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Association between airborne particles and meteorological parameters in Arak industrial city

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ABSTRACT

Introduction: By crossing the borders of cities and countries, air pollution is now a global problem so that it can be claimed that there is no sound and clean air. This study aimed to investigate the effect of meteorological parameters on the concentration of particulate matter ($PM_{2.5}$ and PM_{10}) in the air of Arak city.

Materials and methods: In this study, Arak city was divided into three regions using geographic information system (GIS). Based on air pollution monitoring stations in Arak city, it was tried to select one station from each region for analysis. Meteorological parameters including temperature (°C), relative humidity (٪), precipitation (mm), and wind speed (m/s), were obtained from Arak Meteorological Organization. Finally, the association between the concentration of PM ($PM_{2.5}$ and PM_{10}) and meteorological parameters were evaluated by SPSS.

Results: Annual changes in PM ($PM_{2.5}$ and PM_{10}) showed that the average particle concentrations were 25.34 and 46.81 µg/m^3 in the study periods, respectively. It was also found that the citizens of Arak were 2.5 times more exposed to PM ($PM_{2.5}$ and PM_{10}) pollutants than the standard recommended by the World Health Organization. Our findings also showed strong positive linear correlations of wind velocity and temperature with $PM_{2.5}$ and PM_{10}, as well as relative humidity with PM_{10}, and negative correlations of precipitation with $PM_{2.5}$ and $PM_{10,}$ as well as relative humidity with $PM_{2.5}$.

Conclusion: The distribution map of Arak city indicated that the citizens of Shariati station and the governor's office were facing high concentrations of pollutants, posing them to a serious threat. Moreover, more pollution was recorded toward the north and northwest of the city. To protect the health of citizens in Arak, therefore, it is necessary to adopt appropriate policies and rules to reduce the concentrations of PM and other pollutants in the air of this city.

Introduction

Air pollution is nowadays a substantial environmental issue in metropolises that has affected modern life [1]. Exposure to air pollution and its adverse health effects, particularly in developing countries, has become the most important risk factor [2]. According to the World Health Organization (WHO), more than half of the world's population is exposed to polluted air. Complications of exposure to air pollution are

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categorized into acute and chronic types, which depend on factors such as the type of pollutant and the level, type, and time of exposure to the pollutant [3, 4]. In fact, it can be claimed that air pollution is more or less present everywhere on the globe thus there is no clean air [5, 6]. In 2013, the International Agency for Research on Cancer (IARC) classified air pollution and its causatives factors (in particular particulate matter) as carcinogenic compounds for humans (Group I) [7]. On the other hand, air pollution imposes irreversible damage on the economy of the society so that the cost of air pollution was equal to gross domestic production (GDP) in some countries such as India, Canada, and Mexico, in 2016. In Iran, the economic burden of air pollution is estimated at $ 30 billion or 2.48% of GDP [8]. The main air pollutants include CO, NO_X, SO_2, O_3, and PM. PM smaller than 10 µm (PM_{10}) can enter and deposit in the respiratory tract and cause chronic bronchitis, emphysema, and other diseases in humans [9].

Particles with an aerodynamic diameter of <2.5 µm ($PM_{2.5}$) play a major role in air pollution. Due to their large surface area and small size, these particles can adsorb chemical contaminants, penetrate deeply into the lungs through oxidative pressure and cause respiratory disorders [10, 11]. The concentrations of these particles can vary depending on the geographical location, climatic conditions, and duration [12]. Multiple studies have shown that short-term (acute) and long-term (chronic) exposures to $PM_{2.5}$ increase mortality in humans [13]. The WHO Air Quality Guideline for PM defines annual PM_{10} and $PM_{2.5}$ averages of 20 and 10 µg/m^3, respectively [14]. In 2015, chronic exposure to outdoor $PM_{2.5}$ reportedly resulted in approximately 4.2 million early deaths worldwide [15, 16]. Although $PM_{2.5}$ is widely used to evaluate the health effects of air pollution, gaseous pollutants (e.g. NO_2, CO, O_3, and SO_2) are also directly effective in high mortality rates [17].

Arak city is considered one of the most important and polluted industrial metropolises in central Iran, which is exposed to severe environmental air pollution due to unsustainable development, heavy vehicle traffic, and lack of environmental air quality standards with high daily consumption of fossil fuels and emissions. The effects of PM concentrations on meteorological parameters have been investigated in numerous studies [18]. In a study it was investigated the effect of changes in meteorological parameters on environmental PM and found a weak correlation between $PM_{2.5}$ and average monthly values of temperature and relative humidity [19]. In Isfahan, on the other hand, some researchers reported an inverse and weak relationship between the concentration of $PM_{2.5}$ with wind speed, rainfall, and ultraviolet radiation [20]. A direct relationship was found between temperature and pressure with $PM_{2.5}$ concentrations in Karaj [21]. In addition, other researchers found that there was an unfavorable correlation between meteorological parameters (temperature, precipitation, and pressure) and $PM_{2.5}$ concentrations [22]. A study in Malaysia revealed a negative effect of $PM_{2.5}$ concentrations on wind speed and relative humidity [23].

