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Evaluation of fine particulate matter ($PM_{2.5}$) concentration trends over heavily-industrialized metropolis of Ahvaz: Relationships to emissions and meteorological parameters

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ABSTRACT

Introduction: Today, with the industrialization of societies, the expansion of urbanization and the increasing trend of population growth, sustainable livelihoods are severely polluted and unfortunately around the world, especially in developing countries, urban air quality is declining. This study is designed to determine the concentration of $PM_{2.5}$ particles and the effect of meteorological parameters in 14 selected points in the metropolis of Ahvaz.
Materials and methods: The sampling of Particulate Matter less than 2.5 µm ($PM_{2.5}$) was in four seasons (winter, spring, summer and autumn). Sampling was performed using the Environmental Protection Agency, method TO-13A (EPA/TO-13A) guideline. Particle samples were collected on a fiberglass filter with a pore size of 1 µm and diameter of 37 mm. Information about meteorological parameters was also recorded by PHB-318. Finally, the obtained data were analyzed by SPSS and R.
Results: The results showed that the concentration of $PM_{2.5}$ particles in the metropolis of Ahvaz during the study period is 14 times higher than the value of the guidelines of the World Health Organization (WHO). Also, temperature had a negative relationship and relative humidity and pressure had a direct and positive relationship with concentration of $PM_{2.5}$ particle. It was found that Zargan, Padadshahr 1and 2, Saadi and 17 Shahrivar stations are the most polluted points compared to $PM_{2.5}$ particles.
Conclusion: Planning appropriate strategies of air pollution control to reduce is important and necessary.

Introduction

Air pollution is one of the challenges facing human societies in the 21st century [1]. It can also be said that air pollution is one of the most important and perhaps the worst current crisis in humanity, which, if left unchecked, will endanger our place on earth [2]. Air pollution can be considered a living virus that has taken the lives of millions of people [3].

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The latest report from the International Agency for Research on Cancer (IRAC) in 2019 found that air pollution is the fourth leading cause of death in the world. Therefore, diseases caused by air pollution are noteworthy [4]. It has recently been estimated that exposure to small environmental particles ($PM_{2.5}$) resulted in 3.2 million premature deaths from cardiovascular disease and 223,000 deaths from lung cancer in 2010 [5]. More than half of all lung cancers estimated in China and other East Asian countries are attributable to particulate matter ($PM_{2.5}$) [6]. Various factors play a role in creating air pollution, which can be due to population growth, industrial processes, increased use of vehicles as a result of higher fuel consumption, urban development, depletion of public transport fleet, combustion of household solid fuels and other sources [7, 8]. In association with the compounds that constitute air pollution, there is a very wide geographical diversity and shows many different reasons [9, 10]. The ratio of air pollution composition as well as the amount of different pollutants may also be different. However, the information available to determine the characteristics of air pollution compounds are quite limited [11]. Some of the compounds (such as particulate matter) are commonly measured in many parts of the world, while other pollutants do not have such a privilege [12]. Furthermore, air pollution may contain some compounds that are dangerous and harmful to human health that are not known [13]. In the project of global burden of disease World Health Organization (WHO), urban air pollution has been assessed worldwide. For example, measurements of particulate matter concentration account for about 5% of all tracheal, bronchitis, and lung cancer deaths. The global burden in absolute numbers occurs mainly in developing countries [14]. Therefore, identifying and determining the concentration of airborne particles is one of the most important parameters of air pollution in urban communities [15]. The industrial nature of Ahvaz city and the storm dust that is transported to Ahvaz city from neighboring countries have a major role in the increasing trend of air pollution in this city. In addition to causing air pollution, dust storms also affect environmental, nature and economic issues. But the most important and dangerous effect of these dust storms, along with suspended particles and air pollution, is the mortality of humans due to cardiovascular and respiratory diseases [16].

Ahvaz city is one of the metropolises of Iran. This metropolis is one of the most important metropolises for Iran both in terms of geographical location and in terms of political divisions. Air pollution in the metropolis of Ahvaz can be studied from several perspectives. a) There are many industrial estates in this city, each of which in turn causes the release of pollutants and toxins into the air. b) Iran carbon factory in the south of Ahvaz city in Padadshahr region, plays a role in increasing air pollution. c) A power plant located in the northern region of Ahvaz (Zargan region) causes the release of toxic substances into the air as a result of the effect on the health of the inhabitants of that region. d) Existence of oxin steel industries in bahonar region has caused air pollution in that area. e) In the region of hasirabad and aghajari, due to the existence of a pipe manufacturing company and oil extraction companies such as National Iranian Drilling company, it affects the process of creating air pollution in those areas and f) Finally, we should not be neglected of the traffic areas in the city of Ahvaz, that traffic, in turn, contributes to air pollution and the release of toxic substances into the air [17, 18].

Therefore, to determine the center of pollution in the metropolis of Ahvaz and also to provide a solution to reduce or prevent further spread of pollutants in the air of Ahvaz, identify and determine the concentration of particulate matter less than 2.5 µm and the effect of meteorological parameters such as temperature, pressure and humidity. It is necessary to change the concentration of 2.5 µm particles in the air of Ahvaz metropolis. Therefore, according to the above points, the purpose of this study is: i) Determining the concentration of $PM_{2.5}$ particles from February 2020 to October 2020. ii) Determining the impact of meteorological parameters (temperature, pressure and humidity) on the trend of changes in the concentration of $PM_{2.5}$ from February 2020 to October 2020 in the metropolis of Ahvaz.

