Research Paper

Spatiotemporal Characteristics of Particulate Matters Concentration and Their Influence on Ambient Air Quality in Urban Regions of Khuzestan Province, Iran

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ABSTRACT

Background: One of the most concerning pollutants in urban areas across the globe is particulate matter suspended in the Earth's atmosphere. The main objective of the current investigation is to explore the spatial and temporal patterns of ambient air particles (PM_{10} and $PM_{2.5}$) and $PM_{2.5}/PM_{10}$ ratio in different urban areas of Khuzestan Province.

Methods: In this way, the required data were gathered from the environmental protection organization based on hourly mean concentrations of PM_{10} and $PM_{2.5}$ of six air pollution-monitoring sites for 5 years.

Results: Results indicated that the average concentrations of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ are about 134.14±39.23 μg/m^3, 44.51±13.44 μg/m^3 and 0.33±0.07, respectively. The examinations revealed a reductive trend on annual values of PMs in terms of temporal variations. A detailed investigation of the annual mean concentrations of PMs and $PM_{2.5}/PM_{10}$ in terms of spatial variations demonstrated the largest values for Naderi-Ahvaz and Abadan stations. Furthermore, the measured AQI was larger than 100 and the Exceedance Factor (EF) values of PM_{10} and $PM_{2.5}$ ranged between 1.51-2.73 and 0.77-1.41. The statistical analysis obtained from linear regression revealed a significant positive relation between AQI and $PM_{2.5}$ and PM_{10} with correlation coefficients (R^2) of 0.8259 and 0.7934, respectively.

Conclusion: Although the analysis and measurement revealed a reductive trend in the annual mean concentrations of PM2.5 and PM10, the measured AQI and EF values are still far from the standards of good quality and low pollution. Therefore, it is highly necessary to follow the air pollution protocols to control PM air pollution in Khuzestan Province.

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1. Introduction

Atmospheric pollution issues have become a severe environmental problem in urban areas of developing countries [1, 2] and many cities in developed countries [3]. The high concentration of air pollutants in urban areas is the most serious threat to human health and significantly impacts the ecological environment [4]. Among all atmospheric pollutants, particulates or Particulate Matters (PMs) are the most important compound in air pollution and have become a serious environmental risk globally [5, 6, 7]. PM is a composite of solid and or liquid organic and inorganic species originating from human activities or natural resources. They are suspended in the atmosphere and have different sizes [8, 9].

Atmospheric PMs are classified according to the aerodynamic diameter and include PM_{10} (≤10 microns), $PM_{2.5}$ (≤2.5 microns), or $PM_{1.0}$ (≤1.0 microns) [10]. For urban air quality monitoring, the regarded particles usually are PM_{10} and $PM_{2.5}$. These two particle fractions or ambient air particles are different in terms of the origin, lifetime, location of deposition in the body, various respiratory and cardiovascular diseases, and so on [11]. Because of a large number of natural and anthropogenic sources, PM events may have different origins. Anthropogenic sources of PM include combustion in mechanical and industrial processes, as well as, vehicle emissions but natural sources include volcanoes, fires, dust storms, and aerosolized sea salt [12].

Recently, PM pollution has been one of the most critical issues in expanding cities worldwide, especially in developing cities in Asia [12, 13]. Similarly, different cities of Iran are facing increasing urban air pollution of PM. These areas, like other fast-growing cities around the world, face expanding urbanization, growing energy consumption, high traffic congestion, and rapid industrial development. Finally, poor emissions control of these activities leads to continuous increase and thus exacerbates air pollution [14]. Besides, the findings of various studies indicate that the dust phenomenon considerably increases the levels of PM to values above the ambient air quality standards in many urban areas in the world [15, 16].

For this reason, nowadays, dust storms have increasingly become the most critical environmental problem that threatens the world. Lately, dust storms with regional and international origins in Iran have increased the PM concentration in the south, west, and southwest regions of this country and significantly increased PM levels above the standards set by the World Health Organization (WHO) [17, 18]. In these areas, the Middle East Dust (MED) storms are a serious problem. They are considered the largest dust source affecting these regions, especially Khuzestan Province in the southwest region of Iran [19-21].

Different urban areas of Khuzestan Province have been exposed to high PM values due to their geographical and topographical conditions, expanding urbanization, MED storms, and rapid economic development, especially polluting industries such as oil, gas, petrochemical, and steel industries [19, 21, 22]. So, exposure to MED storms can be considered the most critical problem in the southwest regions of Iran [23]. In recent years, the different cities of Khuzestan Province have encountered several dust storms. So, the World Health Organization (WHO) defined these areas as the most contaminated regions globally in terms of the PM values [17, 18]. Many epidemiological researchers have demonstrated that the increasing levels of ambient particle concentration in urban areas are responsible for various health problems [24]. In addition, PM can affect climate change [25] and atmospheric visibility [26]. Therefore, it is essential to study and accurately identify the spatiotemporal changes of air pollution (different sizes of PM), their associated sources, and their impacts. In this context, the findings of several studies have emphasized the significance of the ambient particulate matter and monitoring PM, especially PM_{10} and $PM_{2.5}$ that are usually considered for urban air quality monitoring (Lithuania [27], India [10, 28] China [29, 30] Cameroon, Central Africa [2], Iran [31-33]). Furthermore, the Air Quality Index (AQI) has been considered as one of the essential tools used in analyzing and reporting air quality status in a particular area [4]. AQI has been used in many studies to determine the severity of pollution and report air quality levels [34-37]. In addition to using the AQI index, several studies have used the exceedance factor (EF) method introduced by the Central Pollution Control Board Central Pollution Control Board (CPCB) to assess the air quality of an area [38-40].

Therefore, our understanding of the spatial and annual variations of air pollutants in different urban areas of Khuzestan Province and reporting air quality levels can be helpful to support the implementation of air contamination control measures. The present study aims to investigate the spatial and temporal patterns of ambient air particles ($PM_{2.5}$ and PM_{10}) in different urban regions of Khuzestan Province and assess the air quality in the investigated areas according to the fine ($PM_{2.5}$) and inhalable particles (PM_{10}) for the entire study period (2015-2019).

2. Materials and Methods

Study area characteristics

In this descriptive and evaluative study of air quality, Khuzestan Province was selected as the study area. This Province is in the southwestern of Iran, covering an area of 63633 km^2 and extending between north latitudes 29° 57'-33° 00' and east longitudes 47° 40'-50° 33'. According to the latest statistics, the total population of this Province is approximately 4.7 million [41]. Of climate, most parts of the Province are dry (average rainfall is 266 mm).

Different urban areas of Khuzestan Province, like other cities in developing states, are facing air contamination problems caused by anthropogenic and natural sources [42]. In this research, 6 monitoring sites in different cities of Khuzestan were selected to evaluate the air quality relating to the fine and coarse particles. In the metropolitan Ahvaz, the capital of Khuzestan, there are four air pollution monitoring stations. In the present research, two of these sites (Naderi and Edarekol) during the study period (2015-2019) were selected (because their data were available) as monitoring stations in this city. Each of the other cities in Khuzestan has only one monitoring station. In the present research, in addition to two monitoring stations in Ahwaz, some monitoring stations in Andimeshk, Shushtar, Shadegan, and Abadan cities were selected. Figure 1 shows the air quality monitoring stations of the Khuzestan Province.

Data collection

To carry out a comprehensive analysis of the PMs in Khuzestan, we obtained data of PM_{10} and $PM_{2.5}$ concentrations from six air pollution-monitoring sites of the Province for 5 years (2015-2019) from the Environmental Protection Organization and Environmental Monitoring Center of Khuzestan Province. The average daily PM_{10} and $PM_{2.5}$ concentrations were calculated from their hourly concentrations. The monthly average of PM_{10} and $PM_{2.5}$ concentrations were calculated by daily mean concentrations for each of the 6 different sites. Then, average seasonal statistics were defined for spring (March-May), summer (June-August), fall (September-November), and winter (December-February). Next, the annual mean concentrations of air pollutants for all stations were averaged using the corresponding daily mean concentrations. Finally, the data of all air pollution-monitoring sites were used to show air pollution situations as seasonal and annual PM_{10} and $PM_{2.5}$ concentrations and their associated air quality indicators in different regions during the study period.

