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Temporal trend of dust storm events and particulate matter ($PM_{2.5}$ and PM_{10}) in Iran's metropolises, 2011-2022

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ABSTRACT

Introduction: This study investigates the temporal trends of Sand and Dust Storms (SDS) and Particulate Matter ($PM_{2.5}$ and PM_{10}) concentrations across nine major Iranian cities from 2011 to 2022, assessing long-term air pollution patterns and associated environmental challenges.

Materials and methods: PM concentration data were obtained from air quality monitoring stations. Dust storm events were identified using World Meteorological Organization (WMO) criteria. The primary objective was to analyze spatiotemporal variations and trends, which were statistically assessed using Sen's slope method.

Results: PM_{10} levels consistently exceeded WHO annual guidelines by 2.13 to 12 times, while $PM_{2.5}$ levels were 1.37 to 6.89 times higher. Ahvaz recorded the highest cumulative SDS hours (25,318), followed by Yazd (10,062) and Tabriz (9,609), with annual stormy days reaching up to 66. The most pronounced increases in PM_{10} occurred in Ahvaz, Yazd, and Tabriz. Maximum annual PM_{10} concentrations were observed in Ahvaz (179.8 μg/m^3 in 2013) and Yazd (135.85 μg/m^3 in 2022), whereas peak $PM_{2.5}$ levels were reported in Ahvaz (57.2 μg/m^3 in 2022) and Shiraz (43.37 μg/m^3 in 2019).

Conclusion: The escalating intensity and frequency of SDS are linked to regional climate variability, drought, and land degradation. The findings underscore an urgent need for comprehensive mitigation strategies, including desertification control, sustainable land management, and enhanced regional cooperation to address these critical environmental and public health challenges.

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Introduction

Sand and Dust Storms (SDS) are meteorological phenomena characterized by strong winds that suspend dust and sand particles into the atmosphere, significantly reducing horizontal visibility to less than 1 kilometer and intensifying air pollution [1-3]. These events predominantly occur in arid and semi-arid environments with dry sediments and sparse vegetation, where particles originating from desert regions represent a major component of tropospheric aerosols [4-8]. Recent investigations emphasize SDS as a major global environmental issue with marked implications for climate change [9, 10].

Wind systems transport soil particles including clay, silt, and sand across extensive distances. Saharan dust, for example, has been shown to affect atmospheric conditions in Northern Europe, the Americas, and Asia, particularly in the Middle East [8, 11-14] The heterogeneous sources of these meteorological disturbances, characterized by particles of disparate dimensions and compositions, present significant obstacles for both global and localized methods of dust identification. Furthermore, the dynamics of suspended particulates, which comprise various soil constituents and sizes, further exacerbate the complexities associated with dust storm phenomena in the atmosphere [15-18]. These particulates have a substantial impact on the climatic conditions of Earth, specifically regarding their effect on radiative forcing. Atmospheric dust modulates air temperature by reducing the incidence of solar short-wave radiation while enhancing the emission of long-wave radiation from the surface [19-22]. This phenomenon alters the spectral and microphysical properties of clouds, affecting parameters such as the effective radius of cloud droplets, nucleation density, and the total number of cloud droplets [23]. as well as resulting in variations in precipitation pattern [24], decreases in agricultural productivity [25, 26], and heightened risks to public health by aggravating respiratory conditions and facilitating the spread of infectious diseases through airborne pathogens [27, 28].

The Middle East, comprising some of the world's most extensive arid regions, is one of the largest contributors to global dust emissions [29-31] Recent research indicates a rising trend in SDS occurrences throughout the Middle East over the past decade, which is expected to intensify under projected climate change scenarios [32-35]. In the last few years, extended periods of drought, water scarcity, and considerable variations in precipitation patterns have been documented at a regional level in Kuwait [36], southern Iraq [37] , and Iran [38]. In addition, Saudi Arabia, Central Asia, China, both North and South America, and Australia, constitute significant contributors to the production of SDSs, with the MENA (Middle East and North Africa) [39] region being recognized as the most arid and dust-laden area on the planet, accounting for 24% of the global dust emissions [40].

Iran has experienced a significant increase in SDS occurrences in recent years [41, 42] A detailed examination of the frequency of SDSs indicates a marked increase in Iran, with the number of SDS days increasing from 150 occurrences in 1991 to 550 occurrences in 2013, as documented by the National Drought Warning and Monitoring Center in 2014 [41, 43, 44].

This research focuses on examining air quality indicators in nine major Iranian cities (Tehran, Ahvaz, Ilam, Kermanshah, Mashhad, Shiraz, Tabriz, Yazd, and Zahedan) between 2011 to 2022. It further explores variations in $PM_{2.5}$ and PM_{10} concentrations and the frequency of SDS events during this period.

Materials and methods

Study area

As illustrated in Fig. 1 this study analyzes fluctuations in ambient air particulate matter ($PM_{2.5}$ and PM_{10}) levels, along with the frequency of dust storms, from 2011 to 2022 across nine of the most densely populated urban centers in Iran.

Air quality data

This research utilized hourly concentration datasets of $PM_{2.5}$ and PM_{10} spanning the years 2011 to 2022 in all identified urban locales (refer to Fig. 1), which were obtained from fixed air quality monitoring stations. The data employed in this analysis for all cities were derived from the National Air Quality Monitoring System, which belongs to the Iranian Department of Environment (DoE) [45].

In Tehran, data from 16 air quality monitoring stations were utilized. Additionally, data from 24 monitoring stations operated by the Tehran Air Quality Control Company (AQCC), which functions under the supervision of Tehran Municipality, were incorporated. The method used in the monitoring stations of both organizations is the beta-attenuation method, including the Met One BAM-1020 from the USA and the Environment SA MP 101 M from France [46-48].