Materials and methods

Description of study area

The city of Ahvaz is located in the southwest of Iran, on both sides of the Karun river. In the western part of this metropolis, there are densely populated residential areas. The central core of the western part of Ahvaz metropolis is Amaniyeh area and Clock square. The eastern parts of the metropolis of Ahvaz are home to most of the markets and economic centers. Ahvaz metropolis has the following specifications: Longitude 48°40′ and latitude 31° 20′, Population: 1200000 people, area 18,650 ha, 12 m above the sea level. Also, this metropolis is one of the most important metropolises of Iran economically. Ahvaz oil field is the fourth largest oil field in Iran, at present, the production capacity of this oil field is equal to 750000 barrels/day on average. So far, 460 oil wells have been drilled in the Ahwaz oil field. A large part of Khuzestan province is a plain and the city of Ahvaz is also located in a plain part, but the severe lack of vegetation has caused the heat and dryness of Ahvaz and has made it one of the hottest regions in Iran. In winter the temperature drops to zero degrees Celsius and in summer it rises to 50° C. The most important causes of air pollution in Ahvaz are dust and transportation within the city and another cause of pollution is the unbridled expansion of urban fabric and factories such as Iran carbon and Khuzestan steel. It has been repeatedly stated by various organizations such as the Department of Environment in Khuzestan province that Ahvaz is 8 times more polluted than allowed. As a result, most flights are canceled and schools and kindergartens in the city are closed. Some government agencies have attributed the dust to pollution from the deserts of Saudi Arabia and southern Iraq, as well as a lack of rain and vegetation in some parts of Khuzestan [16, 19].

Sampling of $PM_{2.5}$

The aim of this study was to determine the concentration of $PM_{2.5}$ particles. For this purpose, 14 points from Ahvaz metropolis were selected. Geographical location and sampling points in Ahvaz metropolis are given in Fig. 1. Sampling points were selected so that 1) Cover the entire surface of Ahwaz metropolis and 2) Based on population density, distance from industrial estates and traffic location. Also, while selecting the sampling points, it was tried to comply with the maximum standards mentioned by the US Environmental Protection Agency (US EPA) [20].