Air quality assessment

In the present study, two different methods were used to calculate the characterization of ambient air quality in selected urban areas of Khuzestan Province. These two methods are as follows.

Average method

The choice of the parameters for calculating AQI depends on various factors, including the objective of the index, the importance of the air quality parameters, and the availability of data [43]. In this research, the purpose of air quality assessment is to evaluate the ambient pollution level in terms of PMs and, therefore, $PM_{2.5}$ and PM10 air pollutants were considered for the calculation of AQI because these two particles usually are used for urban air quality monitoring (Equation 1):

$$(1)\ AQI=\frac{1}{2}\left[\frac{PM_{2.5}}{sPM_{2.5}}+\frac{PM_{10}}{sPM_{10}}\right]\times 100$$

, where applied to calculate the AQI and the standards of ambient air quality presented by the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ and PM_{10}, respectively. $PM_{2.5}$ and PM_{10} exhibited the actual average calculated values at the sampling sites. After obtaining the monitored values, the concentrations of these particle matters are converted into AQI values. The AQI ranges are based on the average method, and the corresponding air quality condition categories and health effects are presented in Tables 1 and 2 [44, 45].

Exceedance Factor (EF) and Average Exceedance Factor (AEF)

In this article, the evaluation of the air quality situation has been done by using the Exceedance Factor (EF) technique presented by CPCB [46]. In EF, the annual average pollutant concentration is related to the specified standards. EF and AEF were calculated using Equations 2 and 3, respectively [43, 47]:

$$(2)\ EF=\frac{C_{\circ}}{C_{I}}$$

where Co is the concentration of each particular pollutant and Ci is the NAAQS annual standard of respective pollutants Equation 3:

$$(3)\ AEF=\frac{1}{N}\sum_{i=1}^{N} EF_{i}$$

where EFi is the exceedance factor of the ith contaminant. N is the number of contaminants. An EF and AEF of 1 can be regarded as the threshold limit of a contaminant or a group of contaminants. According to EF, pollution level and air quality are classified into four categories [43, 48].

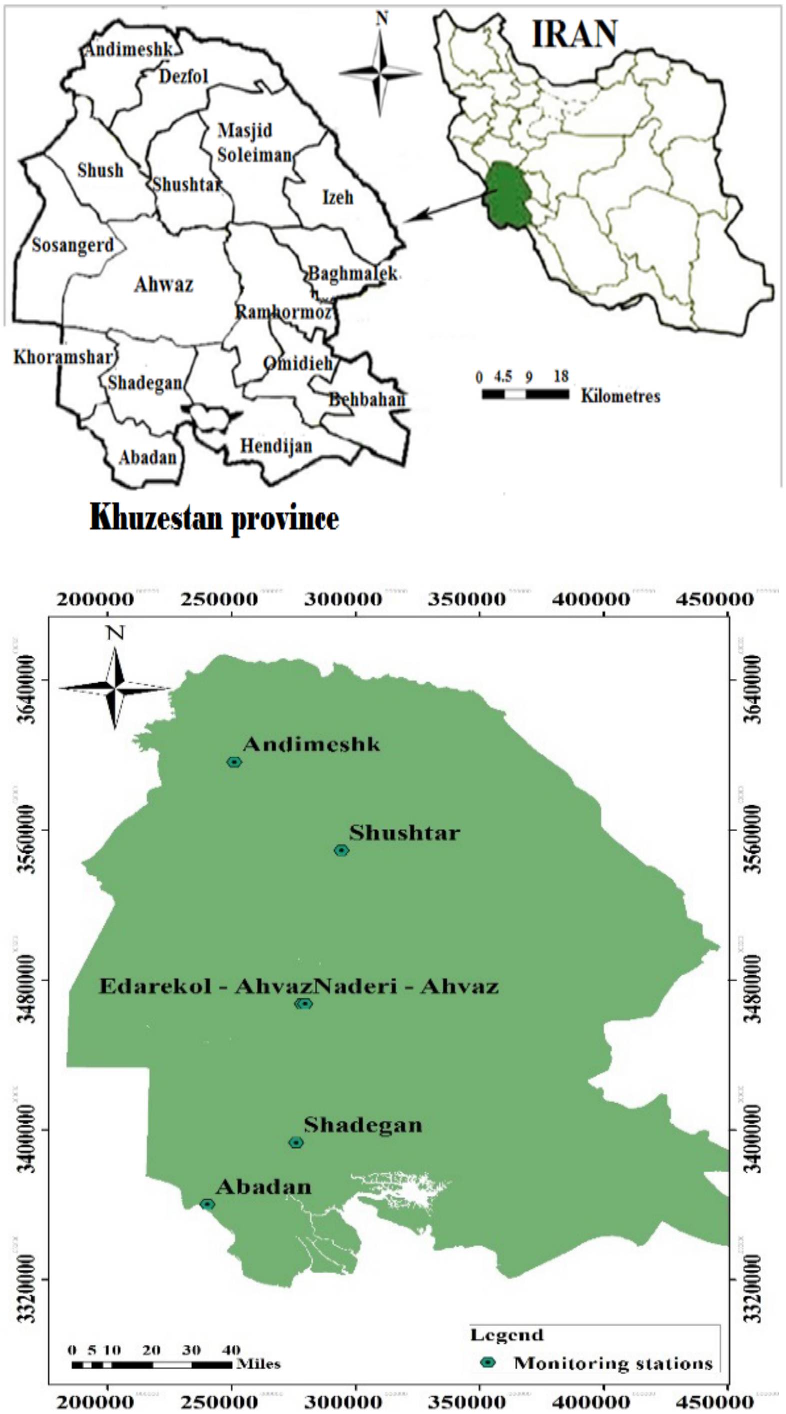

Figure 1. Locations of Khuzestan Province in Iran and the 6 monitoring sites in different cities of this province

Statistical analyses

Eventually, data were analyzed using SPSS v. 20. The Shapiro–Wilk test was applied to assess the normality of the data. A 1-way Analysis of Variance (ANOVA) and Duncan test were used to examine the significance of the differences in average air pollutants concentration (PM_{10} and $PM_{2.5}$) and $PM_{2.5}/PM_{10}$ ratio in the different studied stations, different seasons, and years of the study period. The connections of $PM_{2.5}$ and PM_{10} particulates, and Air Quality Index (AQI), were assessed using the linear regression model. The Spearman correlation test was used to rate the strength of the intra-seasonal and inter-seasonal correlation between PM concentrations. A P-value less than 0.05 was considered the statistical significance. Excel software was used for drawing tables and diagrams.

3. Results and Discussion

Temporal Variations of the PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ Values

Figure 2 shows the comparison of temporal variation of annual mean concentrations of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ ratio in different years of the study period. According to the ANOVA test, comparing the overall average concentrations of PM_{10} and $PM_{2.5}$ between different years of the present study in Khuzestan Province showed significant differences between the annual mean concentrations of PM_{10} and $PM_{2.5}$ in different years. For the entire study period, the highest annual values for PM_{10} were seen in 2017 and 2016, and for $PM_{2.5}$ in 2017 and 2016, respectively. According to the ANOVA test results, there was no significant difference between the overall mean of $PM_{2.5}/PM_{10}$ ratio in different years of study (2015-2019). The Mean±SD $PM_{2.5}/PM_{10}$ ratio for the entire study period was 0.33±0.07.