Based on our knowledge and search in databases, it was found that no comprehensive study has been conducted on the effect of each meteorological parameter on $PM_{2.5}$ and PM_{10} concentrations in Arak city. Therefore, this study aimed to investigate 1) the changes in $PM_{2.5}$ and PM_{10} concentrations in the air of Arak city and 2) the effect of each of the meteorological parameters, such as temperature (°C), relative humidity (٪), wind speed (m/s), and precipitation on $PM_{2.5}$ and PM_{10} concentrations in the air of Arak city during 3 years.

Materials and methods

The geographical location of the study area

With an area of 107 km^2 and a population of >500,000, Arak city is the capital of Markazi province in Iran, which is one of the most important industrial cities in central Iran due to the presence of many industries. The city is located at 49° 40' E and 34° 00' N, with an altitude of 1700 m above sea level. Several reasons, such as climatic situation, special topography, the presence of Mighan desert, the establishment of countless industries along the three axes of Arak-Qom, Arak-Shazand, and Arak-Farmahin without considering the prevailing wind direction, and the excessive entry of vehicles to the urban traffic cycle, have exposed the city to a high daily volume of pollutants. On the other hand, it can be expected that the residents of this city are exposed to the daily concentration of PM due to the proximity of large and small industries and factories to the city, making Arak one of the most polluted cities in the country. The use of fuel oil as the fuel in the cold season by the power plant and the prevailing wind situation have intensified the pollution. The intensification of this pollution in the respiratory level of citizens, in particular with the prevailing weather conditions in autumn and winter, is an alarm for the increasing rates of cardiovascular disease, lung disease, cancer, and increased mortality [24].

$PM_{2.5}$ and PM_{10} data and meteorological parameters

This descriptive-analytical study was conducted in Arak city over three years. For this purpose, the city of Arak was divided into three regions using the Geographic Information System (GIS). Fig. 1 depicts the geographical location of Arak city and the studied stations. Based on the air pollution monitoring stations in Arak, it was tried to select one station from each region for analysis. Therefore, three air pollution monitoring stations were selected in Arak. Then, data related to these three stations were provided to Arak University of Medical Sciences in coordination with the Department of Environment (DOE) in Arak. Data related to meteorological parameters, such as temperature (°C), relative humidity (%), precipitation (mm), and wind speed (m/s), were received from the Meteorological organization of Arak city.