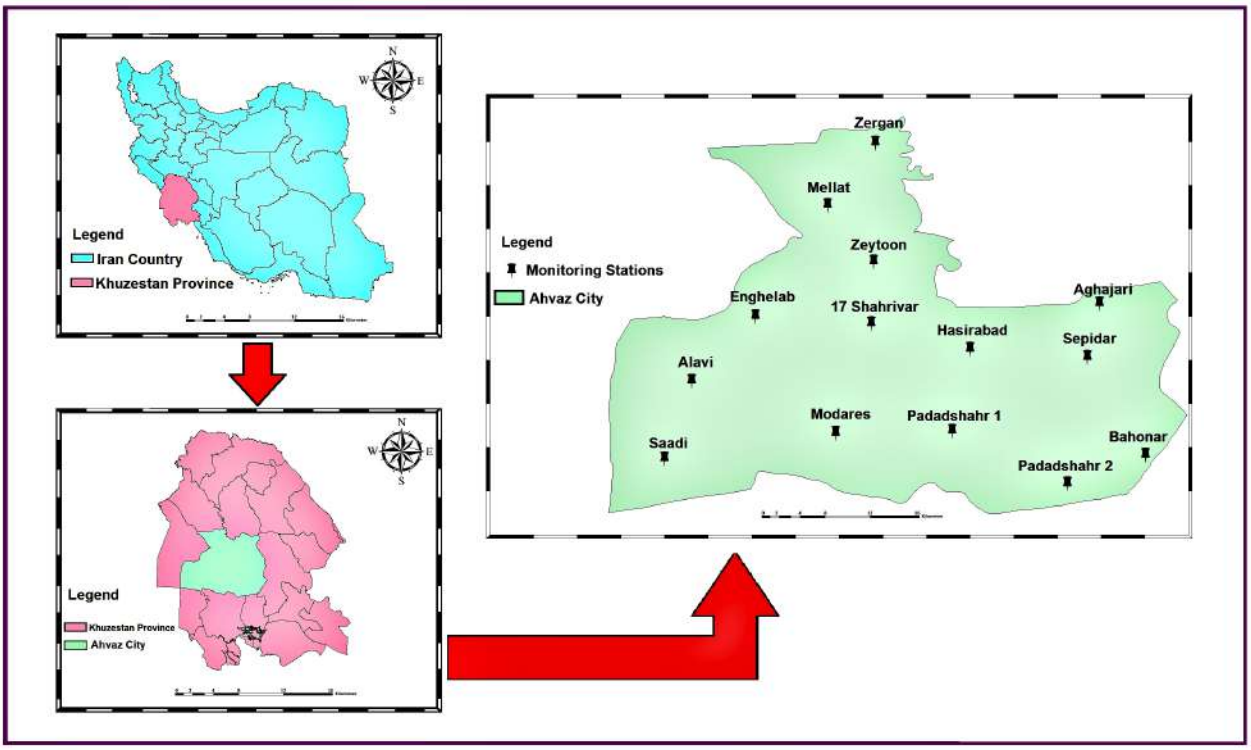

Fig. 1. Geographical location and sampling points

In order to sample of $PM_{2.5}$ particles from the guide EPA-TO/13A was used. Therefore, the sampling equipment included the following: 1) Leland Legacy pump with a flow rate of 3 L/min, 2) Fiberglass filters with the pore size of 1 μm and diameter of 37 mm, 3) Personal Modular Impactor (PMI2.5), and 4) Meteorological parameters were recorded using PHB318 portable device (Fig. 2). It should be noted that sampling was performed for 24 h in selected points. The sampling Arrangement was based on the following steps: 1) Cover the clean gloves to reduce the error caused by hand contact with equipment, especially fiberglass filters, 2) Inserting fiberglass filters into the desiccator at a temperature of 22-24 ° C and a relative humidity of 30-40% for 48 h (Fig. 3a), 3) Weighing fiberglass filters with RADWAG scales model AS-2020-R2 and placing the weighted filters in 37 mm plates and labeling them (Fig. 3b), 4) Deployment at the sampling site and placing the filter inside the PMI2.5 holder and adjusting the flow and sampling time (flow: 3 L/min and time: 24 h), 5) Measuring the amount of flow at the beginning and end of sampling, 6) Recording the temperature, pressure and relative humidity at the beginning and end of sampling, 7) Picking up the filters (after 24 h) and place them in ronmental Protection Agency (US EPA) [20].

Fig. 2. Portable device of PHB-318

Special plates and transfer to the laboratory and place them at a temperature of -18°C, 8) Inserting the sampling filters in the desiccator for 48 h (Fig. 3c), 9) Weighing the sampling filters (Fig. 3d) and 10) Calculation of mass concentration of $PM_{2.5}$ particles based on changes in filter weight at the end and beginning of sampling and flow rate based on the Eq. 1 [21]:

$$PM_{2.5} = \frac{(W_f - W_i) \times 10^{-6}}{V} \quad (1)$$

Wf : Weight of filters after sampling (g)

Wi : Weight of filters before sampling (g)

V: total volume of sampling air (m^3) which is obtained from the time and flow of sampling.

$PM_{2.5}$: concentration of $PM_{2.5}$ particle (μg/m^3)

Fig. 4 shows the location of the sampling device in the sampling points in the metropolis of Ahvaz.

Meteorological parameters

Various parameters such as temperature, pressure, relative humidity, cloud cover, ultraviolet rays, and wind speed can affect the concentration of $PM_{2.5}$ particles. In this study, the parameters of temperature, pressure and relative humidity were investigated. For this purpose, data related to temperature, pressure and relative

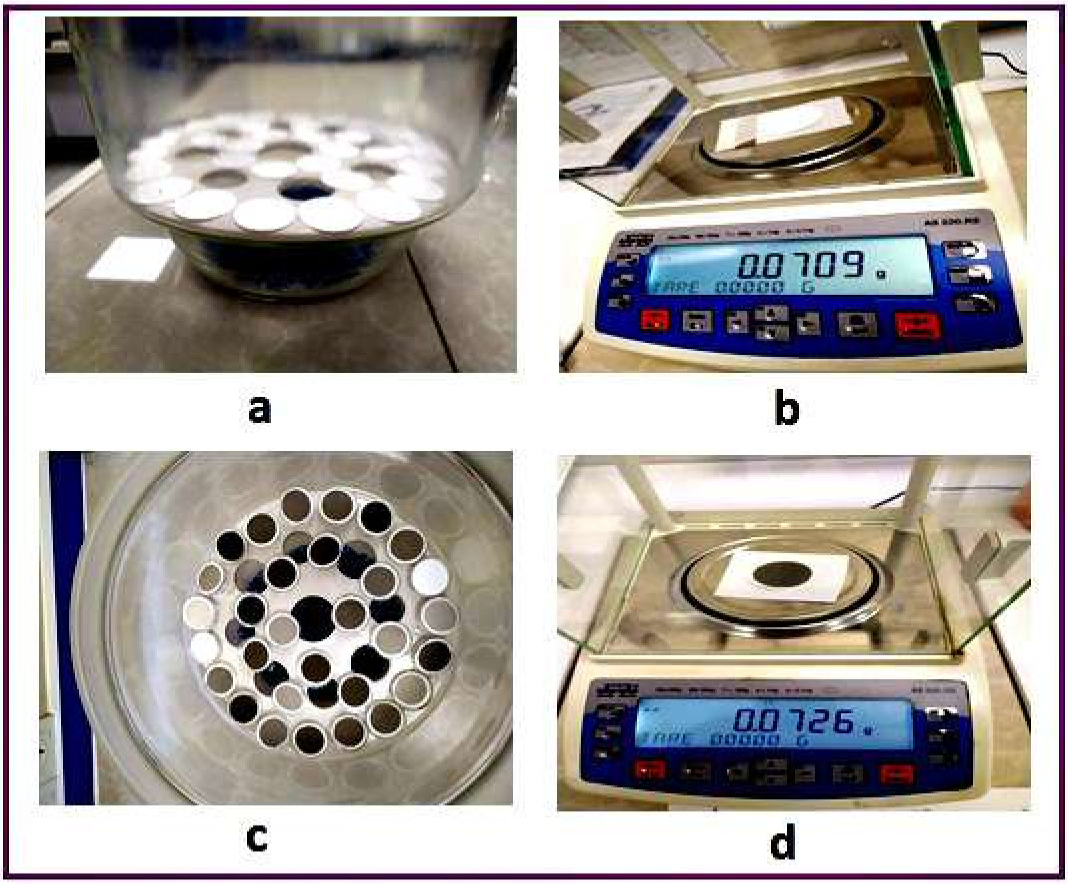

Fig. 3. Steps of preparing samples before and after weighing

Fig. 4. Sampling pilot

humidity were measured by a portable device (PHB-318). Then the data were sorted by Excel software and the data normality was performed by SPSS (V.24) using a KALMOGAROV-Smiranov test. Next, the relationship between each of the meteorological parameters and the concentration of $PM_{2.5}$ particles was performed by ANOVA test.

