Spatiotemporal Distribution of PM_{10} and $PM_{2.5}$ within and Around The City of Arak, Iran: Effect of Natural Sources

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ABSTRACT

In the present study, the concentrations of PM_{10} and $PM_{2.5}$ were measured within and around the city of Arak from March 2016 through March 2017. The measurements were done every 12 days by means of TSI DustTrak sampler containing specific heads for PM_{10} and $PM_{2.5}$. The sampling points included eight stations within the city as well as two stations around the city. The average (±SD) values of 108.56 ±55.56 and 42.58 ±15.88μg/m^3 were obtained for daily concentrations of PM_{10} and $PM_{2.5}$, respectively. PM_{10} showed the maximum concentrations during summer (144.47μg/m^3) followed by spring (109.44 μg/m^3), autumn (100.92μg/m^3), and winter (77.12μg/m^3). On the other hand, the highest values of $PM_{2.5}$ was observed during winter (44.13 μg/m^3) followed by autumn (42.74μg/m^3), summer (37.58μg/m^3) and spring (33.77 μg/m^3). The correlation between PM_{10} and $PM_{2.5}$ was highest in winter (R^2=0.9288) followed by spring (R^2=0.6728), summer (R^2=0.6713), and autumn (R^2=0.5592). It was concluded that more than 57 and 19% of the $PM_{2.5}$ and PM_{10} samples exceeded the Iranian national ambient air quality standards, respectively.

Keywords: PM_{10}; $PM_{2.5}$; Arak; Iran; Air pollution; Spatiotemporal Distribution

INTRODUCTION

Air pollution is one of the most important environmental issues in various cities of both developed and developing countries [1, 2]. In recent years, most major Iranian cities have experienced high levels of particulate matter (PM), especially those with an aerodynamic diameter smaller than 10 (PM_{10}) and 2.5 ($PM_{2.5}$) micron [3, 4]. This pollutant as one of the main indicators of air quality can remain in the atmosphere for a long time [5, 6]. Hence, the increasing levels of PM_{10} and $PM_{2.5}$ impose serious damages on human health and the environment [7, 8]. The potential of PM for causing several adverse health effects is largely dependent on the size of the particles [9, 10]. Moreover, the particle could be toxic by itself, or more frequently carry the toxic substances deposited on it [11, 12]. Various studies have shown an association between high levels of PM and a daily number of deaths or hospital admissions for respiratory and cardiovascular diseases [13-15]. Apart from the abovementioned health effects, particulate matter has a very important influence on the atmosphere in terms of warming, visibility, climate change, and precipitation [16, 17].

Particulate matter generates from a variety of human activities like traffic, industry, and central heating [18, 19]. In addition, natural origins such as windblown dust and dust events also result in high levels of particulate matter [16, 17]. The concentration of the particulate matter derived from these natural phenomena is affected by various factors such as soil properties and wind speed [3, 17]. The particles associated with the windblown dust and dust events can potentially transport different materials over long distances and hence affect downwind populations and environments [3, 20]. Determination of the levels and distribution of particulate matter in different areas is of great importance in order to manage it effectively [21]. Thus, various studies all over the world have been conducted regarding concentrations and the distribution of particulate matter [22-24].

The air quality in Arak is poor because of both anthropogenic and natural sources. Many anthropogenic sources such as various industries and traffic present within and around the city produce huge amounts of pollutants. On the other hand, in recent years, dust event in the Middle East has affected many cities of Iran including Arak. Furthermore, Meyghan salt lake located in the eastern north of Arak is another natural source of particulate matter pollution. Thus, the mixing of all these particles from various sources has resulted in elevated concentrations of PM_{10} and

$PM_{2.5}$ in the city. The main aim of this work was to evaluate the PM_{10} and $PM_{2.5}$ concentrations within and around the city of Arak from March 2015 through March 2016. The trend of PM concentrations in various parts of the city and its seasonal pattern was also investigated.

MATERIALS AND METHODS

Study area

This descriptive study was carried out in Arak, Iran. The city has a total population of about 600000 and a total surface area of about 70km^2. The annual mean daily temperature in Arak is 13.9℃, with highs around 27.1℃ in July and lows around 0 °C in January. The average annual precipitation is 341.7 millimetres (mm), with the maximum in January (54.7mm) and the minimum in August (0.6mm). The average elevation of the city is 170m above sea level.