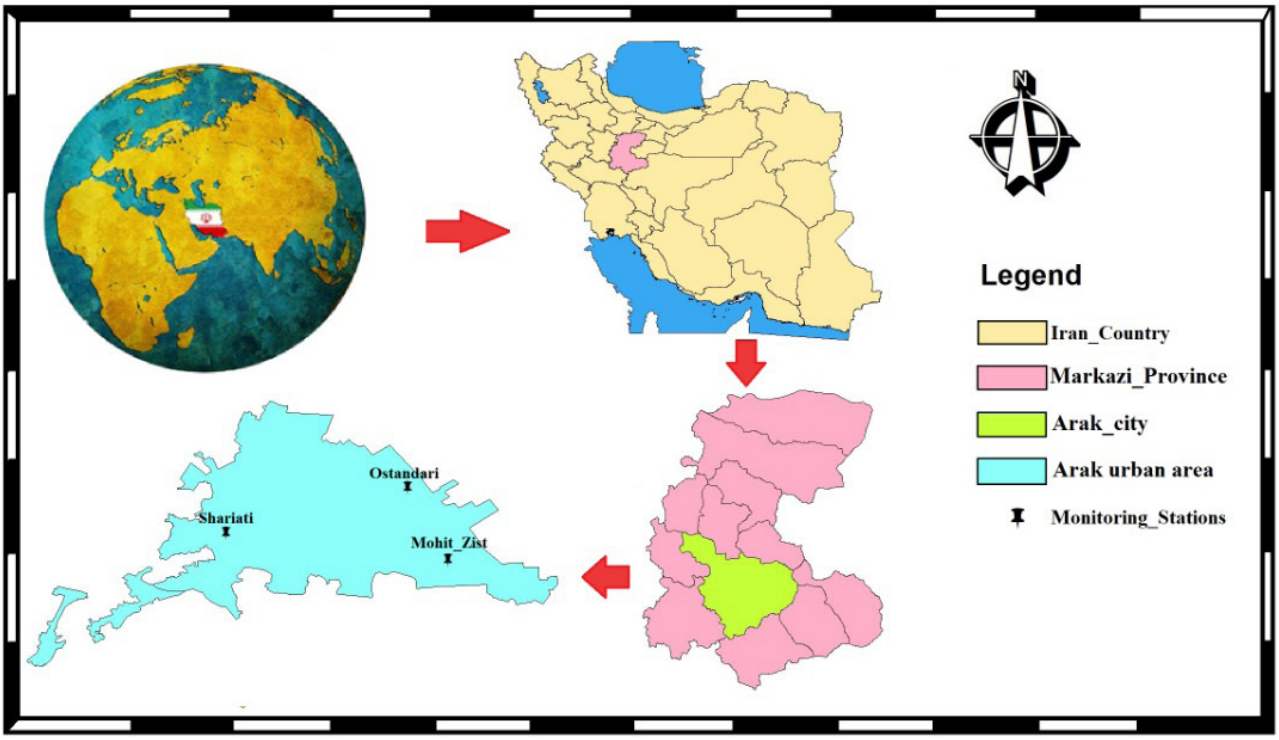

Fig. 1. Map location of the studied stations in Arak

increased Statistical analysis

Raw data of $PM_{2.5}$ and PM_{10} were obtained from Arak DOE and then entered into Excel. The normality of data was examined using the Kolmogorov-Smirnov test by SPSS version 16. It should be noted that the selected stations measured 75% of $PM_{2.5}$ and PM_{10} data during a year. The data were then entered into the R to determine changes in PM concentrations during the 3-year study period. A box diagram of changes in $PM_{2.5}$ and PM_{10} concentrations was also drawn by the R. Then, $PM_{2.5}$ and PM_{10} zoning was drawn for three monitoring stations in Arak using the GIS software. Next, data of PM and meteorological parameters were entered into SPSS, and the relationship between each meteorological parameter and $PM_{2.5}$ and PM_{10} concentrations was determined using Pearson correlation.

Results and discussion

$PM_{2.5}$ concentration

Arak is an industrial city with a high potential that has made it a migrant-receiving city in recent years. In this study, the concentration of $PM_{2.5}$ was calculated in selected stations of Arak city during the study period. Fig. 2 shows a box diagram of $PM_{2.5}$ concentrations at three stations of the governor, the DOE, and Shariati. The maximum and minimum concentrations of $PM_{2.5}$ in Shariati station (located southwest of Arak) are 43.5 and 19 $\mu g/m^3$ in March and February, respectively. At the DOE station, November and June represent the minimum (15 $\mu g/m^3$) and maximum (26.5 $\mu g/m^3$) $PM_{2.5}$ concentrations, respectively. The maximum and minimum $PM_{2.5}$ concentrations at the governor's station were measured in August (40.6 $\mu g/m^3$) and December (11.7 $\mu g/m^3$), respectively. In Isfahan, researchers reported higher $PM_{2.5}$ concentrations in stations located in high-traffic areas, which is in agreement with our study [20]. In our study, higher concentrations were recorded in Shariati station than the DOE station as it is located in a high-traffic area, and in the governor's station (average $PM_{2.5}$ concentration of 29.12 $\mu g/m^3$ during the study period) due to its proximity to the traffic of heavy vehicles and Mighan wetland. In a study in china, the station located in a low-density and low-traffic area showed a low concentration of $PM_{2.5}$, similar to that in our study [25]. The DOE station is located in a low-traffic area in the south of Arak city, which had the lowest average $PM_{2.5}$ concentration (19.83 $\mu g/m^3$) among the other stations during the study period. The $PM_{2.5}$ concentration for Shariati station (mean $PM_{2.5}$ concentration of 27.07 $\mu g/m^3$ during the study period) was significantly higher than that of the DOE station. In our study, the highest concentrations of $PM_{2.5}$ were measured in Shariati station in spring and in the DOE and governor's stations in summer. Similarly, in a study in Iran, the highest concentration of $PM_{2.5}$ was reported in spring and summer because precipitation in winter and autumn wash the particles in the air [13]. In Tehran, other researchers observed a high concentration of particles in the cold seasons due to the inversion phenomenon [26]. A comparison of the average $PM_{2.5}$ concentration in Arak during the study period with the WHO guidelines revealed that the average data (25.34 $\mu g/m^3$) was 2.5 times higher in the studied stations. Average annual $PM_{2.5}$ concentrations were calculated to be 2.7 times in Tehran [27], in Karaj 4.2 times [21], and 8.23 times in Ahvaz [17] higher than the guideline value. This shows that the city of Ahvaz is facing a serious health risk due to the presence of dust centers. It should be mentioned that Arak city hosts industries, such as cement factory, the largest machinery manufacture industry in the Middle East, the largest combine harvester in the Middle East, and the largest gasoline industry in the country, which play a role in increasing the concentration of $PM_{2.5}$ in urban air

