.3 and $10.1\pm1.1\,\mu g/m^3$, respectively. For cold and wet months (such as December and January), the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 16.3 ± 2.6 and $8.4\pm1\,\mu g/m^3$, respectively. The average concentration of $PM_{2.5}$ and smaller for the whole sampling period in this area was $72.74\pm15.4\,\mu g/m^3$. The results of measurement at the Azadi square station showed that the highest concentration of $PM_{2.5}$ was $187\pm25.6\,\mu g/m^3$ that recorded in November. Also, the lowest concentration was recorded at $55\pm14.5\,\mu g/m^3$, in February. The average concentration of $PM_{2.5}$ was 109.5 ± 17.4 and $127.27\pm21.7\,\mu g/m^3$ for the dry months and wet months, respectively. The results of the aerodynamic distribution of particles in this area showed that in hot and dry months, the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 26.6 ± 4.4 and $13.2\pm2.1\,\mu g/m^3$, respectively. Also, for cold and wet months, the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 18.1 ± 2.3 and $9.1\pm1.2\,\mu g/m^3$, respectively. The results showed that the average concentration of $PM_{2.5}$ was $117.4\pm19.5\,\mu g/m^3$. In the South station, the highest and lowest concentration of $PM_{2.5}$ was 160 ± 18.6 and $41\pm6.8\,\mu g/m^3$, which were recorded in December and January, respectively. Also, the average concentration of $PM_{2.5}$ was 90.4 ± 16.7 and $85.1\pm15.2\,\mu g/m^3$ for the dry months and wet months, respectively. The results showed that in hot and dry months, the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 19.2 ± 3.6 and $14.6\pm3.3\,\mu g/m^3$, respectively. Also, the highest and lowest average concentration of $PM_{0.4}$ for cold and wet months, were recorded at 17.8 ± 2.2 and $10.3\pm2.1\,\mu g/m^3$, respectively. The average concentration of $PM_{2.5}$ was $87.9\pm19.4\,\mu g/m^3$. Based on the sampling results in the Hakimiyeh station, the highest concentration of $PM_{2.5}$ was $153\pm18.4\,\mu g/m^3$ that recorded in December. While the lowest concentration was recorded at $28\pm4.4\,\mu g/m^3$, in November. Also, the average concentration of $PM_{2.5}$ in this area was 79.81 ± 12.6 and $70.62\pm14.8\,\mu g/m^3$ for the dry months and wet months, respectively. The results of the aerodynamic distribution of particles in this area showed that in hot and dry months, the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 13.4 ± 1.6 and $11.6\pm2.4\,\mu g/m^3$, respectively. Also, for cold and wet months, the highest and lowest average concentrations of $PM_{0.4}$ in this area were recorded at 16.8 ± 2.3 and $11.4\pm1.2\,\mu g/m^3$, respectively. The average concentration of $PM_{2.5}$ for the whole sampling period in this area was $76.5\pm18.5\,\mu g/m^3$.

Indoor Particle Concentration

The results of indoor particle concentration are showed in Table 2. In residential houses in the northern areas of the city, due to excessive use of natural ventilation in the cold months, smoking, and cooking, see a significant increase in indoor suspended particles. Meanwhile, the houses in this area are

Table 1. Monthly report of particle concentrations Outdoor in the study area ($\mu g/m^3$).

Date	Velenjak		Hakimiyeh		Azadi squar		South	
	$PM_{0.4}$	$PM_{2.5}$	$PM_{0.4}$	$PM_{2.5}$	$PM_{0.4}$	$PM_{2.5}$	$PM_{0.4}$	$PM_{2.5}$
April 2021	13.5	73.87	12.2	67.1	13.2	97.77	11.8	85.58
May 2021	13.3	67.71	11.6	54.96	13.1	96.67	12.3	77.22
June 2021	14.8	69.4	12.8	68.56	12.4	106.51	13.5	78.78
July 2021	15.7	83.9	14.1	79.75	15.7	123.46	14.7	93.41
August 2020	14.3	72.41	15.3	66.21	17.6	107.11	16.3	70.96
September 2020	14.6	84.5	17.8	77.54	17.2	122.8	17.2	84.71
October 2020	11.2	73.46	10	81.63	13.4	121.16	11.1	90.6
November 2020	11.5	61.83	10.7	67.92	12.2	119.61	11.5	82.56
December 2020	10.4	84.93	9.5	105.1	11.8	153.13	10.4	119.48
January 2020	8.2	67.65	7.2	85.66	11.7	124	10.2	97.1
February 2020	8.7	59.6	7.6	78.96	9.3	117.4	8.7	86.92
March 2020	9.3	58.7	7.4	77.56	9.2	102.47	8.5	86.64