Wind rose of the studied city

After receiving the data related to wind speed from February 2020 to October 2020 from the Environmental Protection Organization of Ahvaz metropolis and sorting the data by Excel to draw wind rose and analyze them, it was entered into WRPLOT ViewTM software. This software shows the average wind speed and direction to determine the particle scattering pattern.

Statistical analysis

After calculating the $PM_{2.5}$ particle concentration, the relationship between each of the meteorological parameters (temperature, pressure and relative humidity) was obtained using SPSS and ANOVA test. Then, box diagrams of seasonal variations $PM_{2.5}$ particle concentration and each of the meteorological parameters were drawn using R software. The average annual concentrations of $PM_{2.5}$ particles in 14 measuring stations in Ahvaz metropolis were compared with the amount of the World Health Organization guidelines using Excel software. Also, the concentrations obtained from $PM_{2.5}$ particle sampling were generalized to the whole city using ArcGIS 10.3 and their dispersion was obtained. Finally, the wind rose of Ahvaz metropolis was drawn using WRPLOT ViewTM and its analysis was performed.

Results and discussion

Concentration of $PM_{2.5}$ particles

In this study, the concentration of $PM_{2.5}$ particles in 14 points of Ahvaz city in four seasons from February 2020 to October 2020 was obtained. Fig. 5 shows the concentration of each sampling station in four seasons. Based on the obtained results, it was found that in winter, Saadi station with a concentration of 306.02 $\mu g/m^3$ has the highest value, in spring, summer and autumn, Zargan station with a concentration of 191.57, 306.02 and 250.45 $\mu g/m^3$, respectively have the highest concentration. Zargan station because: 1) The main entrance of the city is from the north of the city and the communication route of cities such as Dezful, Bavi, Shush, Dasht-e Azadegan, Andimeshk, Gotvand, Masjed Soleiman and Izeh and a large number of vehicles are connected on this routes, Therefore, due to the high volume of vehicle traffic and more fuel consumption by cars, it has increased the concentration in the spring, summer and autumn of this area. 2) Zargan station has increased its concentration in that area due to its proximity to the combined cycle power plant [18]. Because the concentration of $PM_{2.5}$ particles in this area is high in spring, summer and autumn, the risk of people in that area also increases, so people in that area are more exposed to the health risks of being exposed to fine particles. On the other hand, in winter, we had the highest particle concentration at Saadi station. The reason is that Saadi station is located near the shopping and commercial centers of Ahvaz metropolis. Because the winter, air temperature in Ahvaz is cooler than other seasons, it causes more people to turn to shopping malls in this season. This will increase traffic and increase the density of vehicles and people, which in turn will increase the concentration of fine particles in that area. In a study in Isfahan, it was found that stations near traffic areas have higher $PM_{2.5}$ particle concentrations [22]. Also, in another study in Karaj, it was found that high-traffic points have higher $PM_{2.5}$ particle concentrations [23]. In the other study in a 4-year period in Ahvaz city, it was found that high-traffic and industrial stations have higher concentrations of $PM_{2.5}$ particle [18]. In a study in China it was founded that areas less distant from industry had higher particle concentrations [24]. On the other hand, in our study in Ahvaz metropolis, Modares station had the lowest average concentration in all four seasons. In winter, the concentration were 46.29 µg/m^3, in spring, summer and autumn, the concentrations of $PM_{2.5}$ were 47.89, 46.29 and 47.08 µg/m^3, respectively. It is important to note that the WHO guideline for $PM_{2.5}$ particles is 10 µg/m^3. While in Ahvaz metropolis, the lowest concentration is 46.29 µg/m^3. It can be said that the residents of Ahvaz city are at serious health risk due to exposure to $PM_{2.5}$ particles and their compounds, including heavy metals and polycyclic aromatic hydrocarbons bonded with $PM_{2.5}$ particles. Modares station in Ahvaz metropolis is a non-industrial area with low traffic, so its concentration is lower than other parts of Ahvaz. In Ahvaz metropolis, Padadshahr 1 station has the second rank in terms of $PM_{2.5}$ particle pollution among sampling points, So that its concentration in summer has reached 282.92 µg/m^3. The region of Padadshahr 1 is near to Iran Carbon factory. For this reason, the material released from this factory has increased the concentration of $PM_{2.5}$ particles in that area. A study in China examined the relationship between $PM_{2.5}$ particle concentrations in industrial and non-industrial areas. It was found that the areas near to the factories have higher concentrations of $PM_{2.5}$ particles [25]. On the other hand, a little further from Padadshahr 1 station, there is a pipe factory. These factors play a role in creating air pollution in that area and its impact on other areas in the city of Ahvaz.