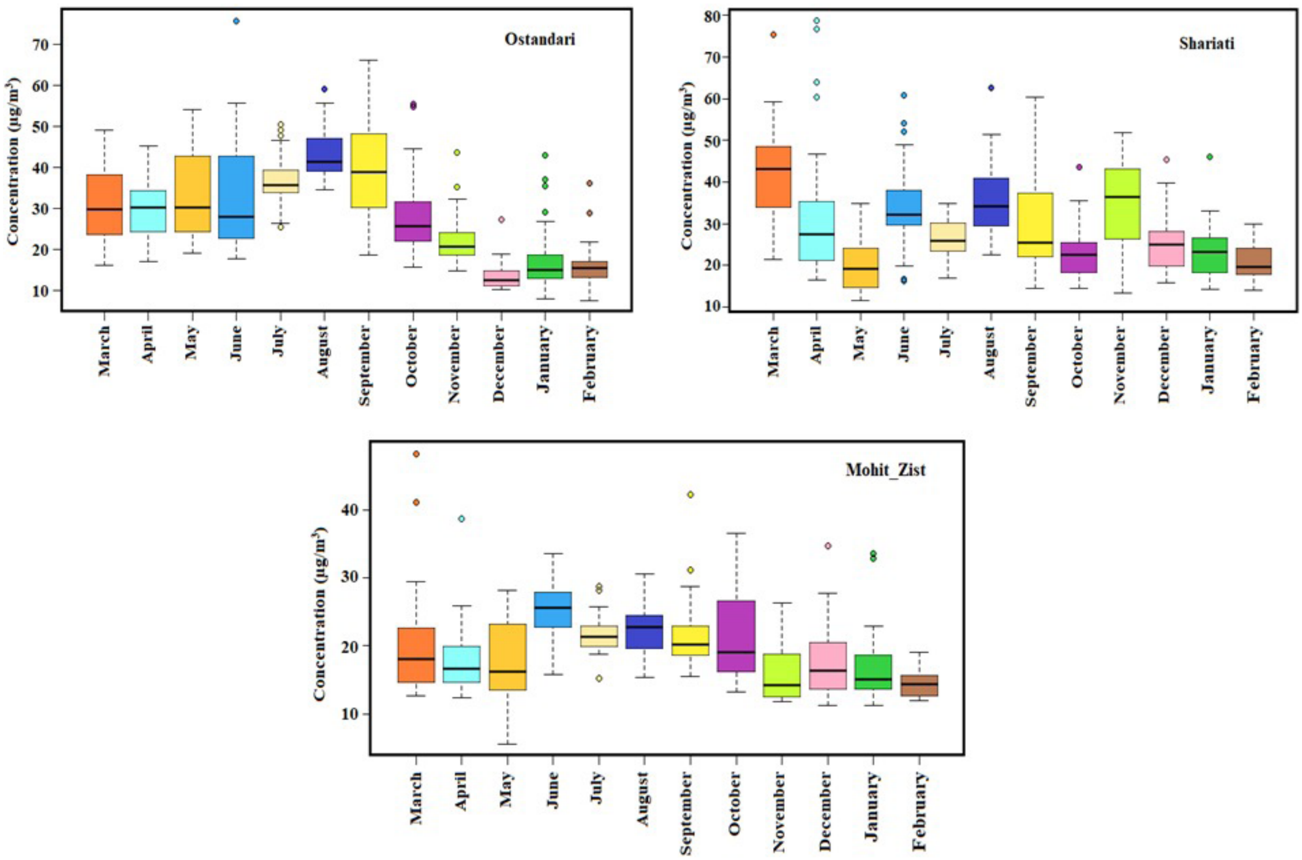

Fig. 2. Average monthly concentration of $PM_{2.5}$ in the target stations during the study period (2017-2020)

This study tried to generalize the concentrations obtained from the three air monitoring stations to the whole city of Arak using the Arc GIS10.3, in which the Inverse Distance Weighting (IDW) method was used to estimate the concentration in other areas of Arak city. Fig. 3 shows the geographical distribution of $PM_{2.5}$ concentrations in Arak. Accordingly, air pollution by $PM_{2.5}$ increases in areas closer to the center of pollution, i.e. the governor's and Shariati stations, due to heavy vehicle traffic in the northern highway, the presence of industrial towns, and some large industries (e.g. aluminum industry), and the proximity to the Mighan desert and the sodium salt plant. Similar to our study, a research in Isfahan demonstrated more pollution toward the north of the city due to the presence of a high-traffic area, brick workshops, and Mobarakeh steel industry [9]. Other studies around the world have concluded that air pollution becomes more pronounced with proximity to the PM or pollution source and further threatens the health of citizens.

PM_{10} concentrations

In this study, PM_{10} was also analyzed alongside $PM_{2.5}$ at two stations located in the city of Arak. Due to no record of hourly concentrations of PM_{10}, the governor's station was excluded from the study. Fig. 4 depicts the maximum (69.40 μg/m^3) and minimum (16.43 μg/m^3) PM_{10} concentrations at Shariati station in September and May, respectively. The DOE station had minimum (12 μg/m^3) and maximum (59.5 μg/m^3) concentrations of PM_{10} in March and October, respectively. As PM_{10} particles are heavier than $PM_{2.5}$ ones, they have more difficulty penetrating the human respiratory system than $PM_{2.5}$. During the study period, the average annual total concentration of PM_{10} (46.81 μg/m^3) was higher than the WHO standard and shows that the citizens of Arak are exposed to high concentrations of PM_{10}.