equipped with modern cooling, heating, and air conditioning systems. At Velenjek station, the average concentration of fine particles ($PM_{2.5}$) for spring was $48.74\pm9.4\,\mu g/m^3$. The concentration was higher than other stations. The highest concentration was recorded in the spring for Azadi station with a value of $68.21\pm7.5\,\mu g/m^3$. This value was $10.65\pm2.35\,\mu g/m^3$ for $PM_{0.4}$. According to the results, the increasing trend in the concentration of indoor particles in the warm months of the year was more than in the cold months of the year. These changes were significant in residential homes that an adequate ventilation. In residential houses that did not have proper cooling and ventilation systems, the I/O value was close to 1. This increase in concentration in 22.5% of residential homes was due to the type of cooking in the kitchen as well as smoking. In the Hakimiyeh station, the concentration of indoor particles was not much different from the concentration of outdoor particles in the building. The mean Pearson correlation coefficient (r) was 0.785. Also, in the northern areas (such as Velenjek station), due to the difference in temperature and relative humidity, the lowest difference between the concentration of outdoor and indoor particles was observed. The concentration of indoor particles in South station was less different from the concentration of outdoor particles. At this station, the average $I/OPM_{2.5}$ was 0.732. While this value was about 0.788 for $PM_{0.4}$.

Indoor/Outdoor Particle Concentration

The results indoor/outdoor particle concentration ratio are shown in Table 3. The results showed that the indoor/outdoor particles concentration ratio is high (~1) in the study area. This rate (I/O) was higher in the cold and wet months of the year in northern areas. Also, in the southern area (Southern station) concentration of the indoor/outdoor particles was high in most months of the year. Using natural ventilation instead of mechanical ventilation is the main factor for the high indoor/outdoor particle concentration ratio. Field research in these areas showed that many residential houses use natural systems for air conditioning. Also, the life of the building, long life of doors and windows, cooking and cigarette smoke are the factors that cause high indoor/out-

Table 2. Average Concentration of the size distribution of the indoor.

Stations	Diameter Particle (μm)	Concentration (μg/m³)			
		Spring	Summer	Autumn	Winter
Hakimiyeh	$PM_{0.4}$	8.22	9.2	10.34	6.25
	$PM_{2.5}$	52.15	49.54	55.61	50.45
South	$PM_{0.4}$	9.13	10.22	12.45	8.64
	$PM_{2.5}$	53.17	60.55	60.16	55.34
Velenjak	$PM_{0.4}$	7.56	8.32	9.22	5.76
	$PM_{2.5}$	48.74	45.24	50.46	45.62
Azadi square	$PM_{0.4}$	8.82	9.73	10.31	7.14
	$PM_{2.5}$	52.63	58.56	58.25	50.42

Table 3. Monthly reporting indoor/outdoor particle concentration ratio in the study area.

Date	Velenjak		Hakimiyeh		Azadi square		South	
	$I/OPM_{0.4}$	$I/OPM_{2.5}$	$I/OPM_{0.4}$	$I/OPM_{2.5}$	$I/OPM_{0.4}$	$I/OPM_{2.5}$	$I/OPM_{0.4}$	$I/OPM_{2.5}$
April 2021	0.78	0.62	0.87	0.72	0.83	0.77	0.87	0.72
May 2021	0.81	0.64	0.82	0.64	0.84	0.78	0.85	0.76
June 2021	0.82	0.68	0.75	0.68	0.81	0.68	0.82	0.78
July 2021	0.72	0.64	0.71	0.67	0.8	0.58	0.84	0.71
August 2020	0.71	0.58	0.68	0.65	0.82	0.72	0.77	0.68
September 2020	0.68	0.55	0.66	0.76	0.75	0.67	0.76	0.67
October 2020	0.67	0.43	0.71	0.67	0.74	0.71	0.72	0.72
November 2020	0.65	0.47	0.7	0.66	0.73	0.7	0.74	0.77
December 2020	0.55	0.57	0.65	0.68	0.72	0.72	0.67	0.71
January 2020	0.74	0.58	0.66	0.72	0.76	0.68	0.67	0.77
February 2020	0.75	0.63	0.72	0.73	0.68	0.8	0.88	0.87
March 2020	0.8	0.7	0.8	0.77	0.78	0.83	0.87	0.85

door particles concentration ratio in these areas. The eastern regions of the study area, due to being in the direction of the prevailing wind direction, are more affected by atmospheric PM. Based on these results, the concentration of PM with a diameter of less than 0.4 µm in these areas was higher than in other stations. Accordingly, the ratio of I/O was higher in the eastern area than in other areas. Due to the concentration of PM produced by pollutant sources in the western parts of the study area, the ratio of I/O was at a high level. The I/O ratio in spring was close to 1 in all stations. This ratio was higher for particles with a diameter of 0.4 µm (more than 2.5 µm). Also, the results showed that the penetration of particles produced from external pollutants into residential houses is high. So, people living in the area are likely to be exposed to PM for a long time. These conditions can cause respiratory and cardiovascular diseases.