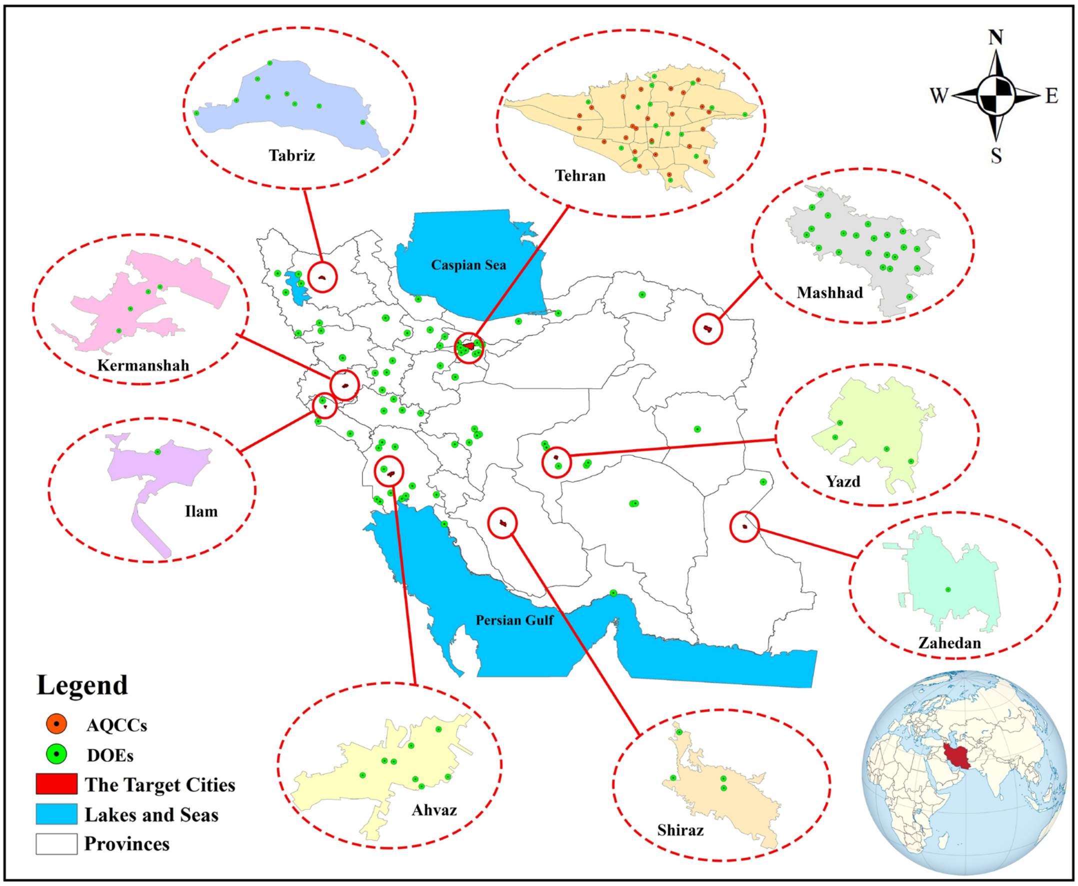


Fig. 1. The location of the cities under study and the air quality monitoring stations in the studied areas

Data processing

Data from all monitoring stations were compiled for each city. Null and negative values for all pollutants were removed, and hourly PM_{10} concentration values exceeding 5000 µg/m³ were removed as outliers [49]. We calculated $PM_{2.5}/PM_{10}$ ratios to ensure data quality, discarding values where $PM_{2.5}$ exceeded PM_{10}, as these are physically unrealistic. In the next phase, the number of hourly data for each station was determined for both pollutants for each year. In addition, stations with at least 50 percent hourly data were recognized as valid stations (4380) and included in the study [50-52] Less than 1% of all original data was excluded during quality control.

The research conducted a comprehensive examination of yearly trends in PM_{10} and $PM_{2.5}$ concentration levels spanning a period of twelve years for each urban area, employing the slope-sen methodology, a non-parametric method utilized for estimating the slope of a regression line, which is based on the least squares criterion. Sen's slope is estimated by computing the slopes between all possible pairs of data points within a time series and then determining the median of these computed slopes. This method is robust against outliers and deviations from normal data distributions [53, 54].

Dust storm identification

The dynamics of fluctuations in $PM_{2.5}$ and PM_{10} concentrations across various urban locales have been analyzed, and the trajectory of these fluctuations in terms of the mean concentration, 90th percentile, and 10th percentile over a twelve-year span for the years with accessible data has been graphically represented (Fig. 2).