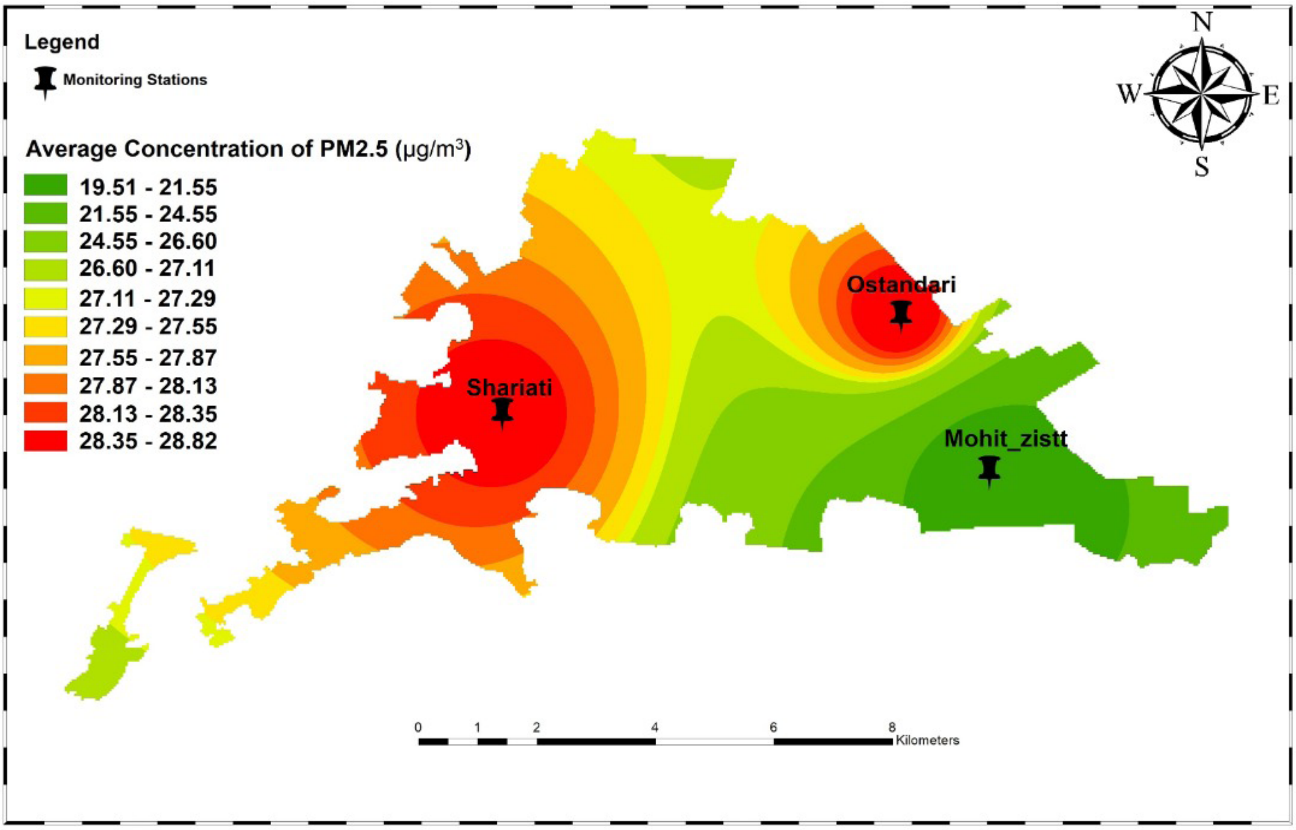

Fig. 3. Geographical distribution of $PM_{2.5}$ concentrations in arak at 2017-2020