Morphology and Chemical Composition of Particles
Figure 3 shows the SEM image of indoor/outdoor particles collected in the study area. The results of SEM analysis of the samples showed that most of the particles are irregular, fibrous and spherical in shape as well as crystalline shapes. Most of the elements in the samples taken in this area in-

clude Chlorine (Cl), Calcium (Ca), Iron (Fe), and Potassium (K), which are found in combination with Zinc (Zn). In the samples of these areas, crystalline, spherical and amorphous shapes are seen in particles with diameter less than 2 µm with compounds rich in Oxygen (O), Fe, Silicon (Si) and Titanium (Ti) along with Magnesium (Mg) and Aluminum (Al). The Si ratio of these compounds with Sodium (Na) and Al indicates feldspar and clay mineral compounds (Shao *et al.* 2007). These results were similar to the findings of the research of Bhardwaj *et al.* (2017) in urban and rural areas of Delhi, India; Kushwaha *et al.* (2013) in the Allahabad region of India. PM with a diameter of 0.4 microns had irregular, spherical, rod and crystalline shapes. These particles are observed in the samples collected in the wet season. These samples contain compounds rich in Ca, and Zn along with Al, Ti and O. This result indicates the origin of construction and urban transportation (Tiwari *et al.* 2014; Tiwari *et al.* 2015). The results of SEM analysis showed that the chemical composition of the indoor particles was similar to the outdoor particles. In some cases, there was a difference in the chemical composition of the indoor particles. This difference was related to the origin of the indoor particles produced (such as cooking and cigarette smoke).
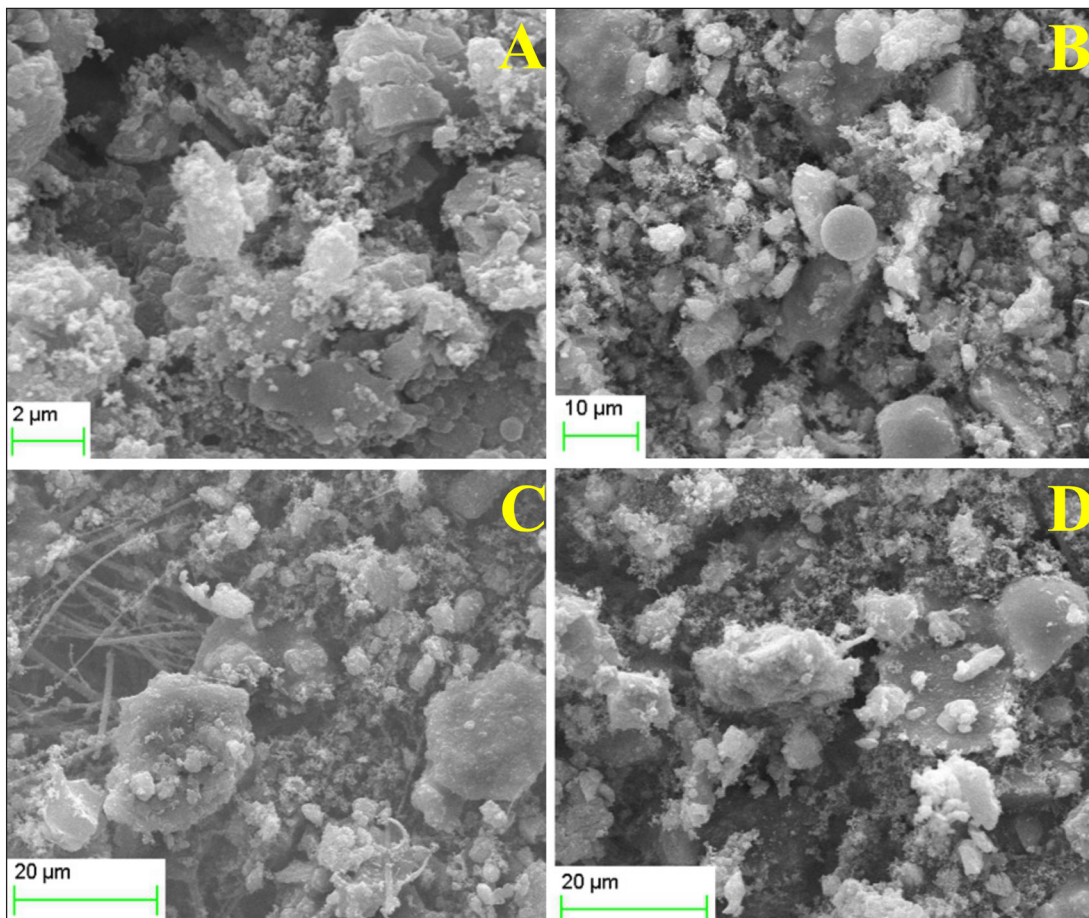

Figure 2. Image of PM collected by SEM method in the study area (A and B outdoor particles, C and D indoor particles).