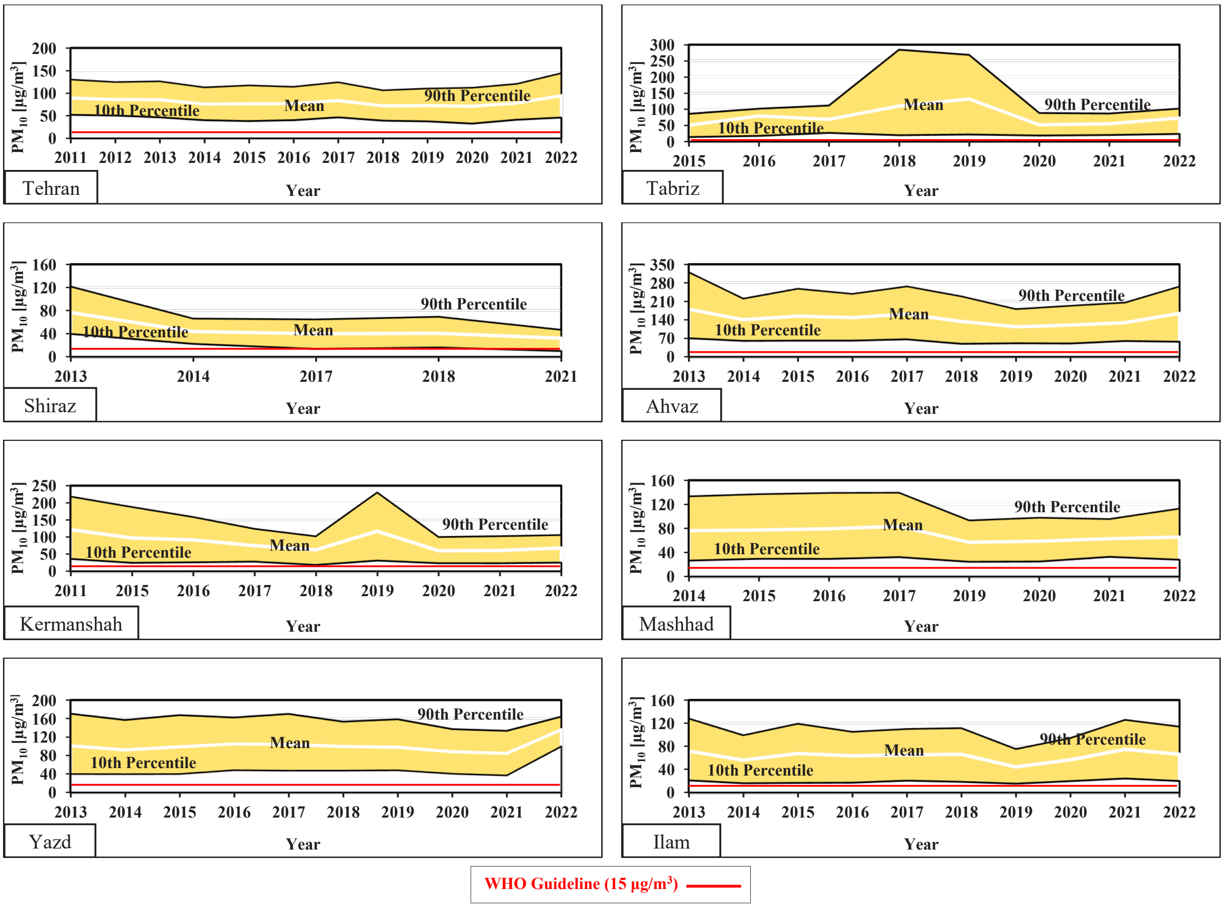


Fig. 2. The trend of PM_{10} concentration changes from 2011 to 2022, broken down by each city (µg/m³)

Note: Zahedan possessed related data solely for the years 2017 and 2018; so, the trend chart for this city has not been generated.

A two-phase methodology was used to identify dust storm hours. In the first phase, hourly concentrations from all monitoring stations for each pollutant were independently averaged into a hypothetical representative station for each city. Subsequently, in the next phase, the characterization of dust storm events was established in compliance with WMO standards and parameters including the $PM_{2.5}$/PM_{10} ratio. Specifically, for PM_{10}, hourly levels surpassing 150 μg/m^3 were regarded as indicative of an hourly dust storm occurrence [55]. Furthermore, the ratio of hourly $PM_{2.5}$ to PM_{10}, being less than 0.2 , was employed as a supplementary criterion to indicate the occurrence of hourly dust storms [55], and the total number identified by these two criteria was recognized as the number of stormy hours. Moreover, a 24-hour mean PM_{10} concentration exceeding 255 μg/m^3 (classified as detrimental to public health) signified a day characterized by a daily dust storm event [56].

Results and discussion

Iran, located in the arid belt, has approximately 50% of its land covered by deserts [57-59],which significantly contribute to particulate matter emissions, particularly desert dust [60]. Due to its geographical location and prevailing wind patterns, Iran experiences frequent dust storms originating from both domestic and external sources [61, 62].

Data availability and coverage

A total of 93 air quality monitoring stations were operational in the cities examined with valid data recorded 831 times over the 12-year study period. Among these, 463 stations were associated with $PM_{2.5}$ and 368 with PM_{10} pollutants. Furthermore, with the exception of the year 2012, when several cities lacked reliable data, an annual assessment for a total of 9 cities under investigation revealed the identification and analysis of at least 10 and up to 59 valid monitoring stations for the $PM_{2.5}$ pollutants, alongside a maximum of 44 and a minimum of 16 stations for the PM_{10} pollutant (Fig. 1).

The highest concentration at valid monitoring stations was recorded in the last three years of the study, suggesting that the organizations responsible for air pollution monitoring in these urban areas had become more effective during this period. Furthermore, the focus on this data is particularly more evident in highly populated cities, such as Tehran, Mashhad, Ahvaz, and Tabriz, in comparison to other municipalities examined in the study (Fig. 1).

Annual and daily trend of $PM_{2.5}$ and PM_{10}

Across various urban centers and years, Ahvaz, Yazd, Tabriz, and Kermanshah emerged as the most severely polluted cities regarding PM_{10} pollution, exhibiting annual mean concentrations of 179.8, 135.85, 131.69, and 121.46 μg/m^3 for the years 2013, 2022, 2019, and 2011, respectively. Additionally, Shiraz, Ilam, Tabriz, and Mashhad exhibited annual average PM_{10} concentrations of 27.7, 44.18, 50.51, and 56.88 μg/m^3 during the years 2021, 2019, 2011, and 2019 respectively, categorizing them among the municipalities with the most minimal PM_{10} pollution levels within the analyzed cities (Table 1).

Regarding $PM_{2.5}$ pollution, Ahvaz, Shiraz, Tehran, and Tabriz exhibited the highest annual mean concentrations at 57.2, 43.37, 39.27, and

35.44 μg/m^3 in 2022, 2019, 2013, and 2022, respectively. Kermanshah, Tabriz, Ilam, and Mashhad recorded the lowest $PM_{2.5}$ annual averages at 16.5, 18.47, 22.62, and 24.92 μg/m^3 during 2021, 2019, 2019, and 2015, respectively.

The annual average concentrations of PM_{10} and $PM_{2.5}$ in nine cities over a twelve-year period consistently exceeded World Health Organization guidelines and Iran's national standards. PM_{10} concentrations were 2.13 to 12 times above the WHO guideline threshold (15 μg/m^3), while $PM_{2.5}$ concentrations were 1.37 to 6.89 times above the guideline limit (5 μg/m^3) and 3.3 to 16.55 times above the national standard (12 μg/m^3). This disparity between environmental conditions and clean air benchmarks poses a significant public health risk.

Daily PM_{10} and $PM_{2.5}$ concentrations in urban areas ranged from 5.01 to 1464 μg/m^3 and from 5.15 to 405.54 μg/m^3, respectively. Additionally, the hourly measurements ranged from 5 to 1500 μg/m^3 for PM_{10} and from 5 to 698 μg/m^3 for $PM_{2.5}$, following the elimination of incorrect data and periods lacking recorded information.

Tabriz recorded the highest daily average PM_{10} concentration in the spring of 2016, while Ahvaz had the highest $PM_{2.5}$ concentration in the spring of 2022. Moreover, the lowest average daily concentrations of PM_{10} and $PM_{2.5}$ were observed in Ilam during the spring of 2017 for PM_{10}, and in Kermanshah during the autumn of 2021 for $PM_{2.5}$, respectively.