Levels of PMs significantly decreased in most monitoring stations from 2016 to 2019. In other words, during the last two years (2018 and 2019) of the present research, the annual mean concentrations of PM_{10} and $PM_{2.5}$ declined compared to the previous years. The decrease in the levels of PMs can mainly be due to the environmental protection strategies and effective control measures by the Iranian Environmental Organization in recent years [49]. In addition, the mass concentration of PM_{10} and $PM_{2.5}$ in 2016 and 2017 were higher than other years of this study period. According to the studies conducted in Khuzestan Province, PMs (especially PM_{10}) are produced chiefly by wind-blown dust caused by frequent dust storms and relatively fast winds [5, 50]. So probably during this period, a large number of dust events have occurred. Based on the study by Momtazan et al. [5] on particulate matter in Abadan and Khorramshahr cities from 2014 to 2016, 152 dust events have occurred. The current study findings revealed that for the entire study period (2014-2016), the highest annual average PM_{10} concentrations occurred in Abadan and Khorramshahr in 2016. During these three years of study, the annual average PM10 concentration in these cities was considerably higher than the standard values recommended by the national standard for human health protection. Also, the high concentration of PMs in 2016 can be attributed to a persistent event in the southwestern region and some areas of western Iran from February 21-24, 2016. During this event, these areas were stormed by a very severe dust phenomenon. Following this event, according to the reports of the Environment Organization of Khuzestan Province from the two stations of Ahvaz and Abadan, the level of pollution in Ahvaz reached 9977 $\mu g/m^3$ (66 times the allowable limit) and in Abadan reached 10000 $\mu g/m^3$ on the first day of the event (February 21) [51]. In another study by Daniali and Karimi [49], analysis

Table 1. Air Quality Index (AQI) values and the air quality condition categories [44]

Air Quality Condition	AQI Values	SI. No
Clean air	0 – 25	1
Light air pollution	26 – 50	2
Moderate air pollution	51 – 75	3
Heavy air pollution	76 – 100	4
Severe air pollution	>100	5

Table 2. Air Quality Index (AQI) values and the level of health concerns [45]

SI. No	AQI Values	Levels of Health Concern
1	0-50	Good
2	51-100	Moderate
3	101-150	Unhealthy For Sensitive Group
4	151-200	Unhealthy
5	>200	Hazardous

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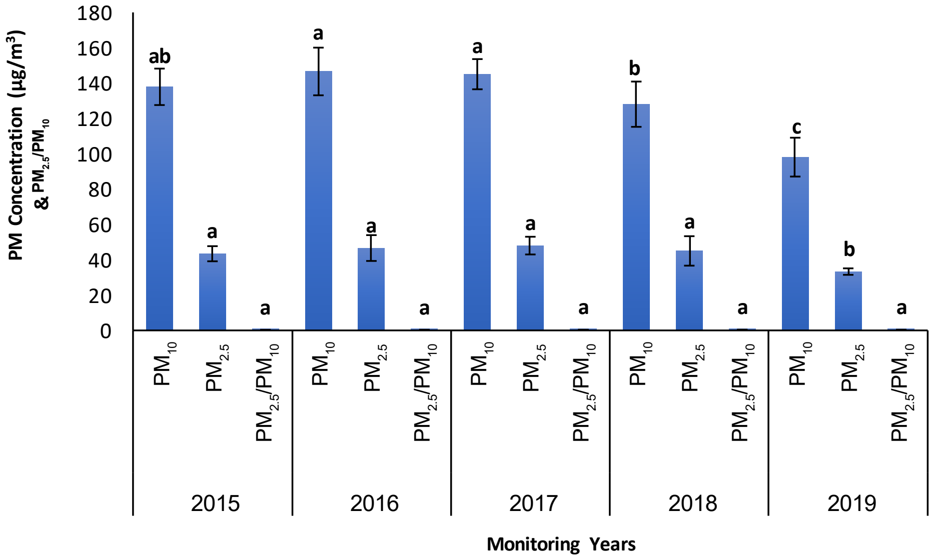

Figure 2. Temporal variations of average annual concentrations of $PM_{2.5}$ and PM_{10} and $PM_{2.5}/PM_{10}$ ratio in 6 regions of khuzestan Province

of spatiotemporal of dust patterns over Khuzestan Province and regions in ancient Mesopotamia (2001-2017) showed that despite the fluctuations in the annual levels of the Aerosol Optical Depth (AOD), an increasing trend had been observed from 2001, peaking in 2008 and 2009. In this study, we observed a slight increase from 2013 to 2017 compared to the early years.

Spatial Variations of the PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ Values

The spatial variation and distribution of annual mean concentrations of PM_{10} and $PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratio between different stations during the study period are displayed in Figure 3. A comparison of the overall mean values of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ ratio between different stations in Khuzestan Province showed significant differences between the annual average values in different stations ($P<0.05$) (Based on ANOVA test). A higher concentration of PM_{10} and $PM_{2.5}$ was observed at Naderi station in Ahvaz and Abadan monitoring stations. These regions are two urban areas of Khuzestan Province with massive annual emissions of air pollutants from different resources. According to studies, the higher PM10 values in Ahvaz and Abadan resulted in more frequent MED events than in other cities [52]. Besides,

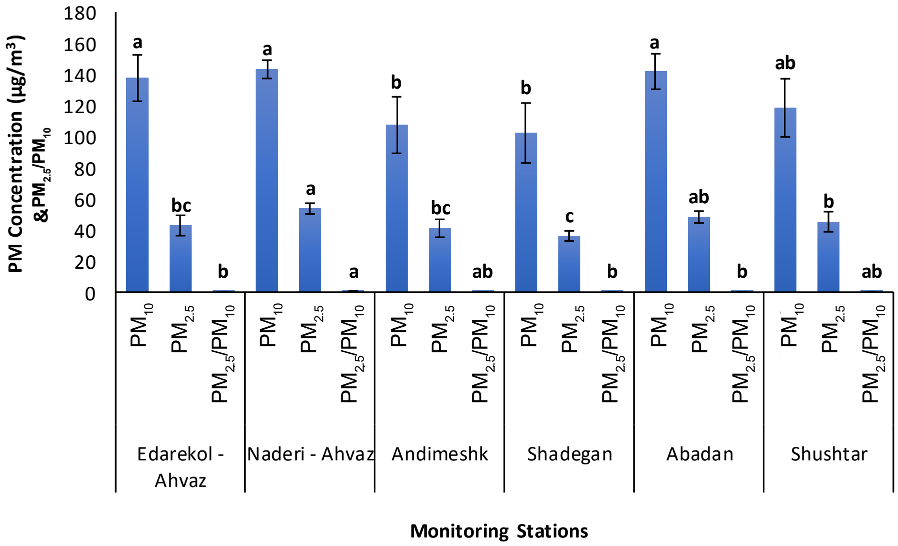

Figure 3. Spatial variation of annual mean concentrations of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ ratio in different stations for the entire study period

these two cities are industrial, densely populated, and areas with high traffic [5, 53].

In Goudarzi et al. studies, the highest average concentration of particles was observed in the Naderi station of Ahvaz. These studies noted that this station is in the center of the Ahvaz and has increased traffic and population density; therefore, the PM concentration of this location was found higher than other stations [33].

In other studies on the particulate matter in Abadan City, results showed that a further increase in PM_{10} concentrations in Abadan could be because this city is usually exposed to dust storms blowing from neighboring arid regions like Iraq and Saudi Arabia and industrial activities [5, 52]. Similarly, according to Mehrabi et al. the maximum number of stormy days in the Abadan station is related to the geographical location of this station [54]. Furthermore, Jahanbakhsh et al. found that Abadan and Ahvaz cities have seen more dust storms than other cities in the western region because of their geographic location, being on the main routes of atmospheric systems, proximity to dust sources such as external dust centers and proximity to dried-up wetlands and their physical-natural characteristics [55]. The lowest concentration of PM_{10} and $PM_{2.5}$ was seen in the Andimeshk and Shadegan monitoring stations. This finding could be due to low traffic and population density and lack of industrial activity in these areas [56].

The average concentration of PM_{10} and $PM_{2.5}$ at all stations throughout the study period is substantially higher than the annual mean standards determined by the NAAQS ($PM_{2.5}$= 40 μg/m^3 and PM_{10}= 100 μg/m^3) and the United States Environmental Protection Agency (USEPA) ($PM_{2.5}$= 15 μg/m^3 and PM_{10}= 50 μg/m^3).