The results of SEM analysis of the samples taken from the Southern areas in the study area show that most of the particles are spherical and fibrous. Most of the elements in the samples taken in this area include Ca, Fe and K, which are found in combination with Ti. Amorphous structures rich in Si and Fe, Mg and Na, were observed in PM smaller than 2.5 μm. In the samples of these areas, spherical and amorphous particles are seen in particles with a diameter greater than 0.4 micrometers with compounds rich in K, Mg, Zn and Ti along with Si and Al. The ratio of Al and Na of these compounds with Si indicates feldspar and clay mineral compounds (Shao *et al.* 2007). PM with irregular, rod-shaped and crystalline shapes was characteristic of particles smaller than 0.4 μm collected from the characteristics of samples taken in the dry season. The size of the collected particles also varied and ranged from nanometers to several tens of micrometers. Smaller particles accumulate in the atmosphere due to collisions with other particles, forming larger particles (Papastefanou 2008). As the particle dimensions grow, their deposition and removal conditions are provided (Schiavo *et al.* 2022). Particles with irregular and amorphous shapes are of internal origin and these particles mainly include particles produced from mobile sources (Transportation), industry and fossil fuel consumption. After suspension in the atmosphere, these particles collide with surfaces form larger dimensions and precipitate cumulatively (Geng *et al.* 2011; Zhai *et al.* 2012). While particles with regular and mostly spherical shapes are of organic origin and are caused by biomass burning in the environment (Campos-Ramos *et al.* 2009; Geng *et al.* 2011). According to the results of other studies, fine particles are emitted during fuel combustion processes by industry and urban transportation, and larger particles during human activities such as dust emitted on roads by vehicles, construction and Industries are produced and disseminated (Adachi and Tainosho 2004; Viana *et al.* 2006; Oroji *et al.* 2019).

The Factors Affecting Indoor Pollution

The monthly average contribution of the factors affecting the increase in the concentration of indoor particles showed in Table 4. These results showed that natural ventilation is the most important factor in increasing the concentration of indoor particles. During the year, the average share of natural ventilation in increasing the concentration of indoor particles was more than 39%. Also, the daily activities of people living in the building play a role in increasing the concentration of indoor particles by about 12%. On average, about 19% of the indoor particle was related to cooking. The life of the building was very different in different areas of Tehran. In some areas, the difference can be as long as 40 years. Studies have shown that this factor is 23% involved in the penetration of external particles into the building. This amount was higher for older buildings. Also, in most stations, the penetration of outdoor particles into the building in the cold season was more than in the hot season. Due to the use of natural ventilation in most residential buildings in the study area, the I/O ratio of $PM_{2.5}$ and $PM_{0.4}$ was on average more than 0.752. At some stations in March, April and May the I/O ratio was over 0.965.

Table 4. Monthly average contribution of the factors affecting the increase in the concentration of indoor particle.

	Factors				
Date	Ventilation (%)	Cooking (%)	Activity (%)	Smoking (%)	Building age (%)
April 2021	45	15	12	8	20
May 2021	57	12	10	5	16
June 2021	36	25	10	7	22
July 2021	29	27	12	7	25
August 2020	31	17	17	8	27
September 2020	30	23	15	6	26
October 2020	32	21	14	5	28
November 2020	35	17	13	10	25
December 2020	32	22	12	9	25
January 2020	37	20	15	11	17
February 2020	42	18	16	10	14
March 2020	54	15	10	6	15

Conclusions

The results showed that internal resources are related to human activities and the intended use of space. In living environments, an important role is played by smoking and cooking, followed by heating, cleaning, and suspension systems due to human presence. In hot months like August and September, most indoor particles are brought in from outside with naturally ventilated buildings. These results showed that mechanical ventilation can reduce exposure to outdoor particles in residential buildings. This crisis will be seen in the future with the development of common diseases among the persons. Prolonged exposure to atmospheric particles inside and outside the workplace and living environment can lead to respiratory and heart disease. Creating awareness and education among the people, renovating places, and using modern mechanical heating, cooling, and air conditioning systems can control the occurrence of health problems to some extent.