The cities of Yazd, Ahvaz, and Tehran were found to have the highest daily PM_{10} pollution levels, with Yazd having 365 days in 2022, Ahvaz having 360 days in 2021, and Tehran having 350 days in 2011 and 2012, exceeding the new WHO daily average concentration guideline (45 μg/m^3). Moreover, Shiraz in 2021, Tabriz in 2015, and Ilam in 2019 had the lowest daily PM_{10} pollution levels, with Shiraz, Tabriz, and Ilam having 16, 94, and 134 days of pollution, respectively.

For $PM_{2.5}$, Tehran (2013, 2014), Ahvaz (2021), and Mashhad (2017) had the highest number of days exceeding the WHO guideline (15 μg/m^3) at 365, 361, and 359 days, respectively. Kermanshah, Tabriz, and Yazd had the fewest days exceeding the daily $PM_{2.5}$ concentration values in 2021, 2013, and 2022. Ahvaz in 2014, like Yazd, had the fewest days above the average daily $PM_{2.5}$ concentration, but in that year, it exceeded the WHO guideline values for all days with $PM_{2.5}$ data, indicating a critical situation in this regard.

Even cities with relatively lower pollution levels, such as Shiraz and Kermanshah had days with daily mean concentrations exceeding the recommended threshold for PM_{10} and $PM_{2.5}$. Shiraz had permissible days four times higher than the guideline, while Kermanshah had 29 times more than WHO recommendations. This highlights the poor air quality in all nine cities.

Fig. 3 shows the trend of $PM_{2.5}$ concentration changes from 2011 to 2022, broken down by city (μg/m^3).

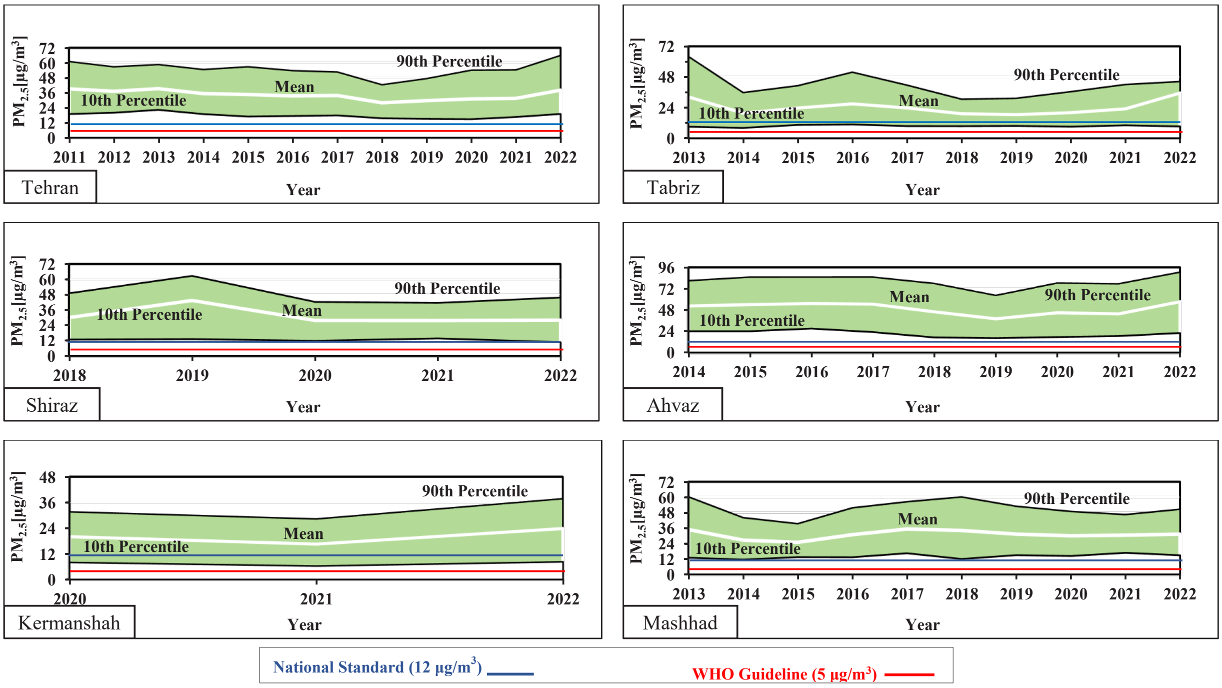


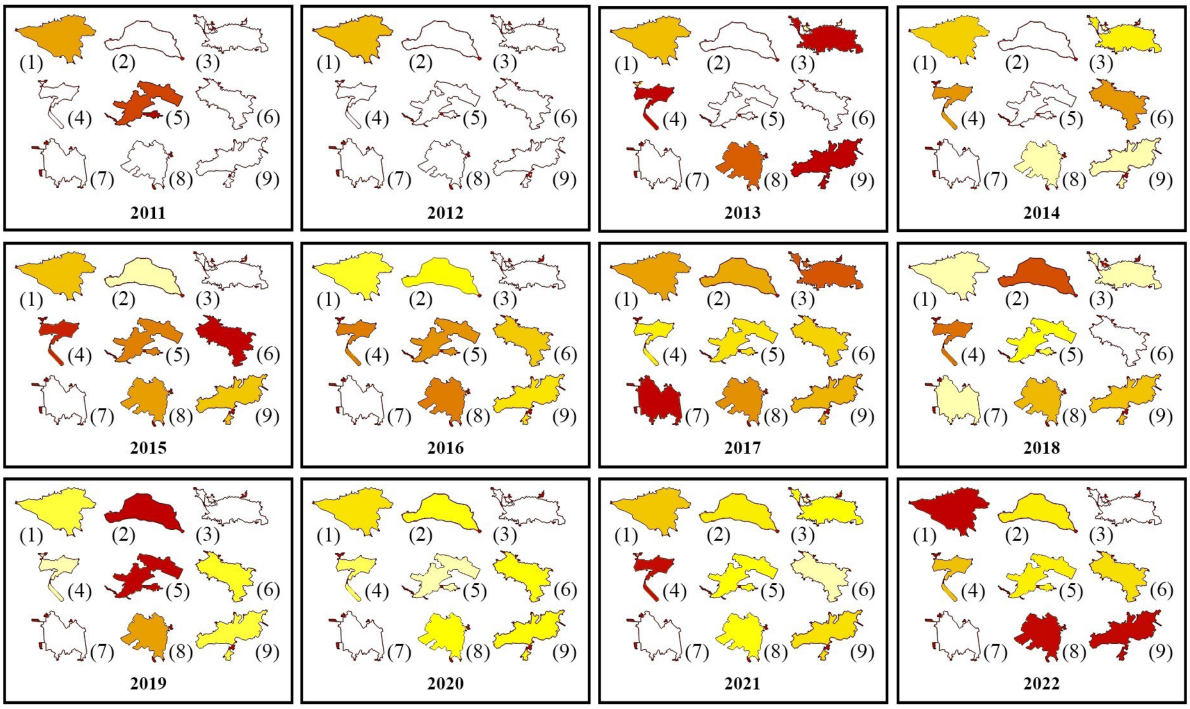
Fig. 3. The trend of $PM_{2.5}$ concentration changes from 2011 to 2022, broken down by city [$\mu g/m^3$]