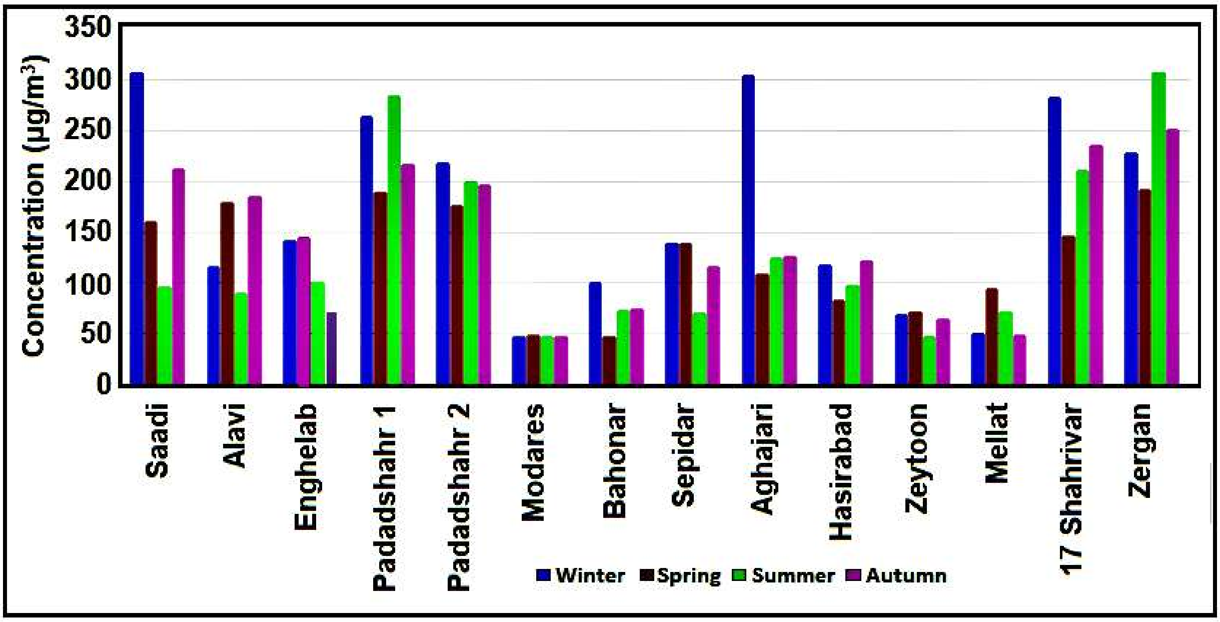

Fig. 5. Concentration of $PM_{2.5}$ particles in the four seasons

Box plot of $PM_{2.5}$ particle concentrations in four seasons in Ahvaz metropolis is shown in Fig. 6. As can be seen, winter season with an average concentration of 169.75 µg/m^3 is the highest concentration, and autumn, summer and spring seasons with concentrations of 140.17, 129.19 and 126.76 µg/m^3, respectively, in the next position in terms of air pollution with $PM_{2.5}$ particles. In the study in Karaj, the highest concentration of $PM_{2.5}$ particles was observed in autumn. Because the highest annual rainfall occurred in winter in the year under study and this reduced the concentration of $PM_{2.5}$ particles in winter at Karaj [23]. In a study in Isfahan, it was found that winter has the highest average concentration among other seasons [22]. In other study in Isfahan at 2019, it was found that the highest particle concentration was observed in winter season [15]. In a study in India, it was found that the particle concentration was the highest in winter and the lowest in spring season, which is similar to the result of our study [26].

Fig. 7 shows a comparison of the average concentration of $PM_{2.5}$ particle during the study period in the metropolis of Ahvaz with the guideline value of the World Health Organization. As it was found, the average concentration of all sampling stations is higher than the WHO guidelines (10 µg/m^3). This shows that dust storms that are transferred from the coasts of Saudi Arabia and Iraq to the city of Ahvaz, have a high share in creating air pollution in the city of Ahvaz and also due to the industrial nature of this city, a high amount of particles are produced. Therefore, the residents of Ahvaz face a serious health risk. In the study in Isfahan, it was found that most sampling stations have higher concentrations than the guidelines of the World Health Organization [22]. In this study, the average annual concentration of $PM_{2.5}$ particles was 141.47 µg/m^3, which is 14 times higher than the guideline value. In a study, it was found that the concentration of $PM_{2.5}$ particles is much higher than the WHO guideline value

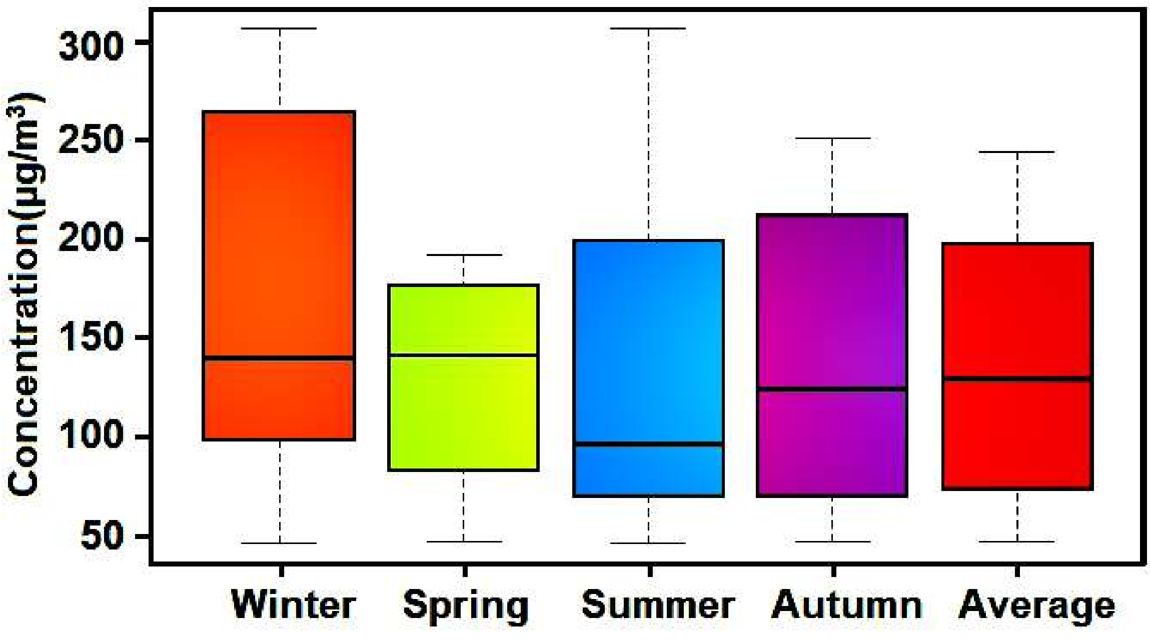

Fig. 6. Box plot of the average concentration of $PM_{2.5}$ particulate in different seasons