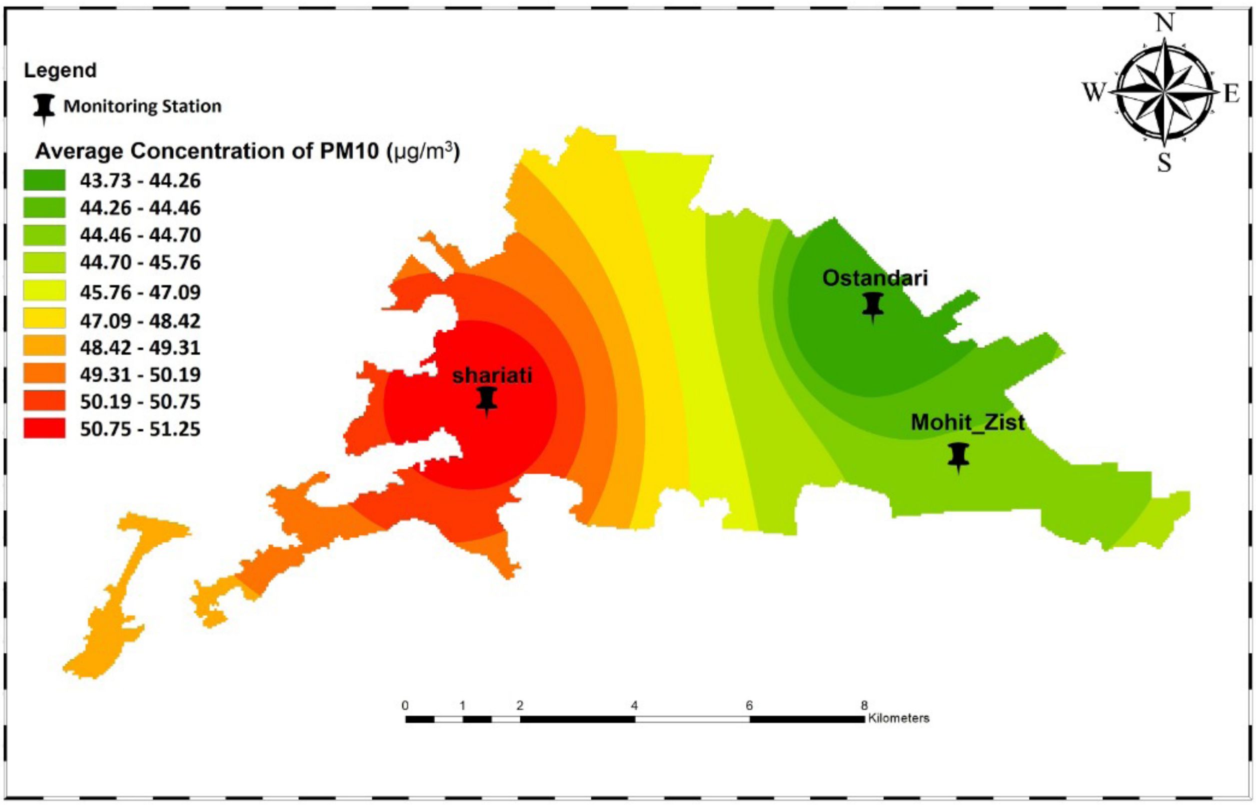

Fig. 4. Average monthly concentration of PM_{10} in the target stations during the study period (2017-2020)

Some researchers also estimated an annual PM_{10} concentration of 727 µg/m³ in Ahvaz, which is a serious threat to public health [28]. High traffic is an important factor in increasing the concentration of these particles. In Isfahan, researchers were measured an average annual PM_{10} concentration of 108 µg/m³ [29].

In Yazd, it was reported an average annual and maximum concentrations of PM_{10} (97 and 731 µg/m³, respectively) during summer [30]. According to the geographical distribution of PM_{10} during the study period (Fig. 5), the governor's station has higher concentrations due to its location in a high-traffic area, which corresponds to other studies in the world.

Association of meteorological parameters with $PM_{2.5}$ and PM_{10} concentrations

PM plays a critical role in climate change and meteorological parameters have a significant impact on the distribution of these pollutants in the atmosphere, which can cause the release, dilution, or accumulation of pollutants to a high extent [31]. Therefore, this study examines the impact of meteorological parameters, such as temperature, humidity, precipitation, and wind speed, on the concentrations of $PM_{2.5}$ and PM_{10}. Each of the parameters has different effects on the particles in the air, which have been confirmed in studies around the world. Researchers in China found that meteorological parameters could play a role in the reduction of $PM_{2.5}$ concentrations by at least 16% [25]. Fig. 6 shows the spider diagram for the statistical summary of meteorological parameters.

According to the results, the average temperature, precipitation, humidity, and wind speed were 14.8 °C, 25 mm, 42%, and 12.2 m/s, respectively, during the 3 years of the study. The spider diagram is used here as it clearly shows the minimum and maximum values of each parameter.