Note: Yazd and Ilam possessed related data solely for 2022 and 2019, respectively, while Zahedan lacked relevant data on hourly monitored $PM_{2.5}$ concentrations; so, trend graphs were not generated for these cities.

Temporal Trends in SDS Hours and Days The cumulative number of dust storm hours was analyzed across metropolitan areas, with annual occurrences ranging from 22 to 3,588 hours. The annual occurrence ranged from 22 h to 3,588 h, with Ahvaz recording the highest total of 25,318 storm hours during a 12-year study. Also, at least 22% of Ahvaz's hours annually are affected by dust storms, indicating a severe environmental issue Fig. 4.

Yazd (10,062 h) and Tabriz (9,609 h) are the two urban areas with the highest stormy hours, accounting for 12.5% and 14.8% of the total hours with data, respectively. Additionally, Shiraz recorded 22 h of storms in 2018, which is equivalent to 2.2% of the total hours with data, but due to the irregular distribution of data, analyzing the trend of storm hours is impossible. However, in general, Shiraz is significantly affected by local and regional dust storms due to its proximity to low-pressure systems, central atmospheric circulation, and air masses from northwestern Iraq and eastern Syria [63].

Tabriz, Ilam, and Tehran had the lowest SDS hours with 71, 73, and 119 h in 2015, 2019, and 2018, respectively. However, Ilam, Tehran, and Mashhad had the least stormy hours, with 3,697, 3,891, and 6,587 h respectively. These cities had proportions of hours characterized by storm data of 4.46%, 3.69%, and 9.87%, respectively. In Tehran, the Bus Rapid Transit (BRT) and Low Emission Zones (LEZ) have helped reduce PM_{10} pollution and SDS in the first half of a 12-year evaluation period. However, factors like motor vehicle degradation, traffic escalation, and population growth along with thermal inversion and wind patterns may influence the trend in the second half [64].



An overview of the number of SDS hours throughout the years 2011 to 2022									
Year	Tehran [1]	Tabriz [2]	Shiraz [3]	Ilam [4]	Kermanshah [5]	Mashhad [6]	Zahedan [7]	Yazd [8]	Ahvaz [9]
2011	398	ND	ND	ND	1470	ND	ND	ND	ND
2012	344	ND	ND	ND	ND	ND	ND	ND	ND
2013	335	ND	364	570	ND	ND	ND	1289	3588
2014	297	ND	47	380	ND	1270	ND	557	1856
2015	328	71	ND	528	1107	2867	ND	1038	2464
2016	179	489	ND	412	994	741	ND	1166	2294
2017	400	1447	253	265	492	650	669	1087	2562
2018	119	2465	22	429	324	ND	514	933	2476
2019	169	3361	ND	73	1893	181	ND	1030	2050
2020	256	444	ND	160	294	195	ND	655	2164
2021	317	671	30	556	324	155	ND	651	2313
2022	749	661	ND	324	418	528	ND	1656	3551

Fig. 4. The trend of changes in the number of stormy hours from 2011 to 2022 by city. (ND: NO DATA)

The frequency of stormy days varied across cities over the twelve-year period, with each city exhibiting a distinct pattern of occurrence (Fig. 5). The annual count of stormy days ranged from zero to a maximum of 66 days in Ahvaz in 2013, attributed to the variability of concentration levels over the 24-h period, indicating the irregular pattern of dust events and the lack of sustained continuity.

In general, the incidence of dust storms in Iran has markedly escalated from the northern to the southern regions [65]. However, Ahvaz, Tabriz, and Kermanshah experienced the highest frequency of stormy days over a 12-year period, with 267, 128, and 80 recorded instances respectively. These western lands, in addition to being exposed to deserts and large saline lakes like Hoor al-Azim [66], Urmia Lake as the largest natural dust centers in Iran, are heavily influenced by neighboring countries, especially Iraq, Syria [67], and Northern Arabia [68], which generate particulate matter and dust. Also, main source of dust in the northwestern region like Tabriz is anthropogenic [10]. However, Tabriz's geographical location, low urban green space, and temperature also increase local dust, leading to instability in pollutant levels [69].

Over the six years leading up to 2022, the number of stormy days and hours remained consistent in Ahvaz, which ranked first, followed by Tabriz in second place and Yazd in third. In contrast, Kermanshah experienced a greater number of stormy days in 2011 to 2016 compared to the six-year period from 2017 to 2022. These changes in Kermanshah are influenced by factors such as dust inflow, reduced humidity, drought, unsustainable water resource use, increased temperature, and wind speed and direction [70, 71].

Yazd experienced a peak in storm activity in 2018, which has since escalated as a consequence of drought conditions and a decline in precipitation levels [65]. Meanwhile, Mashhad recorded the least number of stormy days, indicating stable particulate conditions. Despite 878 storm hours in the three-year period before 2022, no single day was categorized as a stormy day, indicating no consistent weather patterns.

The study also indicates a significant increase in storm hours in urban centers in 2022 compared to 2021, with Ilam experiencing a 0.58-fold increase and Mashhad experiencing a 3.4-fold increase, as a result of atmospheric currents originating from the deserts of Central Asia, localized and regional air currents originating from the central desert region of Iran, indicating an unstable nation's situation [72], except for Zahedan and Shiraz.

Data limitations restrict a comprehensive analysis of Zahedan; However, southeastern Iran has seen an increase in stormy days and land use changes. The desiccation of Lake Hamun and 120-day strong winds are attributed to summer dust storms in the area. Additionally, dust particle dispersion is further exacerbated by contributions from Afghanistan and Pakistan [65, 73].