Sampling stations

The data of PM_{10} and $PM_{2.5}$ concentrations obtained from the eight stations chosen within the city (Fig. 1). The sampling stations were selected to cover all area of the city in all geographical directions including north, south, east, west, northeast, northwest, southeast, and southwest. In addition, two stations were selected around the city, in the western south, where there are three big industries including an oil refinery plant, petrochemical plant, and power plant. These two stations are located in the dust route to Arak. All the stations were selected in such a way that the natural or manmade structures such as trees, hills, and buildings have a minimum effect on PM_{10} and $PM_{2.5}$ concentrations.

Sampling procedure

Measurements were made for a full year from March 2016 through March 2017. The measurements were made every 12 days [25] by means of a TSI DustTrak (Model 8520, USA) sampler equipped with different sampling heads were for PM_{10} and $PM_{2.5}$. The instrument was installed 1.5 m above the ground to be the same as the respiratory height. In all sampling stations, the concentrations of PM_{10} and $PM_{2.5}$ were recorded daily. The temperature, relative humidity (RH), wind speed, and wind direction were also obtained from the Iranian Meteorological Organization.

Data processing

GIS was used to show the spatial distribution of the PM. The differences in PM concentrations were determined by using the one-way ANOVA test with SPSS software (P-value ≤ 0.05). The correlations between various variables were investigated by the regression analysis of Microsoft Excel software.

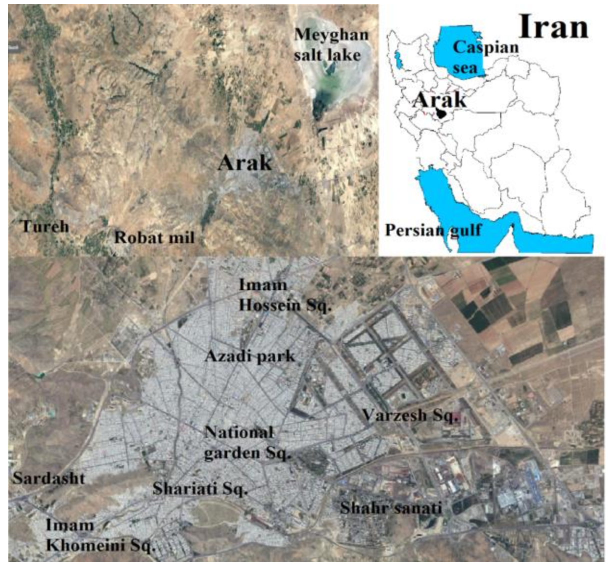


Fig. 1: Location of the study area and sampling stations

Data processing

GIS was used to show the spatial distribution of the PM. The differences in PM concentrations were determined by using the one-way ANOVA test with SPSS software (P-value ≤ 0.05). The correlations between various variables were investigated by the regression analysis of Microsoft Excel software.

RESULTS AND DISCUSSION

Mean concentrations of PM_{10} and $PM_{2.5}$

The summary statistics for PM_{10} and $PM_{2.5}$ concentrations during various months of the study period are presented in Tables 1 and 2. The average (±SD) for daily PM_{10} and $PM_{2.5}$ values throughout the whole year in Arak were found to be 108.56±55.56μg/m^3 and 42.58±15.88μg/m^3, respectively. These values are higher than those reported by Arhami *et al.* [26] in Tehran which was 90 and 33, respectively. However, they are lower than the corresponding values (319.6 and 69.5μg/m^3) reported by Shahsavani *et al.* [3] in Ahvaz. This substantial difference is due to the fact that high numbers of dust events have annually happened in the city of Ahvaz. The obtained values were 5.4 and 4.3 times higher than the WHO standards of 20 and 10 μg/m^3 for annual concentrations of PM_{10} and $PM_{2.5}$, respectively [27]. Moreover, more than 93% and 88% of daily PM_{10} and $PM_{2.5}$ were above the daily average WHO standards of 50μg/m^3 and 25μg/m^3, respectively [27]. The Iranian national ambient air quality standards which are based on EPA standards are 150μg/m^3 and 35μg/m^3 for daily average concentrations of PM_{10} and $PM_{2.5}$, respectively [28]. In this regard, over 19% and 57% of the PM_{10} and $PM_{2.5}$ samples exceeded the Iranian standards, respectively.