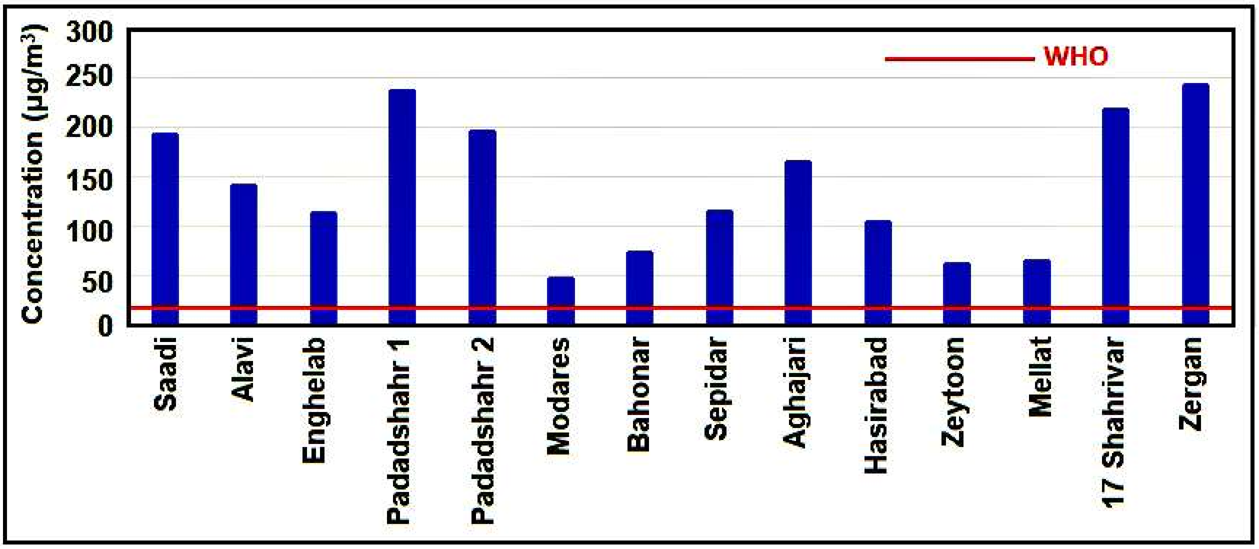

Fig. 7. Concentration of $PM_{2.5}$ particles in period of study and comparison with WHO guidelines

[27]. In the study by other researchers, it was found that with increasing the concentration of $PM_{2.5}$ particles, the rate of related deaths also increases. This shows that in the study city (Mashhad) the concentration of $PM_{2.5}$ particles is higher than the WHO guideline [28].

As the mentioned, the concentration of $PM_{2.5}$ particles is high in industrial and traffic areas. According to the $PM_{2.5}$ particle scattering map in Ahvaz metropolis (Fig. 8), Padadshahr 1 and 2, Zargan, 17 Shahrivar and Saadi stations have the highest particle concentrations. 17 Shahrivar station is the main center of the city and is considered a busy area.

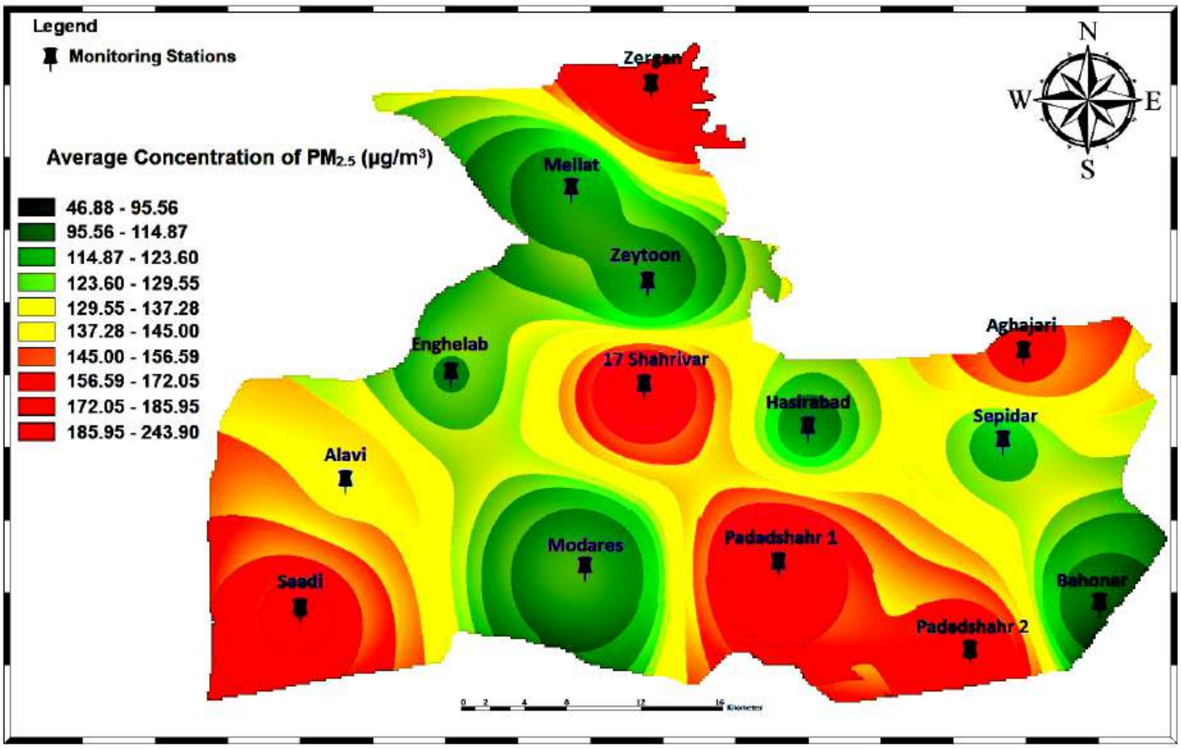

Fig. 8. Distribution of average annual concentration of $PM_{2.5}$ in stations of monitoring