The variability in hourly and daily dust storms across urban areas during a specific timeframe reveals the unpredictable nature of meteorological conditions. storms have largely remained inconsistent, except for the years from 2016 to 2019, indicating a notable absence of consistency in dust patterns and the occurrence of sporadic storms (Figs. 6 and 7).

Furthermore, the air quality in the analyzed cities, except for Ilam, showed positive and upward trends over the three-year period ending in 2022, indicating the aforementioned air quality issues in the previous years. This disparity may be due to meteorological factors, measurement inaccuracies, or combustion events in Ilam [74]. Although the external sources of storms in Ilam are mainly identified as Iraq, Syria, Saudi Arabia, the coastal areas of the Persian Gulf, and Jordan [75, 76], further investigation is needed considering various Iranian publication sources.

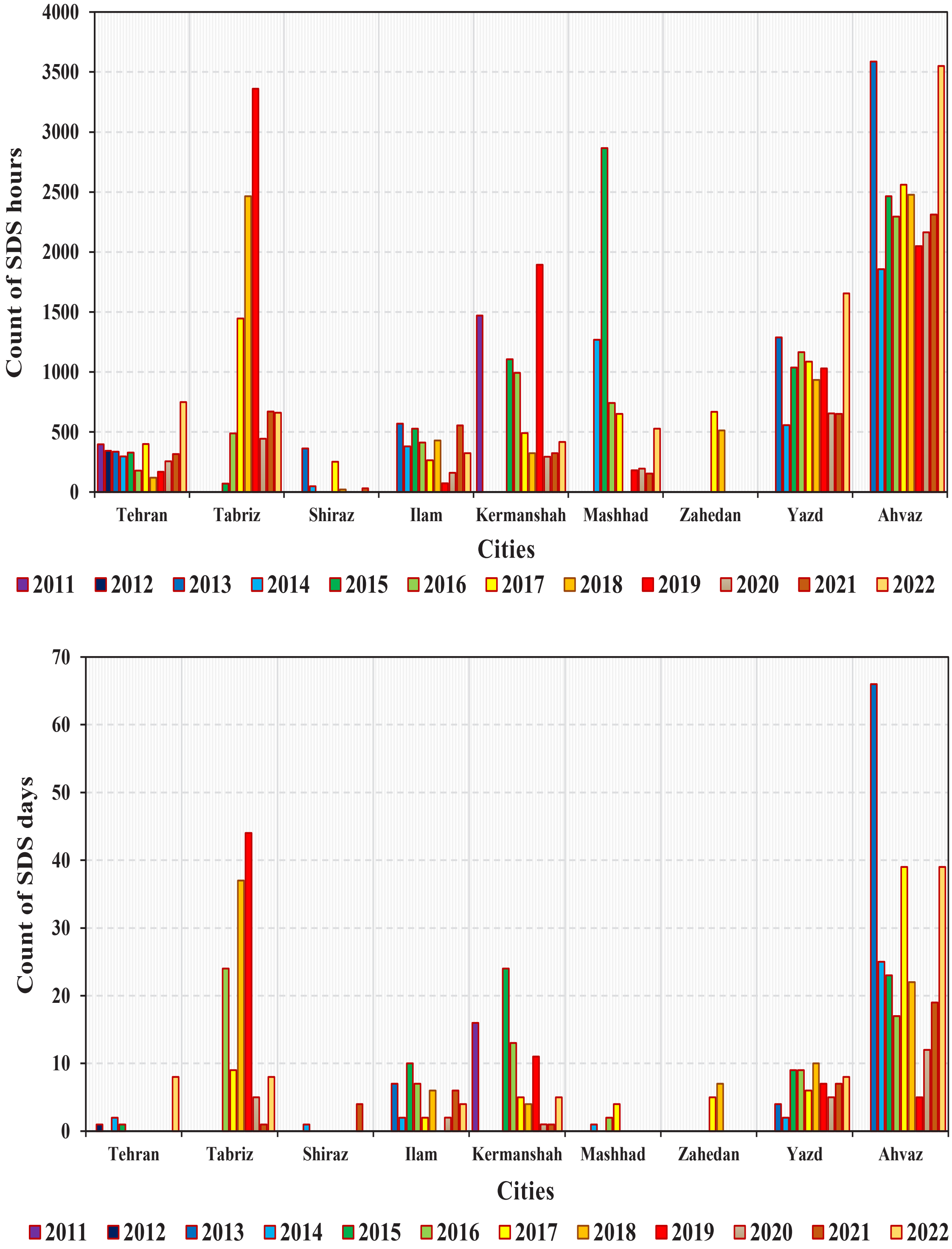


Fig. 5. The count of SDS hours and days throughout the years 2011 to 2022

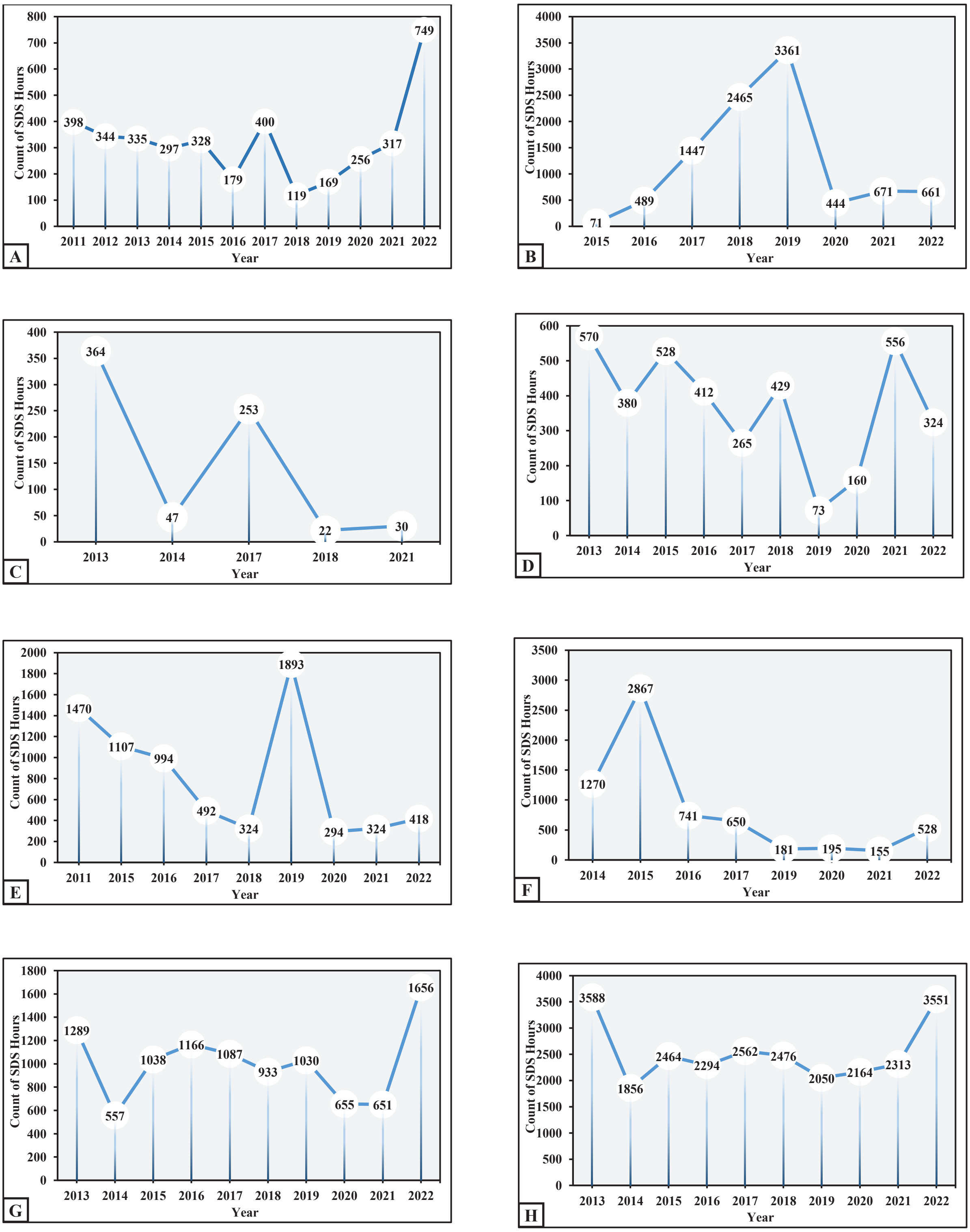


Fig. 6. The change trend of SDS hours during 2011-2022 by city

(A= Tehran, B= Tabriz, C= Shiraz, D= Ilam, E= Kermanshah, F= Mashhad, G= Yazd, H= Ahvaz)

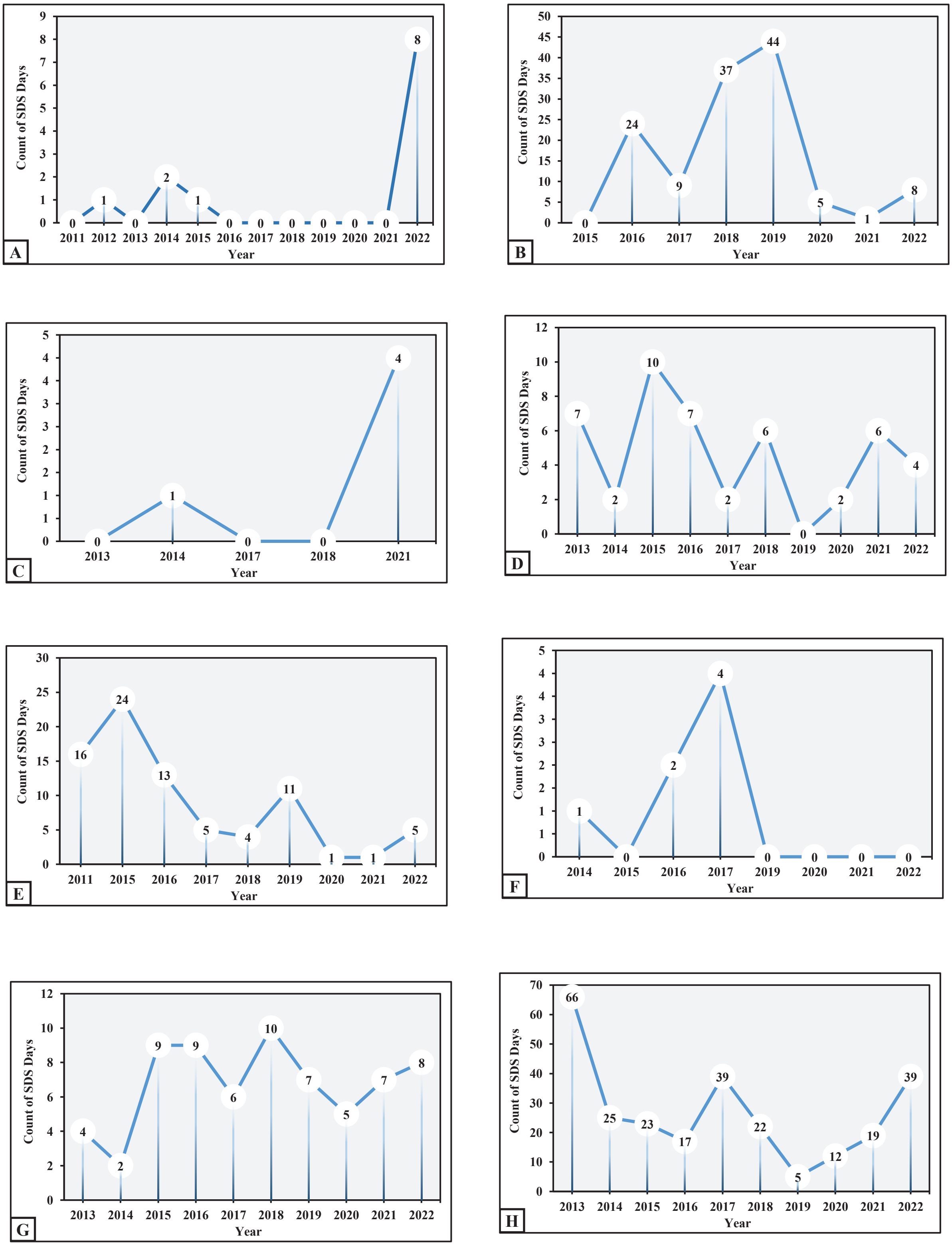


Fig. 7. The change trend of SDS days during 2011-2022 by city

(A= Tehran, B= Tabriz, C= Shiraz, D= Ilam, E= Kermanshah, F= Mashhad, G=Yazd, H=Ahvaz)