Acknowledgments

Reference

Abramesko V, Tartakovsky L (2017). Ultrafine particle air pollution inside diesel-propelled passenger trains. *Environmental Pollution 226*: 288-296. **https://doi.org/10.1016/j.envpol.2017.03.072**

Adachi K, Tainosho Y (2004). Characterization of heavy metal particles embedded in tire dust. *Environmental international*. 30(8):1009-17. DOI: 10.1016/j.envint.2004.04.004

Alizadeh-Choobari O, Bidokhti AA, Ghafarian P, Najafi MS (2016). Temporal and spatial variations of particulate matter and gaseous pollutants in the urban area of Tehran. *Atmospheric Environment 141*:443-53. DOI: 10.1016/j.atmosenv.2016.07.003

Alikhani Faradonbeh M, Mardani G, Raeisi Shahraki H (2021). Longitudinal Trends of the Annual Exposure to PM2.5 Particles in European Countries. *Scientifica*, 2021. doi:10.1155/2021/8922798

Agudelo-Castañeda DM, Teixeira EC, Braga M, *et al.* (2019). Cluster analysis of urban ultrafine particles size distributions. *Atmospheric Pollution Research 10*(1):45-52. DOI:10.1016/j.apr.2018.06.006

Arhami M, Shahne MZ, Hosseini V, Haghighat NR, Lai AM, Schauer JJ (2018). Seasonal trends in the composition and sources of PM2.5 and carbonaceous aerosol in Tehran, Iran. *Environmental Pollution* 2018; 239: 69-81 DOI: 10.1016/j.envpol.2018.03.111

Bourdrel T, Bind MA, Béjot Y, Morel O, Argacha JF (2017). Cardiovascular effects of air pollution. *Arch Cardiovasc Dis* 110(11): 634-642 DOI: 10.1016/j.acvd.2017.05.003

Bhardwaj P, Singh BP, Pandey AK, Jain VK, Kumar K (2017). Characterization and Morphological Analysis of summer and Wintertime PM2.5 Aerosols over Urban-Rural Locations in Delhi-NCR. *Int Journal of Applied Environmental Science 12*(5): 1009-1030.

Bhangar S, Mullen NA, Hering SV, Kreisberg NM, Nazaroff WW (2011). Ultrafine particle concentrations and exposures in seven residences in northern California. *Indoor air*. 21(2):132-44. DOI: 10.1111/j.1600-0668.2010.00689.x

Braniš M, Šafránek J. (2011). Characterization of coarse particulate matter in school gyms. *Environmental Research*. 111(4):485-91. DOI: 10.1016/j.envres.2011.03.010

Brunekreef B, Janssen NA, de Hartog JJ, *et al.* (2005). Personal, indoor, and outdoor exposures to PM2.5 and its components for groups of cardiovascular patients in Amsterdam and Helsinki. *Research report (Health Effects Institute)* (127):1-70.

Campos-Ramos A, Aragón-Piña A, Galindo-Estrada I, *et al.* (2009). Characterization of atmospheric aerosols by SEM in a rural area in the western part of Mexico and its relation with different pollution sources. *Atmospheric Environment 43*(39):6159-6167. DOI:10.1016/j.atmosenv.2009.09.004

Chen C, Zhao Y, Zhang Y, Zhao, B (2017). Source strength of ultrafine and fine particle due to Chinese cooking. *Procedia Engineering 205*: 2231-2237. **https://doi.org/10.1016/j.proeng.2017.10.062**

Dalmora AC, Ramos CG, Querol X, *et al.* (2016). Nanoparticulate mineral matter from basalt dust wastes. *Chemosphere 144*:2013-2017. DOI: 10.1016/j.chemosphere.2015.10.047

Dias CL, Oliveira ML, Hower JC, *et al.* (2014). Nanominerals and ultrafine particles from coal fires from Santa Catarina, South Brazil. *International Journal of Coal Geology*, 122:50-60. DOI:10.1016/j.coal.2013.12.011

Domhagen F, Wahlgren P, Hagentoft CE (2022). Impact of weather conditions and building design on contaminant infiltration from crawl spaces in Swedish schools—Numerical modeling using Monte Carlo method. *In Building Simulation 15*(5)845-858. **https://doi.org/10.1007/s12273-021-0832-5**

Du Y, Xu X, Chu M, Guo Y, Wang J. (2016). Air particulate matter and cardiovascular disease: the epidemiological, biomedical and clinical evidence. *Journal of thoracic disease*. 8(1):E8. DOI: 10.3978/j.issn.2072-1439.2015.11.37

Gao, R, Sang N (2020). Quasi-ultrafine particles promote cell metastasis via HMGB1-mediated cancer cell adhesion. *Environmental Pollution 256*: 113390. DOI: 10.1016/j.envpol.2019.113390

Geng H, Ryu J, Maskey S, Jung HJ, Ro CU (2010). Characterization of individual aerosol particles collected during a haze episode in Incheon, Korea using the quantitative ED-EPMA technique. *Atmospheric Chemistry and Physics Discussions 10*(26):641-26. **https://doi.org/10.5194/acp-11-1327-2011**