Because different PM sizes originate from various sources, the PM ratios can be used as an indicator to identify their sources [57]. A lower value of $PM_{2.5}/PM_{10}$ ratio means that natural sources and dust events have a comparatively significant contribution to the production of PM [58]. A higher ratio of $PM_{2.5}/PM_{10}$ indicates a significant contribution of $PM_{2.5}$, which is generally attributed to primary contamination by anthropogenic activities [57]. In this research, the $PM_{2.5}/PM_{10}$ ratio in the different stations showed variability from 0.11 to 0.74, and the Mean±SD $PM_{2.5}/PM_{10}$ ratio over the 5 study years was 0.33±0.07. In Asia, the ratio is generally less than 0.5, indicating higher coarse particle masses [59]. Furthermore, the lower values of the $PM_{2.5}/PM_{10}$ ratio indicate air pollution caused by natural resources and dust events [59].

In the southwest of Iran, dust storms in the Middle East region are one of the reasons that can lead to this result [22]. This phenomenon is a serious problem and is considered the largest dust particle source and is responsible for significant increases of ambient PMs (especially PM_{10}) concentrations in the southwest region of Iran, especially Khuzestan Province [20, 21, 33]. So, it is clear that the rise in PM_{10} due to local dust emissions and regional dust transfer significantly contributes to higher PM_{10} concentrations and, therefore, lower $PM_{2.5}/PM_{10}$ values [59]. The studies carried out by Li et al. in China [13] and Nducol et al. in Africa [2] to assess the particulate matter pollution in the urban areas revealed similar results. The spatial distribution of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ ratio between different stations for the entire study period is shown in Figure 4.

Seasonal Variation of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ Ratio Values

The seasonal mean values of $PM_{2.5}$, PM_{10}, and $PM_{2.5}/PM_{10}$ ratio during the studied seasons are presented in Figure 5. According to 1-way ANOVA results, significant differences (P<0.05) were observed between the studied seasons regarding the PM_{10} and $PM_{2.5}$ values and $PM_{2.5}/PM_{10}$ ratio. This figure reveals that the mean concentration of PM_{10} and $PM_{2.5}$ are highest in summer and lowest in the winter season, while the $PM_{2.5}/PM_{10}$ ratio was higher in winter and autumn than in summer and spring.

These seasonal changes are attributed to sources of pollution and meteorological conditions. As mentioned, the highest amount of PM concentration during the study period was found in the summer season. This increase mainly occurred because during this time, especially in the late spring and the beginning of summer, the precipitation is very low, and evaporation is very high. So the soil is very dry, which causes wind erosion and the transport of suspended particles of soil over long distances [41]. Also, the higher concentrations of PM_{10} in summer can be associated with the higher numbers of dust events in this season.

The results are almost consistent with other results regarding PM_{10} assessment in Iranian cities. Masoudi et al. found that the seasonal concentration of the PM10 had the highest values in summer and the lowest in winter [41]. The results in this part are consistent with other results regarding PM_{10} assessment in Iranian cities of Kermanshah [60], Ilam [61], and Bukan in West Azerbaijan Province [62]. In these studies, the reasons for the increase in PM concentration in summer compared to winter were attributed to frequent dust entrance originating from neighboring countries, humidity reduc-

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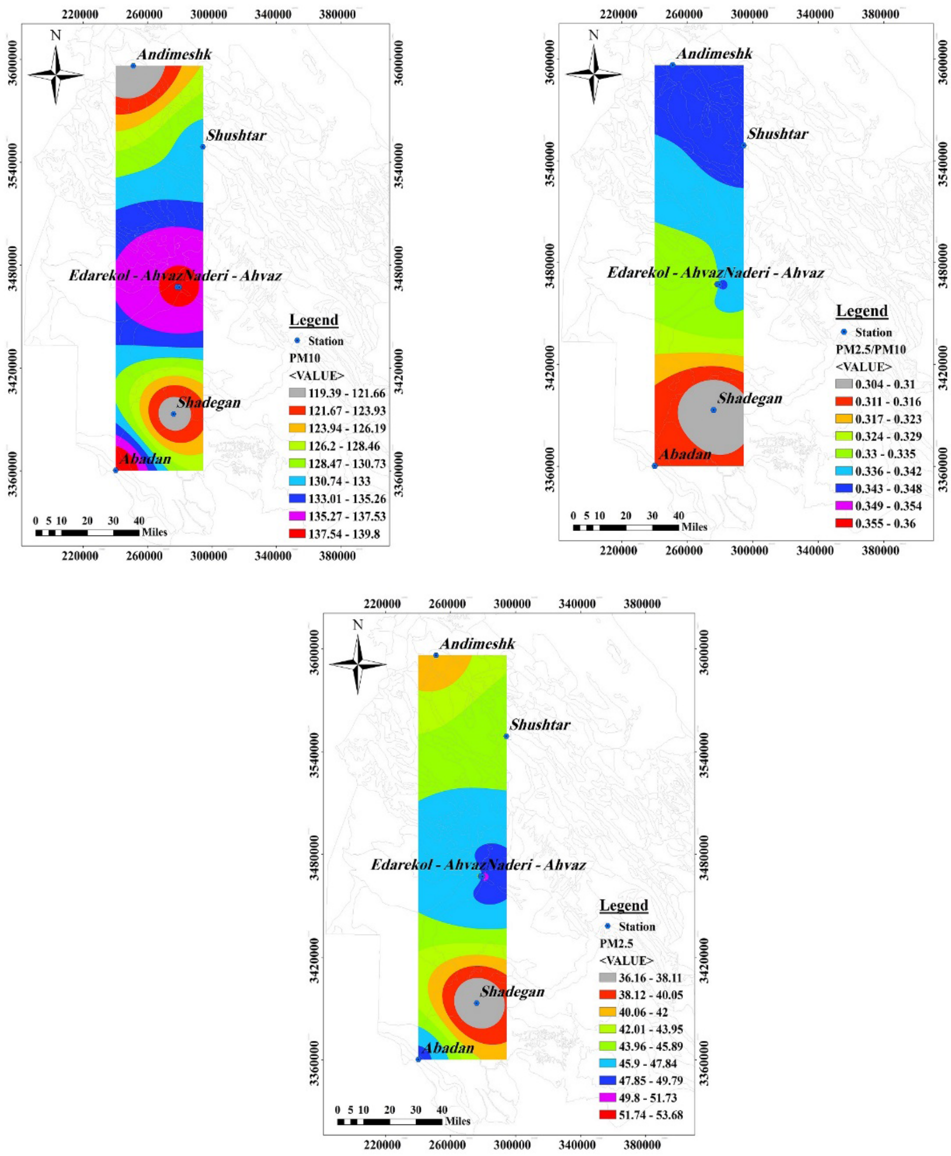

Figure 4. Spatial distribution of annual mean concentrations of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ Ratio in different stations for the entire study period

tion, drought, and the temperature rising, as well as wind speed and direction. In studies performed by Tiwari et al. [10] and Gautam and Brema [28], the higher PM concentration in summer was attributed to dust storm activities this season.

In contrast to these findings, Pandey et al. [24], Trivedi et al. [63], Xu et al. [64], and Kuerban et al. [29] reported that the largest PM concentration was observed in winter and the lowest in summer. The highest values of the $PM_{2.5}/PM_{10}$ ratio were observed in cold seasons (autumn and winter). In another similar study, Xu et al. [65] found that the highest $PM_{2.5}/PM_{10}$ value for winter with 0.75 was 20% more than the minimum ratio of 0.55 obtained for summer in the Wuhan urban area (Central China). Similar findings have been reported by Tiwari et al. whose seasonal $PM_{2.5}/PM_{10}$ ratio calculations showed that the largest value was observed in post-monsoon (0.63) and winter (0.62) [10]. The increase in fine particle emissions and, therefore, this ratio increase in cold seasons could be due to increasing fuel consumption for domestic and industrial heating in these seasons [66].