Wind rose

In this study, the wind rose of Ahvaz was drawn by WRPLOT View™ software. As shown in Fig. 9, the wind direction is northwest in all four season studied. In the east of Ahvaz, there are pipe-making factories, oxin steel company, industrial estates, and National drilling companies. There is Iran Carbon factory in the south of Ahvaz. Therefore, when the wind direction is northwest, pollutants are transferred from the east into the city, and this has increased the concentration of particles in Zargan, 17 Shahrivar, Padadshahr 1 and 2 stations and Saadi. In the study of Mohammadi, In Urmia, it was found that the direction of the wind is very important in the transfer of pollutants and increases their concentration and dispersion in the city.

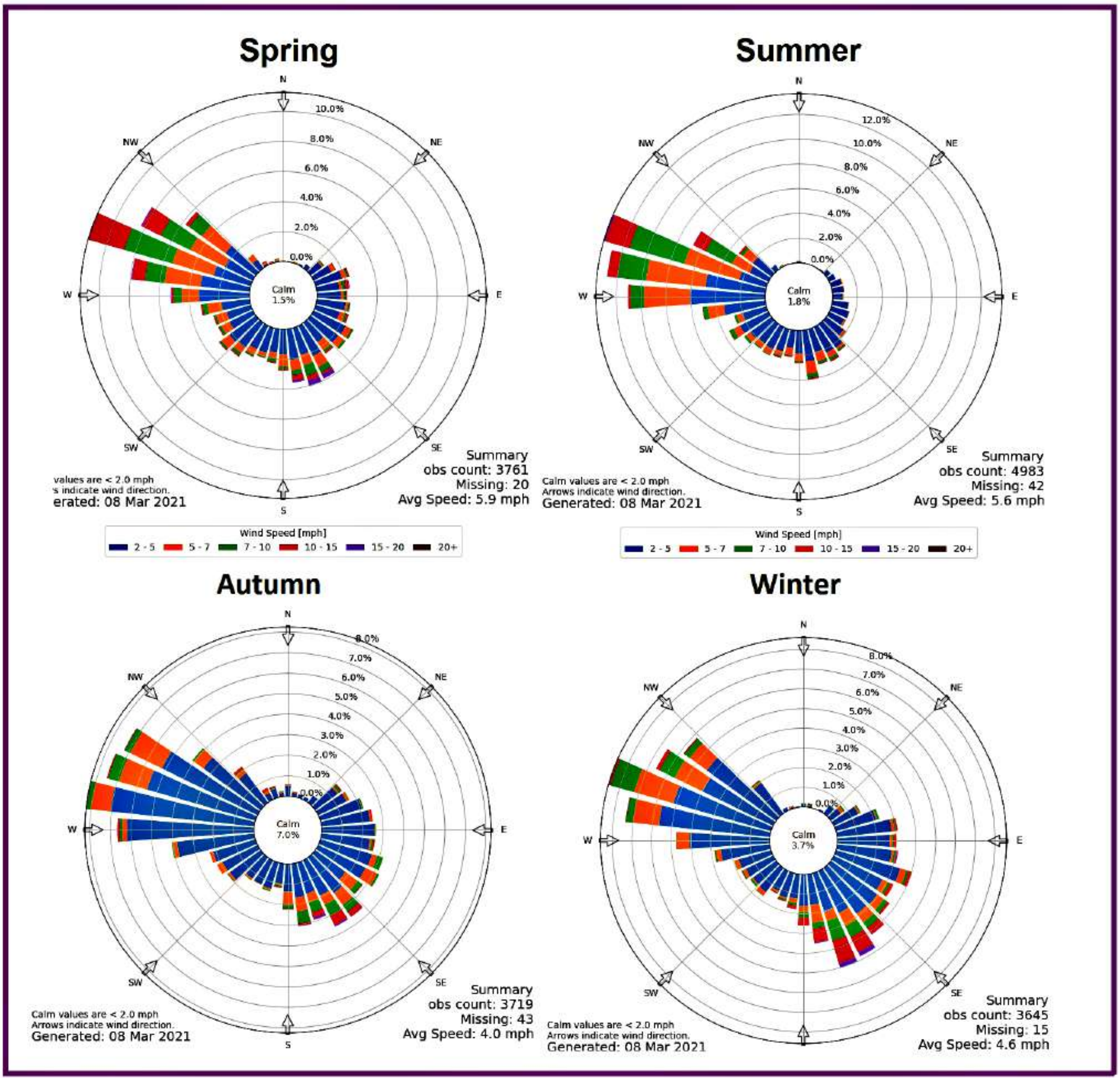

Fig. 9. Wind rose of Ahvaz city in during period of study

Meteorological parameters

During the one-year study period, during the sampling of $PM_{2.5}$ particles, the trend of temperature, pressure and relative humidity changes was also recorded. These parameters were measured using the PHB-318 portable device. Each of these parameters affects the trend of changes in $PM_{2.5}$ particle concentration. Before examining the relationship between each of the parameters with $PM_{2.5}$ particles, we examine the trend of their changes. The box plot of each meteorological parameter is given in Fig. 10 (a-b-c). As expected, the average air temperature in summer season has the highest value (51°C) and in winter season has the lowest (14°C). Also, the highest temperature is 64°C and the lowest is 8°C. The metropolis of Ahvaz in the south of Iran, due to its geographical location and the existence of many industries, as well as being located on the largest river in the country (Karun), is always faced with high temperatures throughout the year. The average temperature in this study from February 2020 to October 2020 (one year) was 34°C. The city of Ahvaz, due to its many rivers, the humidity rises on some days of the year. Sometimes the humidity is so high that it can cause schools and offices to close. In this study, the highest humidity was in summer season (44%) and the lowest was in spring season (27%). Also, the highest humidity content was 80% and the lowest was 13%. Also, the average annual humidity in this study from February 2020 to October 2020 (one year) was 38%. The air pressure in this study was higher in some highlands and lower in some places near to sea level. In this study, winter season had the highest air pressure (762.36 mm Hg) and the lowest value in summer season (745.72 mm Hg). Also, the highest pressure is 770.42 mmHg and the lowest is 744.3 mm Hg. In winter season, air pressure increases due to increasing concentrations of pollutants and their dispersion in the atmosphere. The results of our study are similar to the study of researchers in Karaj and Isfahan [23, 29]. ANOVA test was used on the effect of each meteorological parameter on the concentration of $PM_{2.5}$ particles in Ahvaz metropolis. In addition to the parameters mentioned in this study, other factors such as: the amount of ultraviolet, dew point, cloud cover and Visibility also affect the particle concentration. In the present study, three parameters of temperature, pressure and relative humidity were investigated. Based on the results, it was found that air temperature had a negative relationship ($r=-0.219$, $P<0.035$), pressure ($r=0.25$, $P<0.05$) and relative humidity ($r=0.32$, $P<0.05$) has a direct and positive relationship with $PM_{2.5}$ particle concentration in Ahvaz metropolis (Table 1).

In the study of Wang et al., there was a negative relationship between temperature and concentration of $PM_{2.5}$ particles, which was similar to the results of our study [30]. However, studies in Tehran (capital of Iran) [31], China [32], Japan [30] and Italy [33] had a positive relationship between concentration of particle and temperature. The reason is that in our study in Ahvaz city, the temperature difference in winter season does not even reach below zero degrees, and also the geographical location of Ahvaz city is such that the temperature is high on most days of the year and the particle concentration is also high. In winter season, due to the use of more fuels by power plants and more vehicle traffic, the concentration of particles was increases. Regarding the pressure and relative humidity, the results of our study are in line with the study in Karaj [23], Isfahan city [22], and China [34].

Table1. Bivariate correlations between $PM_{2.5}$ with meteorological parameter

	Temperature	Pressure	Reality humidity
R	-0.124	0.25	0.32
P_{value}	0.035	0.05	0.05

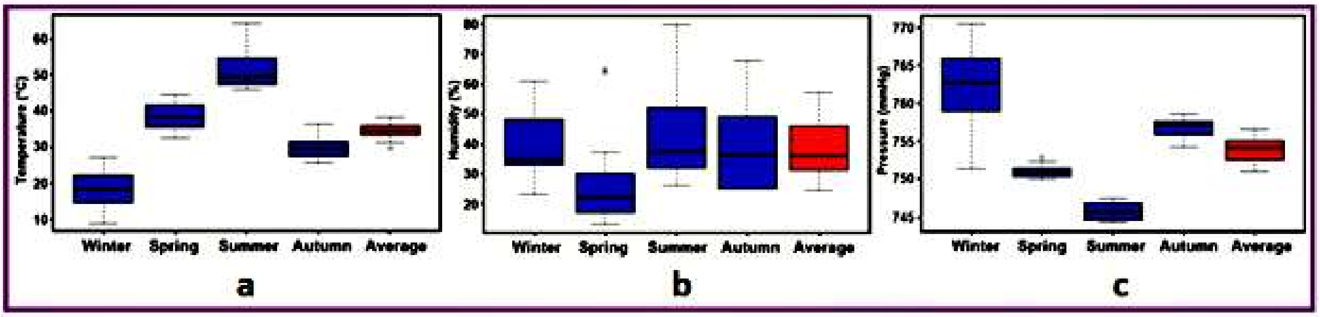

Fig. 10. Box plot of the temperature, relative humidity and pressure in different seasons

Conclusion

The present study was conducted to investigate the trend of changes in concentration of $PM_{2.5}$ particle and meteorological parameters including temperature, pressure and relative humidity and the effect of each of these parameters on concentration of $PM_{2.5}$ particle from February 2020 to October 2020 for one year in Ahvaz metropolis in 14 selected points are designed. The results of this study showed that the concentration of $PM_{2.5}$ particles in this metropolis during the one-year period was 14 times higher than the WHO guideline value. Therefore, the residents of Ahvaz city are in serious health danger against this type of particles. It was also found that temperature has a negative relationship and pressure and relative humidity have a positive relationship with concentration of $PM_{2.5}$ particle. It is hoped that the results of the present study will be effective in reducing the concentration of particles and subsequently reducing air pollution in order to create useful policies for the metropolis of Ahvaz.

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Competing interests

The authors declare they have no actual or potential competing interests.

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Ethical considerations

Ethical issues (Including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors

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