Goel A, Kumar P (2015). Characterisation of nanoparticle emissions and exposure at traffic intersections through fast–response mobile and sequential measurements. *Atmospheric Environment 107*: 374-390. **https://doi.org/10.1016/j.atmosenv.2015.02.002**

Habre R, Zhou H, Eckel SP, *et al.* (2018). Short-term effects of airport-associated ultrafine particle exposure on lung function and inflammation in adults with asthma. *Environment international*, 118:48-59. DOI: 10.1016/j.envint.2018.05.031

Halek F, Kianpour-Rad M, Kavousirahim A (2010a). Seasonal variation in ambient PM mass and number concentrations (case study: Tehran, Iran). *Environmental monitoring and assessment*, 169(1):501-507. DOI: 10.1007/s10661-009-1192-2

Halek F, Keyanpour-Rad M, Kavousi A (2010b). Dependency of polycyclic aromatic hydrocarbon concentrations on particle size distribution in Tehran atmosphere. *Toxicological & Environmental Chemistry* 92(5):841-853. **https://doi.org/10.1080/02772240903173320**

Heger M, Sarraf M (2018). Air pollution in Tehran: Health costs, sources, and policies. World Bank

Hu, R., Xu, Q., Wang, S., *et al.* (2020). Chemical characteristics and sources of water-soluble organic aerosol in southwest suburb of Beijing. *Journal of Environmental Science 95*: 99-110. DOI:10.1016/j.jes.2020.04.004

Isaev E, Ajikeev B, Shamyrkanov U (2022). Impact of Climate Change and Air Pollution Forecasting Using Machine Learning Techniques in Bishkek. *Aerosol and Air Quality Research 22*: 210336.

Islam N, Rabha S, Silva LF, Saikia BK (2019). Air quality and PM10-associated poly-aromatic hydrocarbons around the railway traffic area: statistical and air mass trajectory approaches. *Environmental Geochemistry and Health 41*(5): 2039-2053. DOI:10.1007/s10653-019-00256-z

Kecorius S, Kivekäs N, Kristensson A, *et al.* (2016). Significant increase of aerosol number concentrations in air masses crossing a densely trafficked sea area. *Oceanologia 58*(1):1-12. **https://doi.org/10.1016/j.oceano.2015.08.001**

Kushwaha R, Hazarika N, Srivastava A (2013). SEM-EDX analysis of size segregated particulate matter in Allahabad located in north India. *International Journal of Advance Research 1*(5): 248-255.

Ji W, Zhao B (2015). Contribution of outdoor-originating particles, indoor-emitted particles and indoor secondary organic aerosol (SOA) to residential indoor PM2.5 concentrations: A model-based estimation. *Building and Environment 90*:196-205. DOI:10.1016/j.buildenv.2015.04.006

Juginović A, Vuković M, Aranza I, Biloš V. (2021). Health impacts of air pollution exposure from 1990 to 2019 in 43 European countries. *Scientific Reports.* 11(1):22516. **https://doi.org/10.1038/s41598-021-01802-5**

Li Z, Zhou R, Li Y, *et al.* (2021). Characteristics and Sources of Organic Aerosol Markers in PM2.5. *Aerosol and Air Quality Research 21*:210180. **https://doi.org/10.4209/aaqr.210180**

Lim JM, Jeong JH, Lee JH, *et al.* (2011). The analysis of PM2.5 and associated elements and their indoor/outdoor pollution status in an urban area. *Indoor Air* (2):145-55. DOI: 10.1111/j.1600-0668.2010.00691.x

Liu X, Pan X, Wang Z, *et al.* (2020). Chemical characteristics and potential sources of PM2.5 in Shahe city during severe haze pollution episodes in the winter. *Aerosol and Air Quality Research 20*(12):2741-2753. **https://doi.org/10.4209/aaqr.2020.03.0124**

Møller KL, Brauer C, Mikkelsen S, (2020). Cardiovascular disease and long-term occupational exposure to ultrafine particles: A cohort study of airport workers. *International Journal of Hygiene and Environmental Health 223*(1):214-219. DOI: 10.1016/j.ijheh.2019.08.010

Mellouki A, George C, Chai F, *et al.* (2020). SI: Climate Friendly Air Pollution Control: Sources, Processes, Impacts, and Regulation Preface. *Environmental Science 95*: 1-1.