Relationship Between $PM_{2.5}$ and PM_{10}

To estimate the relationship between various sizes of particulate matter and the impact of seasonal changes on their relationships, the analysis of the linear regression model for $PM_{2.5}$ and PM_{10} was performed. Figure 6 shows the scatter diagrams of the linear regression of $PM_{2.5}$

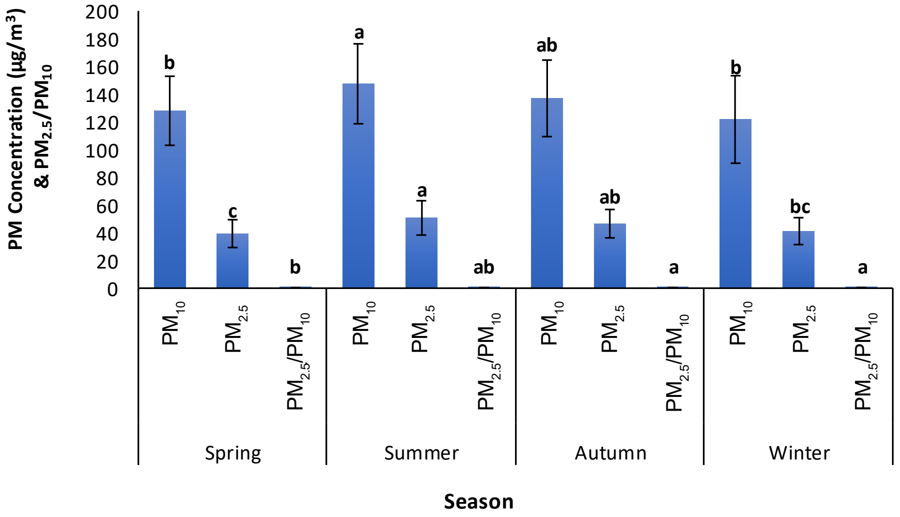

Figure 5. Influence of seasonal variation on PM_{10} and $PM_{2.5}$ concentration (μg/m^3) and $PM_{2.5}/PM_{10}$ ratio at all regions of Khuzestan Province, 2015-2019

Different letters in each column indicate a significant difference between the seasons in terms of mean values of PM and $PM_{2.5}/PM_{10}$ ratio.

against PM_{10} concentration in various seasons. According to Figure 5, the correlation between $PM_{2.5}$ and PM_{10} in different seasons is significant, with the correlation coefficients (R) of 0.66 in spring, 0.61 in summer, 0.56 in autumn, and 0.82 in winter. The correlation between both parameters (PM_{10} and $PM_{2.5}$) in each season can be characterized as shown below.

Spring, Figure 6-A: In this season, the connection between the particles with different sizes (PM_{10} and $PM_{2.5}$) is moderate ($0.5<R<0.7$), and only 40% ($R^2=0.4$) of $PM_{2.5}$ is predictable using the equation.

Summer, Figure 6-B: In this season, similar to the spring season, there is a moderate relationship between the two pollutants ($0.5<R<0.7$), and 37% ($R^2=37$) of particulate matter concentrations are acquired by equation.

Autumn, Figure 6-C: In this season, we also observed a moderate connection between the two pollutants ($0.5<R<0.7$), and 30% ($R^2= 0.3$) of contaminant concentrations were found by the equation .

Winter, Figure 6-D: In this season, there was a reasonably strong connection since $R^2>0.6$. The linear regression showed that 68% of concentration levels follow.

The regression equations obtained in this section indicate that in all seasons of the study period, the PM_{10} concentration increases with increasing $PM_{2.5}$ concentration. The highest correlation (0.82) was obtained between PM_{10} and $PM_{2.5}$ for the winter season, followed by 0.66, 0.61, and 0.51 for spring, summer, and autumn, respectively. These findings indicate that during these four seasons, especially the winter season, either the two PM sizes (PM_{10} and $PM_{2.5}$) have the same resources or are generated by different sources at the same time and place [63]. Similarly, in many other studies, the correlations between different particle sizes have been attributed to common and the same emission resources and occasionally common meteorological influences on concentrations [67-69]. So in the present research, the more significant association between $PM_{2.5}$ and PM_{10} in the winter than other seasons can be due to emissions of these pollutants from similar sources in this season [2, 63]. On the other hand, less correlation between PM_{10} and $PM_{2.5}$ in other seasons may be because, in these seasons, PM_{10} originates more from dust storms and $PM_{2.5}$ from industrial and transportation activities.

Spatial and temporal variation characteristics of aqi and the corresponding air quality condition

Figure 7 displays the spatial and temporal variations of AQI and the corresponding air quality condition based on the average method at the different locations over the 5 years (2015 to 2019). Comparing the spatial and temporal variations of the AQI (according to the ANOVA test) showed significant differences between different years of the study period ($P<0.05$) (Figure 8). However, AQI variations were not significantly different between different cities ($P>0.05$). Although the highest mean of AQI was observed in Naderi and Abadan and the lowest in Andimeshk and Shadegan stations, their difference

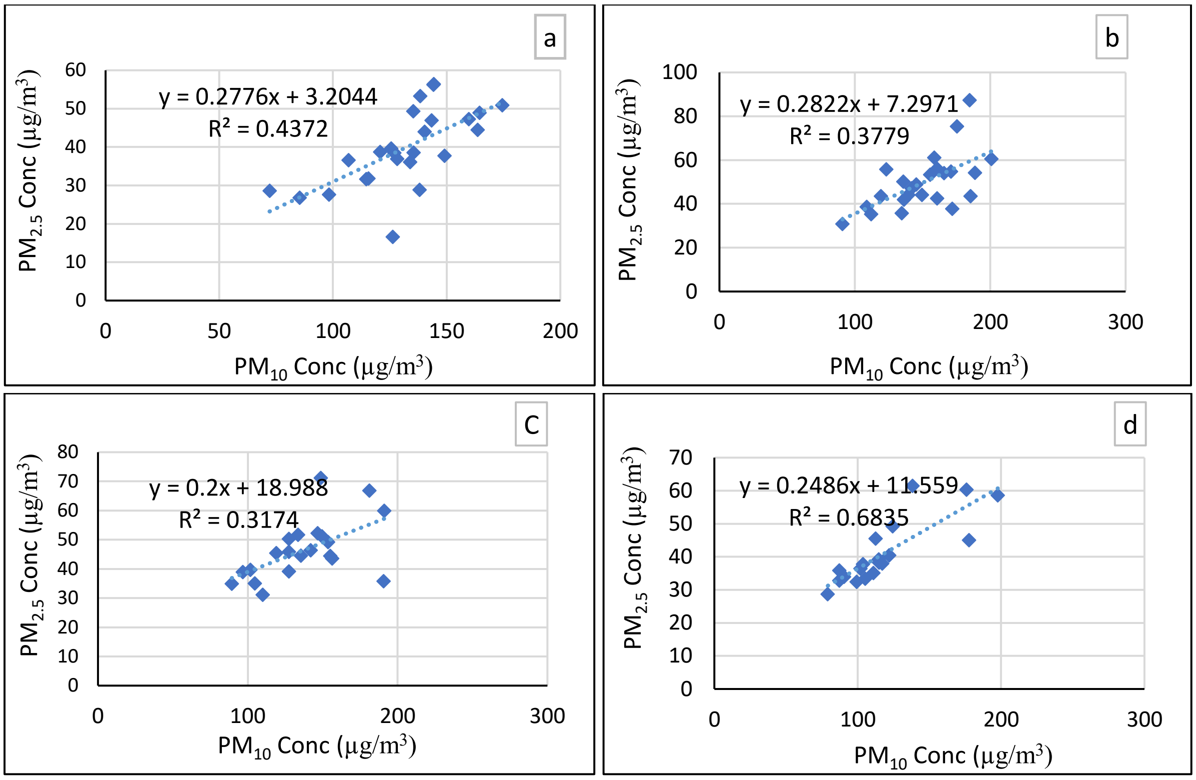

Figure 6. Linear regression between $PM_{2.5}$ and PM_{10} during different seasons

A= Spring; B=Summer; C=Autumn; and D=Winter.

was not significant. According to the results of checking the air quality condition in Figure 6, all regions experienced severe air pollution during the study period. Only in 2019, Naderi, Ahvaz, and Abadan areas show moderate to heavy air pollution status.