Table 1: Summary statistics of PM_{10} and $PM_{2.5}$ concentrations (μg/m^3) within the city of Arak

Pollutant	Months	Average	Min.	Max.	SD
PM_{10}	March	94.66	60.08	176.32	36.57
	April	100.56	55.57	199.58	58.84
	May	122.57	63.25	162.03	42.73
	June	187.05	69.54	342.18	113.77
	July	124.55	93.52	176.06	33.09
	August	126.96	93.22	168.78	26.65
	September	128.74	81.52	163.48	31.47
	October	98.57	89.56	105.96	4.56
	November	81.96	57.93	126.62	25.94
	December	76.07	33.23	105.34	28.14
	January	70.09	36.02	98.35	22.54
	February	90.91	43.94	168.77	49.00
$PM_{2.5}$	March	30.87	14.96	50.96	11.47
	April	36.72	23.24	67.69	11.26
	May	38.26	20.36	54.19	10.85
	June	43.43	22.75	63.45	15.41
	July	36.45	16.16	58.44	12.38
	August	42.46	29.01	68.91	11.02
	September	47.28	27.54	79.87	14.69
	October	46.23	38.95	58.52	4.81
	November	43.10	25.14	75.87	15.77
	December	51.76	22.15	76.90	18.70
	January	43.72	15.01	65.82	15.89
	February	50.69	24.41	93.76	27.11

Spatial distribution of PM_{10} and $PM_{2.5}$

As more polluted areas within cities show higher health effects than less polluted areas [29], the values of PM_{10} and $PM_{2.5}$ were monitored at different points of Arak. As shown in Table 3 and Fig.2, the values of PM_{10} and $PM_{2.5}$ differed in various sampling points. The concentration of particulate matter in ambient air is affected by both source conditions and meteorological parameters such as wind direction and speed, temperature, humidity, stability of the atmosphere, precipitation [30, 31]. Among them, wind direction is of great importance as it shows a strong correlation with particulate matter concentrations [32, 33].

In Arak, western and southwestern winds are the most frequent from March to May. Therefore, since Iraq as the primary source of dust storms are located in the southwest of Arak, the mean concentrations of PM_{10} in the stations Tureh and Robat mill (123.47μg/m^3) were higher than those in the other stations (105.93μg/m^3) located within the city. On the other hand, the Meyghan salt lake located in the northeast of Arak is the source of PM_{10} especially in June and July as the prevailing wind is northeast wind during this period. Accordingly, the mean levels of PM_{10} in the stations Azadi park, Varzesh Sq., and Imam Hossein Sq. (157.07μg/m^3) were higher than those in the other stations (153.12μg/m^3). High temperature and low humidity are also suitable conditions for the generation of dust events in this region from May to August.

On the other hand, the mean values of $PM_{2.5}$ (42.41μg/m^3) in the eight-station located within the city were higher than those around the city (30.67μg/m^3). This significant difference is predictable since the anthropogenic sources are mainly responsible for the generation of $PM_{2.5}$ within the cities.

Table 2: Summary statistics of PM_{10} and $PM_{2.5}$ concentrations ($\mu g/m^3$) around the city of Arak

Pollutant	Months	Average	Min	Max	SD
PM_{10}	March	118.44	67.50	221.06	71.90
	April	120.49	62.16	234.78	83.12
	May	131.47	65.92	169.02	50.83
	June	185.53	63.31	369.60	140.47
	July	113.65	100.54	135.38	16.47
	August	113.62	64.64	168.90	39.46
	September	112.17	80.22	143.94	25.87
	October	90.46	78.71	107.88	13.49
	November	74.12	44.02	90.16	22.62
	December	54.91	48.56	63.39	5.85
	January	45.81	40.08	50.14	4.04
	February	107.74	73.15	165.00	41.85
$PM_{2.5}$	March	25.88	10.14	47.45	15.77
	April	25.96	17.38	38.75	9.69
	May	31.30	18.65	42.36	9.78
	June	40.87	20.51	66.34	20.49
	July	28.36	14.20	47.08	14.72
	August	35.51	20.20	52.78	12.33
	September	45.94	27.10	86.24	21.59
	October	35.78	30.81	44.54	6.09
	November	29.29	18.69	36.14	6.97
	December	18.31	14.81	23.34	3.18
	January	17.05	13.36	20.83	3.03
	February	41.90	25.37	55.74	12.40