Meng QY, Turpin BJ, Korn L *et al.* (2005). Influence of ambient (outdoor) sources on residential indoor and personal PM2.5 concentrations: analyses of RIOPA data. *Journal of Exposure Science & Environmental Epidemiology 15(1)*:17-28. DOI: 10.1038/sj.jea.7500378

Meza-Figueroa, D., Pedroza-Montero, M., Barboza-Flores, M., Navarro-Espinoza, S., Ruiz-Torres, R., Robles-Morúa, A., Romero, F., Schiavo, B., González-Grijalva, B., Acosta-Elias, M. and Mendoza-Córdova, A. (2021). Identification of refractory zirconia from catalytic converters in dust: An emerging pollutant in urban environments. *Science of the Total Environment*, 760, p.143384. **https://doi.org/10.1016/j.scitotenv.2020.143384**

Mullen NA, Bhangar S, Hering SV, Kreisberg NM, Nazaroff WW. (2011). Ultrafine particle concentrations and exposures in six elementary school classrooms in northern California. *Indoor Air.* 21(1):77-87. DOI: 10.1111/j.1600-0668.2010.00690.x

Nho R (2020). Pathological effects of nano-sized particles on the respiratory system. *Nanomedicine: Nanotechnology, Biology and Medicine 29*: 102242. DOI: 10.1016/j.nano.2020.102242

Oroji B, Solgi E, Sadighzadeh A (2018a). Recognition of the source and nature of atmospheric aerosols in Tehran, Iran. *Aerosol Air Quality Research 18*(8): 2131-2140. **https://doi.org/10.4209/aaqr.2018.03.0098**

Oroji B, Sadighzadeh A, Solgi E, Oliaei MS (2021). Impact of air quality on students' behavior in the Educational Centers. *Air Quality, Atmosphere & Health 14*(6): 793-806. DOI:10.1007/s11869-021-00979-y

Oroji B, Sadighzadeh A, Solgi E, *et al.* (2019). Size distribution and chemical composition of indoor and outdoor particles in lab building. *Journal of Air Pollution and Health 4*(1): 15-26. **https://doi.org/10.18502/japh.v4i1.600**

Oroji B, Solgi E, Sadighzadeh A (2018). Characterization and morphological analysis of aerosols in Tehran traffic zone. *Journal of air pollution and Health 3*(1):9-16.

Ortega-Rosas CI, Meza-Figueroa D, Vidal-Solano JR, González-Grijalva B, Schiavo B. (2021). Association of airborne particulate matter with pollen, fungal spores, and allergic symptoms in an arid urbanized area. *Environmental Geochemistry and Health.* 43:1761-82. DOI: 10.1007/s10653-020-00752-7

Parajuli I, Lee H, Shrestha KR (2016). Indoor air quality and ventilation assessment of rural mountainous households of Nepal. *International Journal of Sustainable Built Environment 5*(2):301-11. DOI:10.1016/j.ijsbe.2016.08.003

Papastefanou C (2008). Radioactive aerosols. *Radioactivity in the Environment 12*:11-58.

Ramírez O, da Boit K, Blanco E, Silva LF (2020). Hazardous thoracic and ultrafine particles from road dust in a Caribbean industrial city. *Urban Climate 33*:100655. DOI:10.1016/j.uclim.2020.100655

Ramirez-Leal R, Valle-Martinez, M, Cruz-Campas M (2014). Chemical and morphological study of PM10 analysed by SEM-EDS. *Air Pollution 3*(04):121. DOI:10.4236/ojap.2014.34012

Ranft U, Schikowski T, Sugiri D, Krutmann J, Krämer U (2009). Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly. *Environmental research.* 109(8):1004-11. DOI: 10.1016/j.envres.2009.08.003

Rojas JC, Sánchez NE, Schneider I, *et al.* (2019). Exposure to nanometric pollutants in primary schools: environmental implications. *Urban Climate 27*:412-419. DOI:10.1016/j.uclim.2018.12.011

Schneider IL, Teixeira EC, Oliveira LFS, Wiegand F (2015). Atmospheric particle number concentration and size distribution in a traffic–impacted area. *Atmospheric Pollution Research 6*(5): 877-885. **https://doi.org/10.5094/APR.2015.097**

Schneider IL, Teixeira EC, Agudelo-Castañeda DM, et al (2016). FTIR analysis and evaluation of carcinogenic and mutagenic risks of nitro-polycyclic aromatic hydrocarbons in PM10. *Science Total Environmental 541*:1151-1160. DOI: 10.1016/j.scitotenv.2015.09.142

Schiavo, B., Meza-Figueroa, D., Vizuete-Jaramillo, E., Robles-Morua, A., Angulo-Molina, A., Reyes-Castro, P.A., Inguaggiato, C., Gonzalez-Grijalva, B. and Pedroza-Montero, M., (2022). Oxidative potential of metal-polluted urban dust as a potential environmental stressor for chronic diseases. *Environmental Geochemistry and Health*, pp.1-22. **https://doi.org/10.1007/s10653-022-01403-9**

Schiavo B, Meza-Figueroa D, Pedroza-Montero M, Vidal-Solano J, González-Grijalva B, Navarro-Espinoza S, Romero F, Hernández E, Gutiérrez-Ruiz ME, Ceniceros-Gómez AE. (2021). In vitro assessment oral and respiratory bioaccessibility of Mn in school dust: Insight of seasonality in a semiarid environment. *Applied Geochemistry*. 134:105102. **https://doi.org/10.1016/j.apgeochem.2021.105102**