The trend analysis of the annual average AQI in different regions of Khuzestan Province shows that the AQI in this province is high. During the study period from 2015 to 2019, the AQI was higher than 100, indicating severe air pollution in this province. Specifically, during these 5 years of study, air pollution was significant in 2016 and 2017, with a Mean±SD AQI of 180.42±17.91 and 180.85±11.52, respectively. In later years (2018–2019), the amount of AQI has decreased; however, the value of AQI in the past two years is still more than the standard to achieve excellent quality, where AQI<50. This decrease can be attributed to the environmental protection measures such as controls on emissions from various industries, fossil fuel consumption, and other actions in recent years in this province.

The highest Mean±SD of AQI was observed in Naderi (176.53±24.88) and Abadan (173.98±24.88). Ahvaz and Abadan cities face major air pollution issues due to the high population density and many vehicles and industries compared with other study regions. Dadhich et al. [4] conducted a study on temporal and spatial changes in the air quality of Jaipur City (India) from 2004 to 2015. They found out that AQI calculation indicates that the urban areas of Kishanpole, Hawa Mahal, faced severe air pollution problems due to the high density of population and motor vehicles. Moreover, Lin and Zhu [70] examined the affecting factors on air quality. Their results confirmed that the factors such as population density, energy consumption, and industrialization could deteriorate air quality in China. In addition, the results of a study performed by Dai and Yi in the assessment of spatial and temporal variations and affecting factors on air quality in Chinese cities indicated that AQI could also be affected by topographic, meteorological, and socioeconomic factors [71].

Spatial and temporal variation characteristics of AQI and the corresponding health effects

The annual variation of AQI and the corresponding health effects during the study period (2015–2019) for all regions are summarized in Figure 8. Assessment of the ambient air quality levels regarding PM_{10} and $PM_{2.5}$ and the related health impacts indicates that the AQI values were in the unhealthy category at different stations from

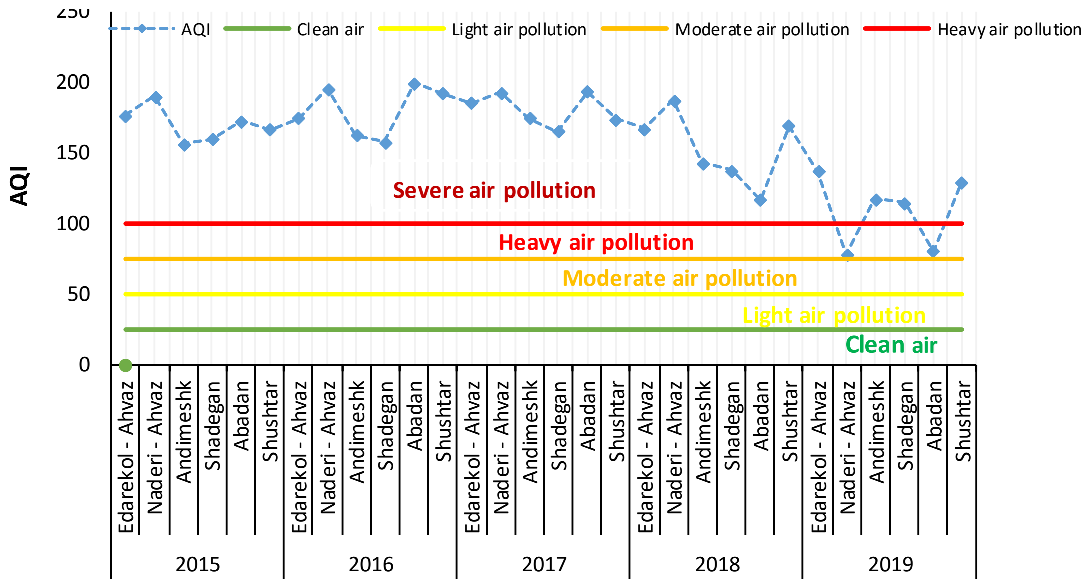

Figure 7. Annual variations of air quality index and the corresponding air quality condition based on average method at the different regions of Khuzestan Province, 2015-2019

2015 to 2017. In 2018 and 2019, the AQI categories regarding PM were frequently "unhealthy" to "unhealthy for sensitive groups" and "moderate" to "unhealthy for sensitive groups", respectively, at the different locations. Calculating the AQI levels and assessment of the corresponding health effects in different regions from 2015 to 2019 indicates that although air quality improves from 2015 to 2019, the values of AQI are still more than the standard to achieve excellent quality (AQI<50). In 2017, Dastoorpoor et al. [72] reported that according to the AQI in relation to PM10 in Ahvaz during the study period, only in 2.1% of the days, the Ahvaz air was clean (0-50). Also, in 15.7, 26.5, 20.8, 17.1, and 10.7% of the days, the air quality was "moderate", "unhealthy for sensitive groups", "unhealthy", "very unhealthy", and "hazardous", respectively. In this study, based on the AQI and the corresponding health effects, on most days, the air quality was "unhealthy" and "unhealthy for sensitive groups", which is almost consistent with the present research findings. Therefore, the computed AQI values clearly show the alarming air quality in the urban regions of Khuzestan Province, especially Ahvaz and Abadan.

According to Figure 9, the spatial variation of AQI values at different selected locations during 2015-2019 can be observed. Based on these figures, significant annual variation could be easily identified.

Analysis of Correlation Between AQI, $PM_{2.5}$, and PM_{10}

To further examine the relationship between AQI and $PM_{2.5}$ and PM_{10}, their linear relations were examined. Figure 10 illustrates the relationship between PM concentrations and AQI. As seen in Figure 10-A and Figure 10-B, AQI has a significant positive relationship with $PM_{2.5}$ and PM10 (R^2=0.8259, P<0.01; R^2=0.7934, P<0.01). In general, the relationship between AQI and $PM_{2.5}$ was slightly better. The relationship between AQI and PM concentrations illustrated that the fine particle contamination of different cities of Khuzestan had significant air quality impacts. Similarly, Wang et al. [73] evaluated the AQI variation trend and its possible relationship with $PM_{2.5}$ and PM_{10} in the Beijing-Tianjin Hebei area from July 2015 to 2018. According to their findings, a significant positive correlation can be seen between AQI and $PM_{2.5}$ and PM10 (R^2 was 0.8225 and 0.7749, respectively, P<0.01) and PMs (PM_{10} and $PM_{2.5}$) showed a larger impact on the air quality of Beijing-Tianjin-Hebei. Furthermore, in a research conducted by Zhao et al. [57], the Spearman correlation analysis revealed a significant positive correlation between the $PM_{2.5}/PM_{10}$ ratio and the AQI value, and $PM_{2.5}$ contributed to more reduction in air quality than PM_{10} (especially in winter).

Spatial and temporal variation characteristics of Exceedance Factor (EF)

Spatial-temporal changes of EF of PM_{10} and $PM_{2.5}$ at the different regions of Khuzestan Province during the

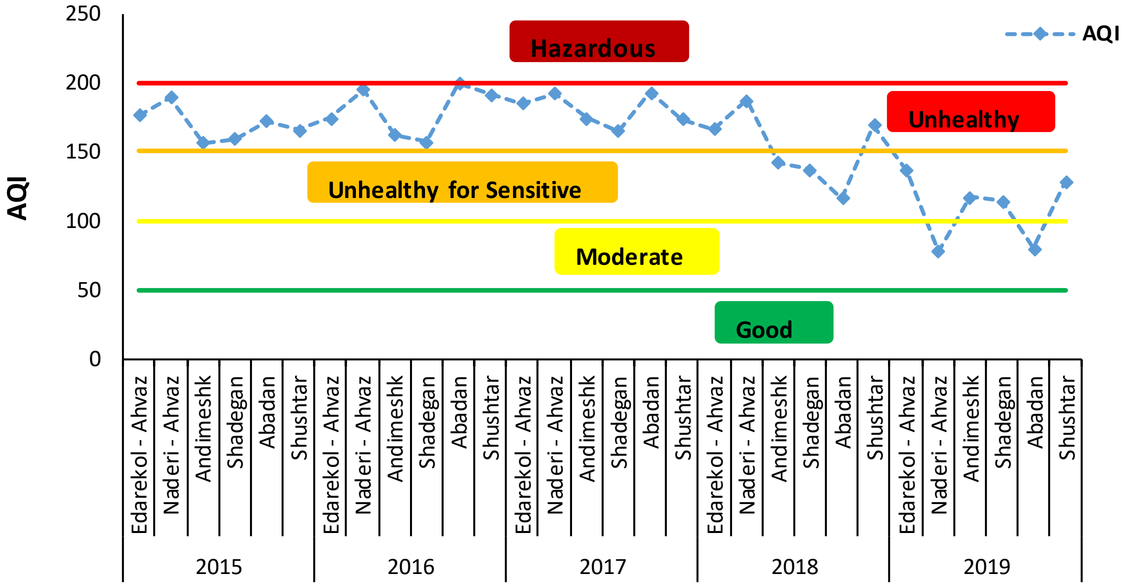

Figure 8. Annual variations of air quality index and the corresponding health effects based on average method at different regions of Khuzestan Province, 2015-2019