Table 3: Mean annual concentration of PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) in various sampling stations

Pollutant	Sampling stations	Average	Min	Max	SD
PM_{10}	Tureh	107.05	44.77	187.64	38.17
	Robat Mil	104.36	46.86	183.43	35.80
	Sardasht	107.00	61.53	182.61	32.13
	Varzesh Sq.	107.63	76.27	185.89	31.57
	Imam Hossein Sq.	108.94	72.61	187.94	32.53
	Azadi park	109.36	70.38	187.31	32.00
	Sahr sanati	107.20	67.49	185.36	32.47
	National garden Sq.	110.85	75.37	188.98	31.88
	Shariati Sq.	109.30	70.51	189.57	32.34
	Imam Khomeini Sq.	108.19	66.59	188.73	32.17
$PM_{2.5}$	Tureh	29.33	14.92	40.36	8.62
	Robat Mil	32.02	19.17	43.86	7.69
	Sardasht	37.94	27.23	52.19	7.42
	Varzesh Sq.	39.73	29.11	51.08	6.29
	Imam Hossein Sq.	40.82	30.71	49.94	6.07
	Azadi park	42.88	32.22	53.14	6.58
	Sahr sanati	41.23	30.18	50.60	5.80
	National garden Sq.	50.06	35.21	61.30	7.11
	Shariati Sq.	44.63	32.89	51.63	6.27
	Imam Khomeini Sq.	41.99	28.85	51.38	6.26

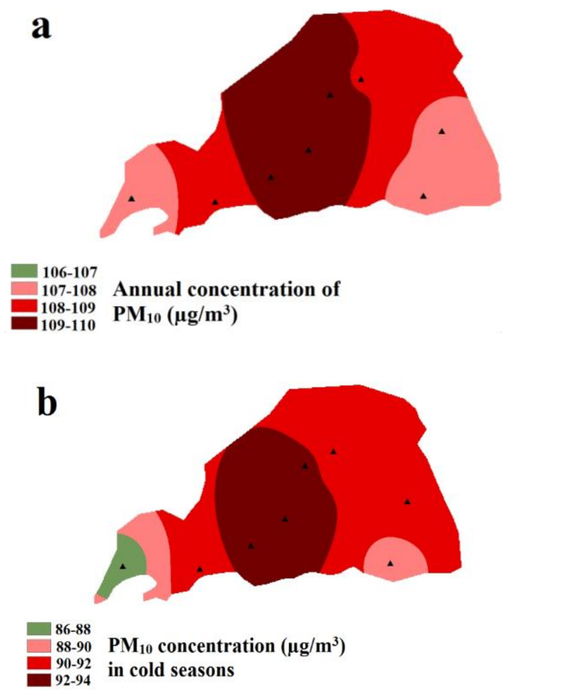


Fig. 2: Annual distribution of (a) PM ۱۰ and (b) $PM_{2.5}$ ($\mu g/m^3$) within the city of Arak

Seasonal variations of PM_{10} and $PM_{2.5}$

The seasonal trend and distribution of PM over the study period are presented in Figs. 3, 4, and 5. The higher level of PM_{10} in summer (144.47µg/m^3) compared to that in winter (77.12µg/m^3) is due to an increase in coarse particles (PM_{10}) originated from natural sources especially dust storms during the hot and dry periods. This finding is consistent with the results of Shahsavani *et al*. [3] reporting the values of PM_{10} were maximum in summer. Low relative humidity, high temperature and wind speed results in the instability of atmospheric and hence increase the dispersion of PM_{10} during the summer months. Another reason for higher levels of PM_{10} can be attributed to the fact that most dust events in the Middle East happen during the late spring and early summer. Since the dust sources are highly active during the hot and dry season, it is expected that the PM_{10} concentrations decreases in winter. Further, PM_{10} settle down very easily through rainfall and thus washing out of the pollutants occurred in winter. Accordingly, the values of PM_{10} decreased in winter in all the sampling stations. Gogikar & Tyagi [34] also attributed the lowest concentrations of pollutants during the winter to rainfall.