Silva LF, Milanes C, Pinto D, *et al.* (2020a). Multiple hazardous elements in nanoparticulate matter from a Caribbean industrialized atmosphere. *Chemosphere 239*:124776. **https://doi.org/10.1016/j.chemosphere.2019.124776**

Silva LF, Pinto D, Neckel A, *et al.* (2020b). Atmospheric nanocompounds on Lanzarote Island: Vehicular exhaust and igneous geologic formation interactions. *Chemosphere 254*:126822. **https://doi.org/10.1016/j.chemosphere.2020.126822**

Steinfeld B, Scott J, Vilander G, *et al.* (2015). The role of lean process improvement in implementation of evidence-based practices in behavioral health care. *The Journal of Behavioral Health Services & Research 42*(4):504-518. DOI: 10.1007/s11414-013-9386-3

Soppa VJ, Shinnawi S, Hennig F, *et al.* (2019). Effects of short-term exposure to fine and ultrafine particles from indoor sources on arterial stiffness–A randomized sham-controlled exposure study. *International Journal of Hygiene and Environmental Health*, 222(8):1115-1132. DOI: 10.1016/j.ijheh.2019.08.002

Stacey, B., 2019. Measurement of ultrafine particles at airports: A review. *Atmospheric Environment*, 198:463-477. DOI:10.1016/j.atmosenv.2018.10.041

Tiwari S, Pipal AS, Hopke PK, *et al.* (2015). Study of the carbonaceous aerosol and morphological analysis of fine particles along with their mixing state in Delhi, India: a case study. *Environmental Science Pollution Research 22*(14): 10744-10757. DOI: 10.1007/s11356-015-4272-6

Tiwari S, Bisht DS, Srivastava AK, *et al.* (2014). Variability in atmospheric particulates and meteorological effects on their mass concentrations over Delhi, India. *Atmospheric Research 145*: 45-56. **https://doi.org/10.1016/j.atmosres.2014.03.027**

Thangavel P, Park D, Lee YC. (2022). Recent insights into particulate matter (PM2.5)-mediated toxicity in humans: an overview. *International journal of environmental research and public health*. 19(12):7511. doi: 10.3390/ijerph19127511

Viana M, Querol X, Alastuey A (2006). Chemical characterization of PM episodes in North-Eastern Spain. *Chemosphere 62*: 947–956. **https://doi.org/10.1016/j.chemosphere.2005.05.048**

Voss U, Uller L, Ansar S, *et al.* (2022). Airway exposure to urban aerosolized PM2.5 particles induce neuroinflammation and endothelin-mediated contraction of coronary arteries in adult rats. *Environmental Advances 8*:100184. **https://doi.org/10.1016/j.envadv.2022.100184**

Xiao X, Cao L, Wang R, Shen ZX, Cao YX (2016). Airborne fine particulate matter alters the expression of endothelin receptors in rat coronary arteries. *Environmental Pollution 218*: 487-496. DOI: 10.1016/j.envpol.2016.07.028

Yang L, Li C, Tang X. (2020). The impact of PM2.5 on the host defense of respiratory system. *Frontiers in cell and developmental biology*. 8:91. **https://doi.org/10.3389/fcell.2020.00091**

Zamberlan DC, Halmenschelager PT, Silva LFO, Da Rocha JBT (2020). Copper decreases associative learning and memory in Drosophila melanogaster. *Science Total Environmental 710*: 135306. **https://doi.org/10.1016/j.scitotenv.2019.135306**

Zhai YB, Fu ZM, Wang LF (2012). Characteristic, Composition, and Sources of TSP Investigated by HRTEM/EDS and ESEM/EDS. Environmental Monitoring Assessment 184: 6693-6707. DOI: 10.1007/s10661-011-2452-5

Zhao X, Zhao X, Liu P, Ye C, (2020). Pollution levels, composition characteristics and sources of atmospheric PM2.5 in a rural area of the North China Plain during winter. Journal of Environmental Science 95: 172-182. DOI: 10.1016/j.jes.2020.03.053

Zhao B, Wang M, Song W, Ma H, *et al.* (2022). Increasing risk of gestational diabetes and preeclampsia associated with long-term exposure effects of air pollution. Air Quality, Atmosphere & Health 11:1-2. DOI: 10.1007/s11356-022-20594-3

Zhou X, Cai J, Chen R, Wang C, Zhao A, *et al.* (2018). Estimation of residential fine particulate matter infiltration in Shanghai, China. Environmental pollution 233:494-500. DOI: 10.1016/j.envpol.2017.10.054