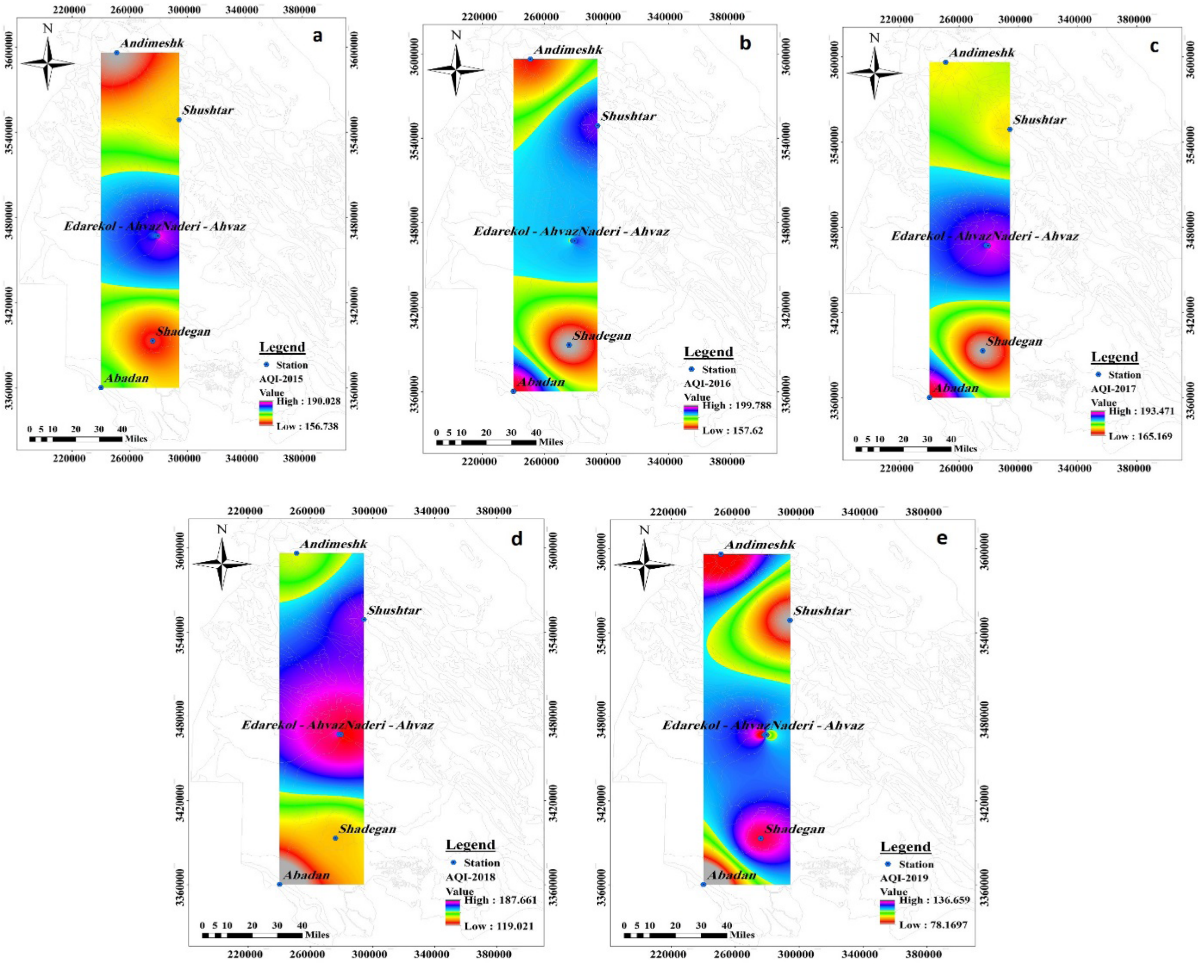

Figure 9. Spatial distribution of the Air Quality Index (AQI) in 6 regions of Khuzestan Province

A: 2015; B: 2016; C: 2017; D: 2018; and E: 2019.

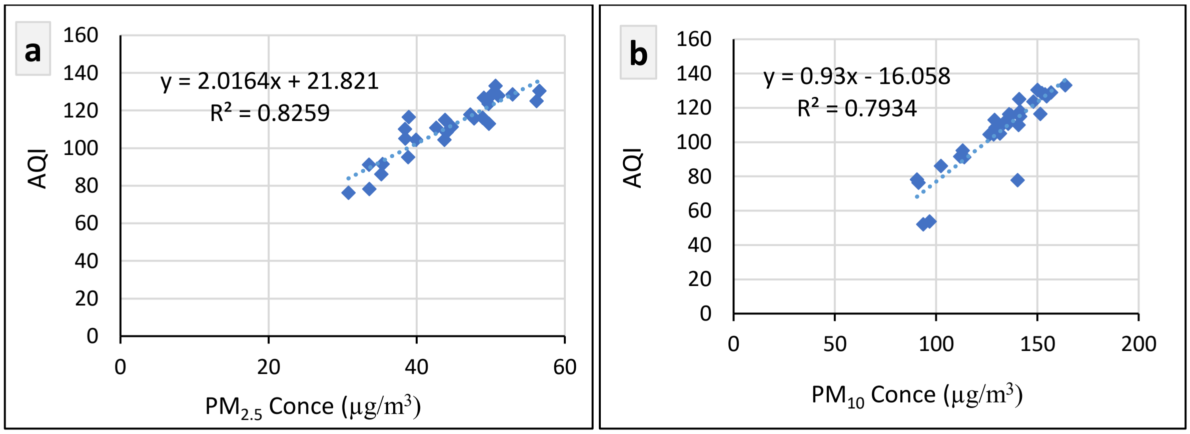

Figure 10. Linear fitting of AQI with $PM_{2.5}$ and PM_{10}

study period (2015 – 2019) are shown in Figure 11. The results showed that the EF of PM_{10} in the different years of the study period was between 1.51 and 2.73, and there was a significant difference between the years in relation to EF of PM_{10} ($P=0.001$). But in terms of spatial variation of EF (PM_{10}), no significant difference was found between different stations ($P>0.05$).

The EF values of $PM_{2.5}$ for all study years ranged from 0.77 to 1.41. A significant difference in EF ($PM_{2.5}$) was seen between the stations ($P<0.05$), with the highest concentrations in the Naderi station in Ahvaz and Abadan. Comparing the temporal variations of EF ($PM_{2.5}$) showed a significant difference in EF values of $PM_{2.5}$ among the different years of the study period ($P<0.05$), with the highest in 2017 and 2016 and lowest in 2019.