As depicted in Figs. 3, 4, and 5, the trend of $PM_{2.5}$ differed from that of PM_{10}, as the values were higher during the colder seasons. Unlike PM_{10} which are noticeably affected by dust storms in summer, the fine particles ($PM_{2.5}$) are largely affected by anthropogenic sources such as vehicles and heating system in winter. Moreover, fine particles remain in the atmosphere for a longer time because of frequent stable weather conditions and poor dispersal that occurred during the colder seasons [6, 26].

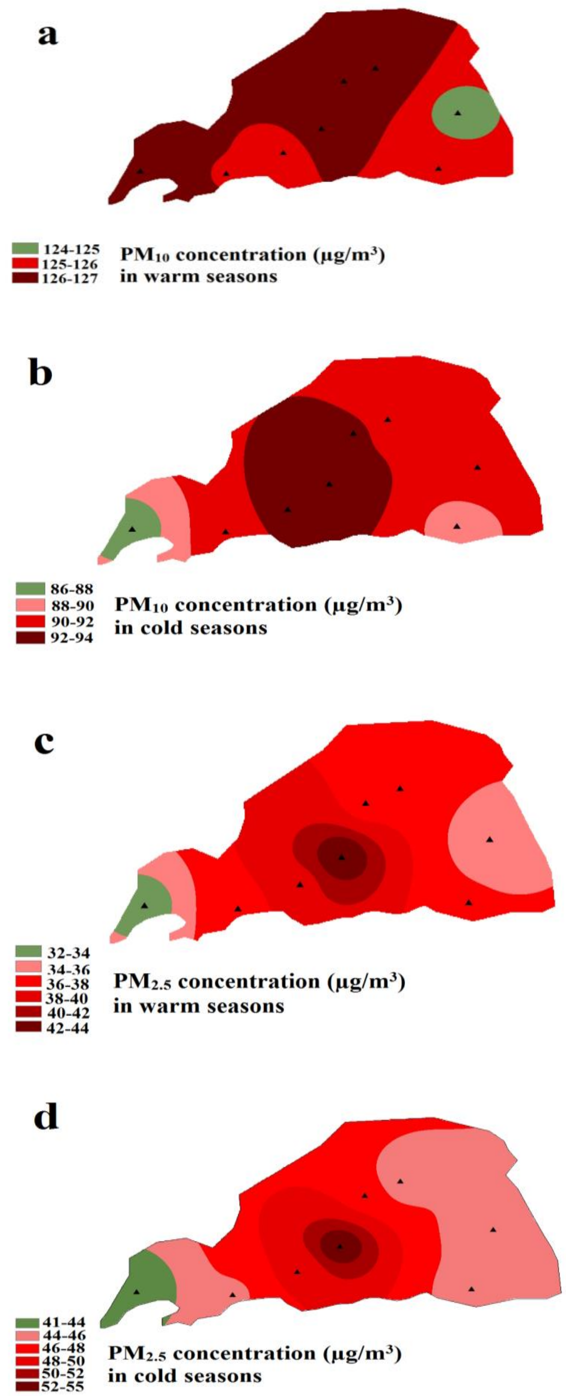


Fig. 3: Seasonal distribution of PM_{10} and PM2.5 ($\mu g/m^3$) within the city of Arak: (a) PM_{10} in warm seasons, (b) PM_{10} in cold seasons, (c) $PM_{2.5}$in warm seasons, and (d) $PM_{2.5}$ in cold seasons