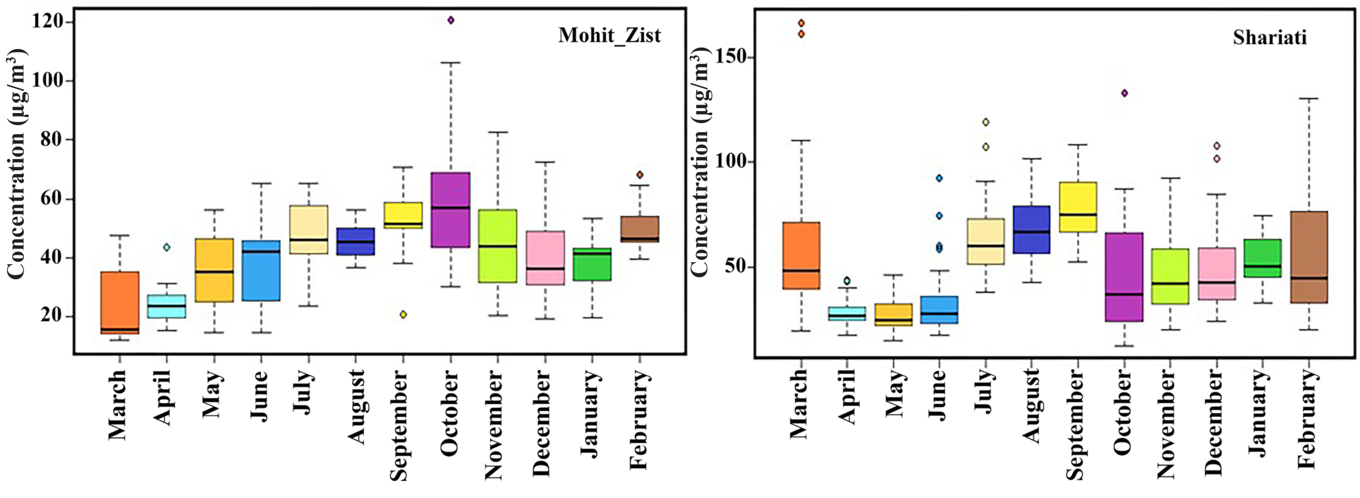

Fig. 5. Geographical distribution of PM_{10} concentrations in arak at 2017-2020

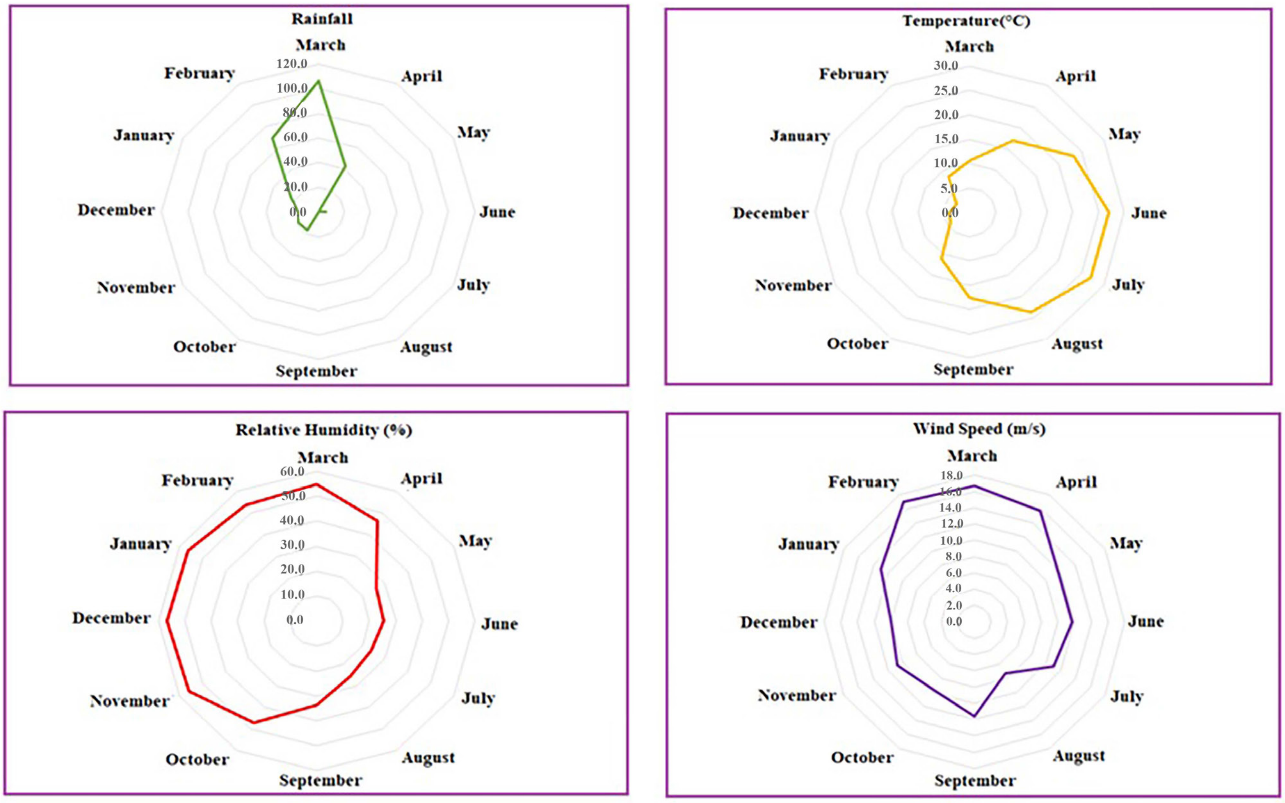

Fig. 6. Statistical summary of meteorological parameters

The association between each meteorological parameter and the average annual concentrations of $PM_{2.5}$ and PM_{10} (Table 1) indicates that there are strong positive relationships between the mean $PM_{2.5}$ concentration and temperature (r=0.345, p<0.412) and wind speed (r=0.26, p<0.034). On the other hand, there are weak and negative relationships between the average annual $PM_{2.5}$ concentration and relative humidity (r=−0.119, P < 0.018) and precipitation (r=−0.104, p<0.124). In addition to $PM_{2.5}$, the effect of each meteorological parameter on PM_{10} was also investigated in this study. As shown in Table 1, PM_{10} has positive relationships with temperature (r=0.259, p<0.206), relative humidity (r=0.4, p<0.012), and wind speed (r=0.48, p<0.05), but it has a weak and negative relationship with precipitation (r=−0.326, p<0.21).

Table 1. Correlation of between $PM_{2.5}$ and PM_{10} particles and meteorological parameter

		Temperature	Relative humidity	Precipitation	Wind speed
$PM_{2.5}$	R	0.345	-0.119	-0.104	0.26
	P_{Value}	0.412	0.018	0.124	0.034
PM_{10}	R	0.259	0.4	-0.326	0.48
	P_{value}	0.206	0.012	0.21	0.05