Comparison of air quality categories based on EF of PM pollutants at all sampling stations over the entire study period revealed that the EF of PM_{10} was higher than the factors defined by the CPCB for critically polluted regions (EF>1.5). Still, the observed EF of $PM_{2.5}$ pollutant varied from the highest pollution ($1.0\leq EF<1.5$) to moderate pollution ($0.5\leq EF<1.0$) (Figure 12). The results of this section indicate that these pollutants (spatially PM_{10}) are responsible for high or critical pollution, which considerably leads to the deterioration of air quality in all studied regions. Similarly, Robert and Pirro [74] assessed the ambient air quality status in ma-

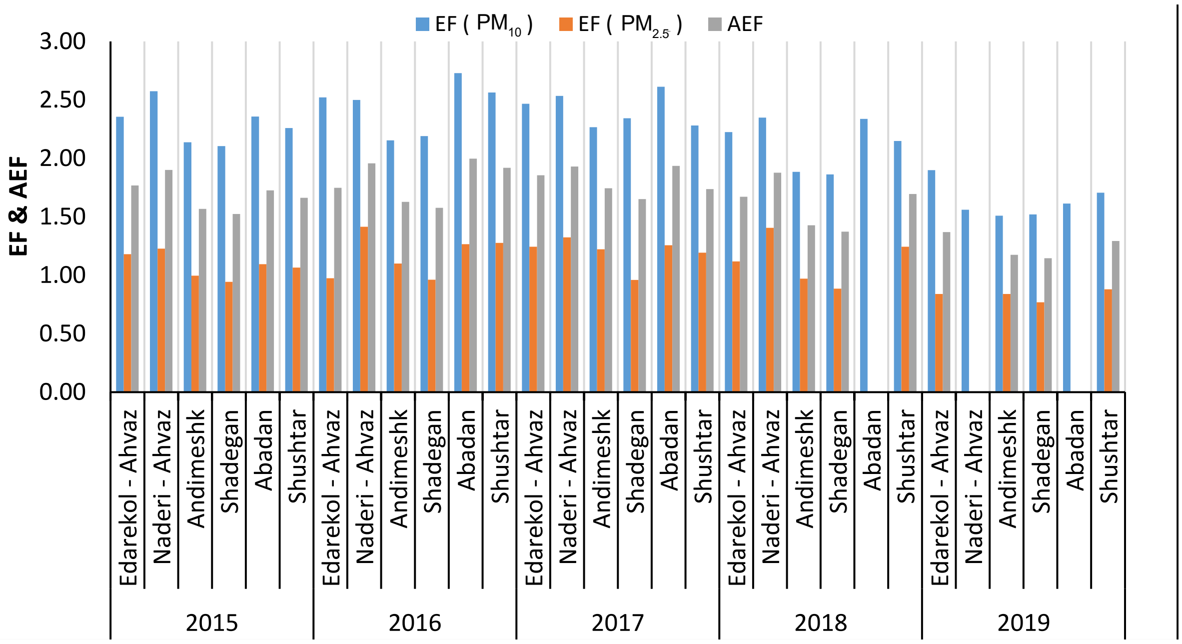

Figure 11. Annual trends of urban ambient air quality based on exceedance factor method at different regions of Khuzestan Province, 2015-2019

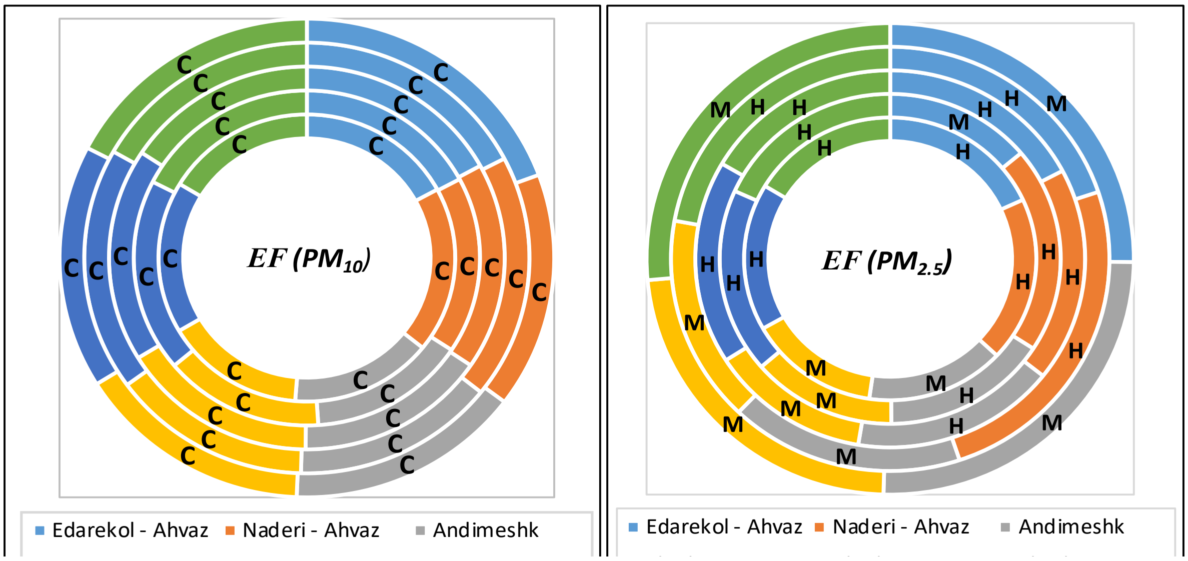

Figure 12. Annual variations of air quality categories based on EF at different regions, 2015-2019

EF categories: L= Low Pollution; M =Moderate Pollution; H= High Pollution; C= Critical.

jor cities of Albania based on EF. They found that the PM_{10} and Suspended Particulate Matter (SPM) are the most important polluting factors which must be carefully examined. In addition, Banerjee and Srivastava [43] reported that the EF values for certain pollutants showed that respirable suspended particulate matter (RPM) with an EF value of 1.14 is the main contaminant responsible for the deteriorating air quality at Integrated Industrial Estate-Pantnagar (IIE-Pantnagar) and SPM with an EF of 0.78 is responsible for creating moderate contamination. According to the results, the mean values of AEF at all regions of Khuzestan during the study period were higher than 1, and the AEF value of 1 is the threshold limit of a contaminant or a group of contaminants.

4. Conclusion

This investigation was performed to understand the spatiotemporal characteristics of air quality and the PM pollutants that affect the AQI in different cities of Khuzestan Province in recent years (2015-2019). Although the annual mean concentrations of $PM_{2.5}$ and PM_{10} indicate a gradual decline trend in the PM pollutants, the obtained AQI and EF values suggest that ambient air quality of urban regions of Khuzestan is still far from the standards for good quality and low pollution. The performed linear regression of AQI with PMs ($PM_{2.5}$ and PM_{10}) and air quality assessment based on EF demonstrates that PMs pollutants are responsible for high or critical pollution, which significantly deteriorate air quality in all studied regions. The obtained results also revealed that inconsistent pollution levels in different cities (i.e., Ahwaz and Abadan were the most polluted) could be due to varying levels of human activities, which makes it necessary to monitor and control these cities even more.

Finally, based on the assessment of spatial and temporal changes of air contaminants, it is possible to manage the air pollution in the studied areas using a scientific basis since these areas need urgent action to control these pollutions. The current investigation provides a good insight for urban contamination control in Khuzestan Province and can act as a basis for further studies and a guide to enforce required regulations by relevant authorities. Based on the obtained results, a region-oriented emission management approach is required to support further air quality improvement in Khuzestan Province. It must be mentioned that the performed investigation has some limitations and shortcomings.

First, the level of atmosphere contamination in urban regions is shown according to the average point-monitored concentrations in the area, which may cause extrapolation errors. Second, air quality can be affected by different factors such as meteorological conditions (relative humidity, temperature, and wind speed), the topographic status of the area (such as elevation and vegetation coverage), human activities, socioeconomic factors, and even health challenges (e.g., COVID-19 pandemic). These factors affect the quantitative analysis of air quality in the present research. In other words, any efficient contamination management requires evaluating spatiotemporal changes of PMs and determining their relationship with these parameters. In addition, there is a necessity for future studies to combine remote-sensed and ground-monitored data to manage extrapolation errors and investigate associations between air contaminants and other factors for more urban regions.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles such as the informed consent of the participants, the confidentiality of information, the permission of the participants to cancel their participation in the research are considered in this article.

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Authors' contributions

Conceptualization and supervision: Nasrin Hassanzadeh; Writing – original draft: Fariba Hedayatzadeh; Writing – review & editing: Nasrin Hassanzadeh; Data collection, data curation, and data analysis: Fariba Hedayatzade; Validation: Nasrin Hassanzadeh; Methodology and funding acquisition and resources: All authors.

Conflict of interest

The authors declared no conflict of interest.

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