The study examines the changes in mean concentrations of PM_{10} and $PM_{2.5}$‘ as well as the frequency of SDS days and hours across nine cities. Overall, Tabriz and Ahvaz experienced an upward trend in the number of stormy hours with slopes of 79.44 and 3.8, respectively, during the study period, and Yazd also went through this period with positive changes in the number of stormy days (Table 1). However, the negative or zero slope in the studied cities does not indicate an improvement or stability in air quality and dust storms, as overall air pollution in all these cities remains in a poor condition. Considering numerous fluctuations, significant case-by-case increases, and air quality instability, the slope of changes in particulate matter concentration and storms in target areas during the study period generally remained negative in most cities (Table 1). However, the results reveal a total persistent upward trend for all variables over the three years preceding 2022 in the cities with reliable data. The mean value was 11.5, 3.35, 265.64, and 3.36 with a range from 3.41, 0.12, 62, and 0 to 23.79, 7.7, 693.5, and 13.5 for PM_{10}, $PM_{2.5}$, SDS hours and days, respectively. Yazd, Ahvaz, and Tehran showed the most pronounced upward trends, while Mashhad, Kermanshah, and Ilam showed the least pronounced upward trends.

Table 1. Total Slope's Sen of annual PM_{10} and $PM_{2.5}$ and count of SDS days and hours changes in 2011 - 2022

City	Year	Mean		Count	
		$PM_{2.5}$	PM_{10}	SDS Hours	SDS Days
Tehran	2011 - 2022	-0.76	-0.96	-6.08	0
Tabriz	2015 - 2022	-	0.83	79.44	-0.02
	2013 - 2022	-0.11	-	-	-
	2014 - 2022	0.24	-	-	-
Shiraz	2013 - 2021	-	-2.42 (5)	-34.75 (5)	0.21 (5)
	2018 - 2022	-0.63	-	-	-
Ilam	2013 - 2022	NA (1)	0.02	-28.2	-0.33
Kermanshah	2011 - 2022	1.9 (2)	-4.56 (6)	-97.21 (6)	-1.5 (6)
Mashhad	2014 - 2022	0.52	-1.79 (7)	-144.08 (7)	0 (7)
	2013 - 2022	-0.0047	-	-	-
Zahedan	2017 - 2018	-2.22	-2.22	-155	2
Yazd	2013 - 2022	NA (3)	-0.65	-35	0.33
Ahvaz	2013 - 2022	-1.01 (4)	-4.11	3.8	-2

(1): Data available only in 2019,

(2): Data available only in 2020 – 2022,

(3): Data available only in 2022,

(4): No data in 2013,

(5): No data in 2015, 2016, 2019 and 2020,

(6): No data in 2012, 2013 and 2014,

The increasing frequency of dust storms requires strategic policies to address desertification. Increasing vegetation, specifically by 100 km^2 with 25% tree cover per year, can significantly reduce airborne particulates. Additionally, extra strategies to reduce adverse effects on health, property, and infrastructure include regulating greenhouse gas emissions to combat global warming and drought, along with preventing overexploitation of land and soil degradation, can be significant and effective [77, 78].

Limitations

The temporal and spatial variations of atmospheric contaminants, together with the frequency and intensity of dust storm events, limit the direct comparability of the results with those of other studies. This limitation arises from differences in geographical settings, meteorological conditions, and the diversity of air pollution sources across urban environments. In addition, the limited number of air quality monitoring stations in some cities during the twelve year study period resulted in considerable data gaps, which required the exclusion of those periods from the subsequent analyses. Although the number and spatial distribution of monitoring stations in several cities across the country have been validated, there remains an urgent need to enhance and expand online, real time air quality monitoring systems to improve the completeness and reliability of future assessments.

Conclusion

Considering the geographical distribution of the analyzed municipalities across various regions of the nation, as well as acknowledging the dynamic nature of airborne pollutant particles which can be influenced by environmental variables, the findings may suggest a comparable scenario in adjacent municipalities and, more broadly, throughout Iran concerning the dispersion of pollutant particles and occurrence of dust storm events. Overall, the observed increase in pollutant concentrations contributing to dust storm phenomena in most of the examined cities, particularly during the three years leading up to 2022, underscores the continued severity of dust storm events and the need for more effective mitigation measures. Addressing the sources of these particles within pollution mitigation strategies could be highly beneficial, particularly given Iran's susceptibility to particulate matter from both international and domestic sources. This necessitates the establishment of national and regional collaborations in domains such as the mitigation of desertification, the management of vegetative cover, and the regulation of industries including automotive and petrochemical sectors. The recent escalation of valid air quality monitoring stations underscores the heightened attention of the responsible entities (namely, the Air Quality Control Company and the Iranian Department of Environment) towards this critical issue. However, these organizations should not only focus on expanding the network of air quality monitoring stations but also work to improve the reliability of the data collected from existing stations. At the same time, it is essential to extend the monitoring hours and enhance the temporal coverage of hourly data.

Ultimately, despite the prediction that the increase in technological advancements across various global industries would facilitate better management of pollutant control and consequently lead to a reduction in storm hours, this trend has moved upwards in 2022. This increase can be attributed to a significant decline in precipitation across the country, along with reduced surface water levels, wetland desiccation, and other contributing factors. Therefore, it is recommended that thorough investigations be conducted to identify the sources of dust within each urban and regional area, and that international collaboration be fostered across various sectors, including environmental and industrial fields, to address the origins of dust particle generation. This approach would facilitate the development of more effective management strategies to reduce the pollutants responsible for dust storms at both local and regional levels.

It is recommended that a comprehensive assessment of dust storm conditions, particularly in the years preceding the current period, be carried out, taking into account the rapid climate change processes in the region. This work should include integrating satellite data, incorporating information from other monitoring stations in the surrounding areas and using interpolation techniques. In addition, examining the sources and factors influencing dust storm occurrences in each of the cities studied may provide valuable insights for a wider national assessment of Iran.

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Competing interests

The authors declare that they have no conflicts of interest.

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Ethical considerations

This study received the ethical approval of research (IR.TUMS.SPH.REC.1401.224) by Tehran University of Medical Sciences. Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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