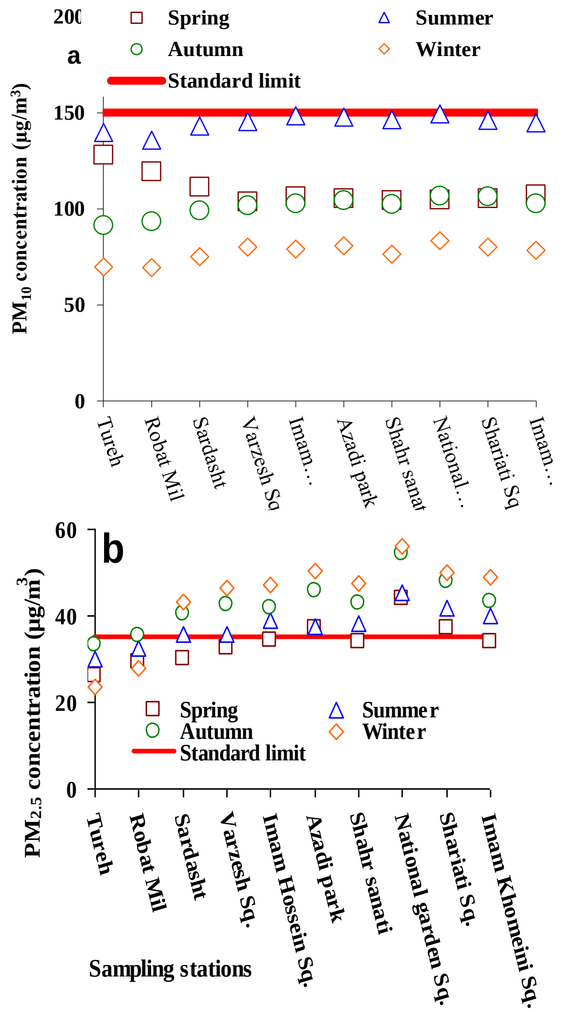


Fig. 4: Mean concentrations of PM_{10} and $PM_{2.5}$ in various sampling stations over the various seasons

Associations between PM_{10} and $PM_{2.5}$

The determination of the $PM_{2.5}/PM_{10}$ ratio is of great importance as it can be used to identify the sources of the particles [6]. The trends in the monthly averages of $PM_{2.5}/PM_{10}$ ratios over the study period within and around the city of Arak have been shown in Fig. 6. As depicted from the data, PM_{10} comprised 42% and 0.31 of $PM_{2.5}$ within and around the city, respectively. These values are higher than that (0.23) reported by Shahsavani *et al.* [3]. This difference is mainly due to the fact that the ratio in the present study was calculated for the entire year including autumn and winter. During these cold seasons, the fine fraction of particulate matter ($PM_{2.5}$) is high because the related sources primarily release finer particles and therefore the ratio of $PM_{2.5}/PM_{10}$ increases.

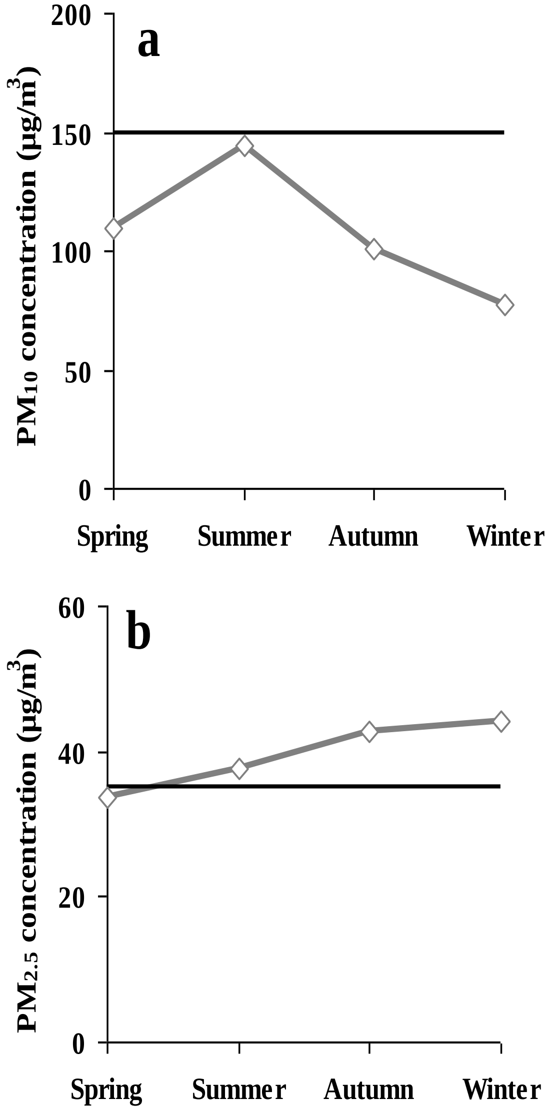


Fig. 5: Mean concentrations of PM_{10} and $PM_{2.5}$ in all sampling stations over the various seasons