Similar to the results of our study, a positive relationship between $PM_{2.5}$ and temperature was reported in studies on the relationship between meteorological parameters and $PM_{2.5}$ in Tehran [19], Karaj[21], and Isfahan [20]. This issue was also emphasized by studies in China [32] and Italy [33], demonstrating a direct and positive relationship between $PM_{2.5}$ and air temperature. The presence of scattered clouds in the air reduces the concentration of PM because the atmospheric precipitation washes the particles in the air, transfers them to the earth's surface, and cleans the air of particles. Hence, this study also showed a negative relationship of precipitation with $PM_{2.5}$ and PM_{10}. Ansari in Tehran [19] and Hosseini et al. in a joint study on Asian countries concluded that there was a negative relationship between PM and precipitation [8]. Williams showed that the maximum concentration of PM in the air reduced the amount of precipitation in winter, indicating a weak correlation between these two parameters [34]. This study also showed a direct relationship between wind speed and PM. Wind speed and direction are important factors in the dispersion of these pollutants in the air. Fig. 7 illustrates the wind rose of Arak city during the study period, indicating that the main direction of the wind is northward and partly northwestward in this city. In the previous sections, it was explained that the station located in the north of Arak city had more PM pollution. In the air of Arak city, there is no significant difference between $PM_{2.5}$ and PM_{10} pollutants and air humidity, but there were negative and positive relationships between $PM_{2.5}$ and PM_{10}, respectively, which was shown in studies by some researchers in Iran [19, 6, 35].

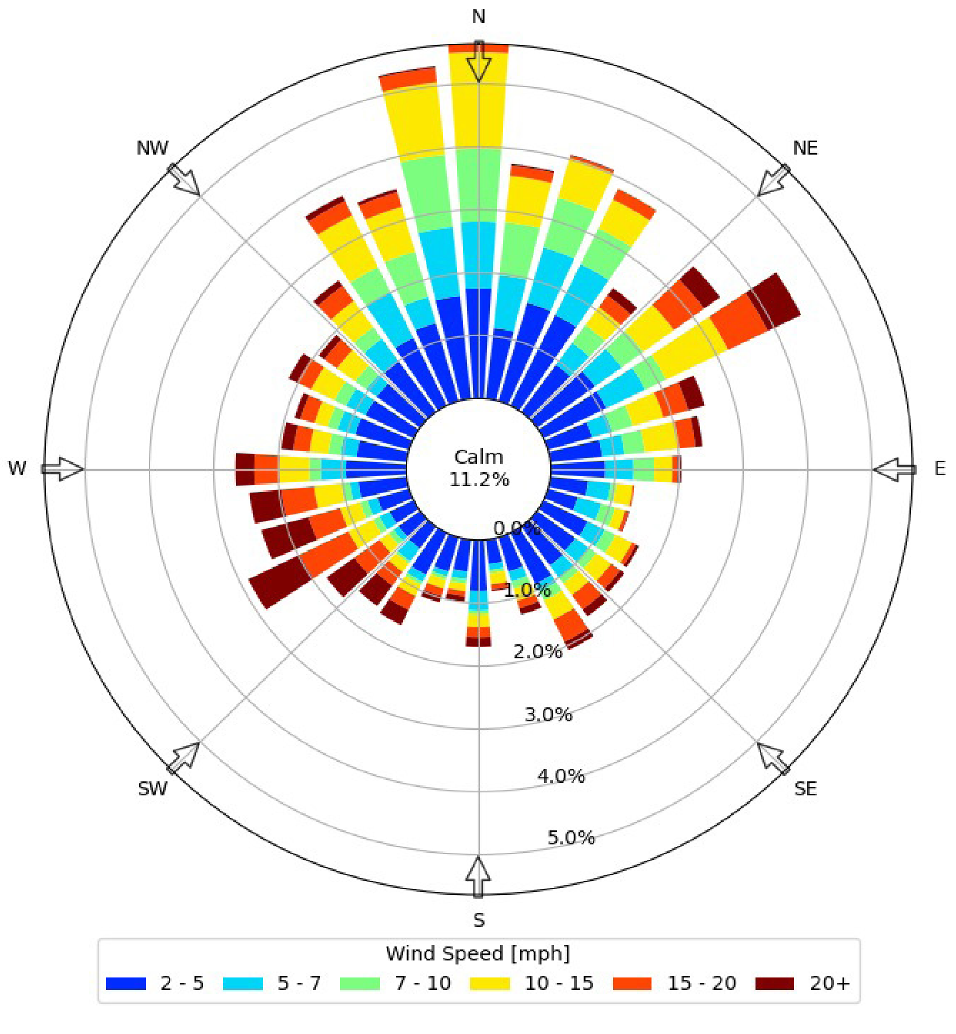

Fig. 7. wind rose in Arak city (2017-2020)

Conclusion

The present study aimed to determine the trend of changes in $PM_{2.5}$ and PM_{10} concentrations, as well as their associations with meteorological parameters, during a three-year period in Arak city. The results showed that the PM concentrations in this city were higher than the WHO guidelines. As mentioned above, there was a positive correlation between the mean annual concentration of $PM_{2.5}$ with temperature and wind speed, and a negative correlation with humidity and precipitation. Besides, a positive correlation was observed between the mean annual concentration of PM_{10} with temperature, humidity, and wind speed, and a negative correlation with precipitation. It is also noteworthy that more accurate analyses can be performed using other advanced software. Furthermore, the limitations mentioned in this study should be considered in other studies.

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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, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors.” This study was approved by the Ethical Committee of Arak University of Medical Sciences with code: IR.ARAKMU.REC.1400.047

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