In the current research, the ratios were calculated to be in the range of 0.23-0.68 and 0.22-0.41 within and around the city, respectively. Similarly, the annual mean ratios of $PM_{2.5}/PM_{10}$ in urban and semi-rural areas of the USA were reported to be 0.3-0.7 [6] which correspond to the values calculated in the present study. As can be seen from the figure, the ratio decreased from April (0.37) to June (0.23) and then rose from June through December (0.68) within the city. On the other hand, the trend of the ratio around the city was different compared to that within the city. It was observed a gradual increase from March (0.22) through September (0.41) and then a decrease from September to February (0.39). The mean values of the ratio during the spring, summer, autumn and winter were 0.34, 0.28, 0.46, and 0.62, respectively within the city. The corresponding values were 0.23, 0.26, 0.40, and 0.36 around the city, respectively. The low ratio in summer can be attributed to dust storm containing high levels of coarse particles. In winter, the ratio observed around the city was lower than that within the city due mainly to the fact that there were fewer anthropogenic activities and local traffic around the city.

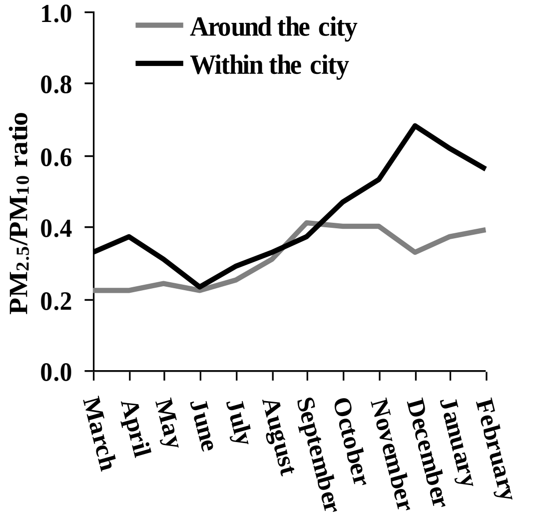
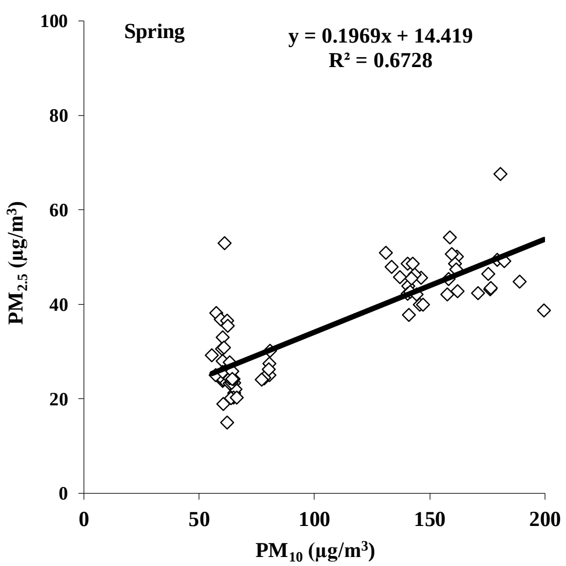
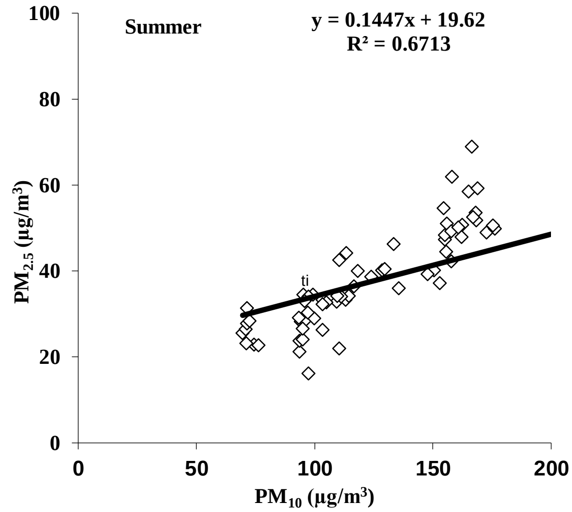
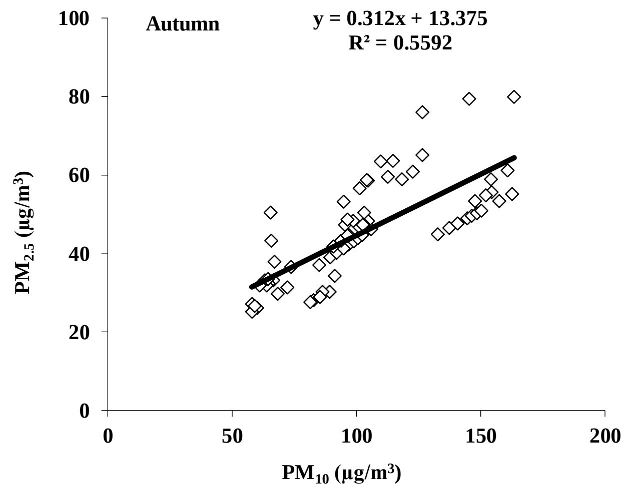


Fig. 6: Monthly averages of $PM_{2.5}/PM_{10}$ ratios within and around the city of Arak

The scatter plots of $PM_{2.5}$ against PM_{10} concentration for each season of the study period are presented in Fig. 7. As shown, linear relationships were observed between $PM_{2.5}$ and PM_{10} since both fine and coarse particles are to some extent linked with similar sources. Since Iran is located in an arid/semi-arid area and has a high background level of particulate matter, it is suggested that the exact contribution of various sources of particles be investigated in further studies.







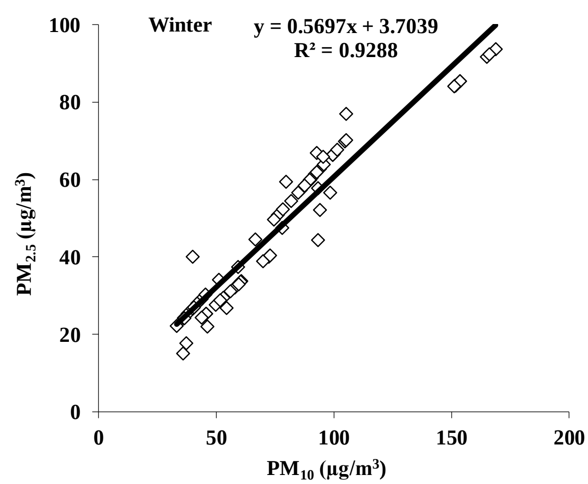


Fig. 7: Correlation between $PM_{2.5}$ and PM_{10} in the city of Arak

CONCLUSION
The average concentrations of PM_{10} and $PM_{2.5}$ during the whole study period were calculated to be 108.56 ±55.56 µg/m^3 and 42.58±15.88 µg/m^3, respectively. The concentration of particulate matter in various points of the city differed depending on the season and the direction of the prevailing wind. The higher level of PM_{10} in summer indicated that the coarse particles originated from natural sources especially dust storms that occurred in the region. The main sources of PM_{10} in spring and summer were found to be the Meyghan salt lake and Middle East dust events, respectively. The highest concentration of $PM_{2.5}$ in winter was mainly attributed to anthropogenic sources such as vehicles and heating system. It was also found that there were relations between PM_{10} and $PM_{2.5}$ data sets in all seasons of the study period.

ETHICAL ISSUES
The authors confirm that the research is their original study. It has not been published, nor is it under review in another journal, and it is not being submitted for publication elsewhere. The authors certify that all data collected during the study is presented in this manuscript, and no data from the study has been or will be published separately. Other ethical issues such as plagiarism have been observed by the authors.

CONFLICT OF INTEREST
The authors have no conflicts of interest to declare.

AUTHORS' CONTRIBUTIONS
DS and AM gathered the data. AK, MJG, MSR, and RS analyzed the data and prepared the manuscript. All authors read and approved the final manuscript.

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